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Abstract

This study examines how extreme heat affects workplace accidents in Italy's various economic sectors. Using granular data by sector, day, and province (NUTS-3) for 2018–2024, we evaluate the contribution of occupational exposure as a source of diverse effects at the sector level. Our findings imply that while the average effects of extreme heat on workplace accidents are, at best, negligible, high temperatures significantly raise the frequency of medium-to-low severity accidents for sectors with high levels of exposure, while exposure and extreme heat alone do not account for fatalities.

Keywords: workplace accidents, heterogeneous effect, fixed-effect regression, vulnerability, extreme temperature

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1 Introduction

According to the Global Climate Risk Index Report, 83% of climate change-related deaths in 2022 were caused by heatwaves, which were the deadliest extreme weather events.[1] The main causes of the high death tolls in 2022 were a series of heatwaves that struck Europe, with Italy ranking third with over 18,000 deaths (Adil et al., 2025; CRED, 2025). If global warming reaches 2°C, heatwave frequency will increase by 5.6 times for every 2.6°C increase in temperature (Clarke et al., 2022; IPCC, 2022).

Since the 1980s, the rate of global warming has doubled, making Europe the continent with the fastest rate of warming. The typical summer maximum temperature in South-Western Europe was surpassed by around 10°C during the 2022 heatwaves (Copernicus, 2022; EEA, 2024a). Extreme temperatures and climate change are risk factors for the population as they may have an influence on their health and raise the likelihood of work-related accidents, injuries, and fatalities. Furthermore, heat-related disorders such as heat stroke, exhaustion, heat cramps, and rash are predicted to rise in frequency and intensity due to heatwaves (Morabito et al. 2020, Vicedo-Cabrera, 2021, EEA 2024b).

Extreme temperatures affect employees in their cognitive and physical capacities (Filomena and Picchio, 2024). Heat stress considerably increased the rate of injuries in the construction industry, according to studies by Bendak et al. (2022) and Depalo (2023). This was mainly because it caused fatigue and decreased cognitive function. Recent research has examined the connection between high temperatures and occupational accidents in Italy (Marinaccio et al., 2019; Gariazzo et al., 2023; Di Blasi et al., 2023; Filomena and Picchio, 2024), Germany (Winklmayr et al., 2023), Spain (Martinez-Solanas et al., 2018), and Switzerland (Drescher and Janzen, 2025).

According to the Italian post-pandemic Recovery Plan and the European Green Deal, Italy is working to ensure a smooth ecological transition, with a focus on adaptation measures, better management, and the application of preventive measures to deal with the growing frequency of extreme temperatures in sectors and areas that are already at risk. According to Martin and Islar (2021), the effectiveness of climate adaptation plans is contingent upon the efforts of local public authorities as well as the degree of tolerance

[1] https://www.germanwatch.org/en/cri

and capacity of communities, sectors, and societies to change. As the frequency and severity of extreme heat events increase due to climate change, studies on developing efficient policies and procedures that protect workers' health and preserve productivity become crucial. Workers may have difficulty concentrating or might be forced to exert less effort to deal with the heat, according to Picchio and van Ours (2024). The construction sector is one of the sectors where heat-related deaths or mortality risk are most frequently documented (Gasperini et al. 2015; Gariazzo et al. 2023; Dong et al. 2019, Flouris et al. 2024). The number of days of leave is rising in parallel with the severity of workplace accidents. An average of 8–10 days of absence was required for one-third of incidents, according to research by Gariazzo et al. (2023). Therefore, it is essential to understand how heat impacts workplace accidents, injuries, fatalities, and worker compensation in order to establish a well-balanced set of treatments that can protect workers while reducing accidents and increasing labour productivity.

According to a review paper by Borg et al. (2021), occupational heat stress is predicted to have a substantial financial impact in the future. Loss of productivity is expected to cost the world between 2.4 and 2.5 trillion USD (>1% of GDP) in 2030 and 4.0% of GDP by 2100. Additionally, they pointed out that worker costs were greater for males, workers aged 25 to 44, medium-sized enterprises, and outdoor sectors. De Sario et al. (2023) also documented consistent evidence of the influence of occupational heat stress on socioeconomic outcomes in their scoping study. Szewczyk et al. (2021) looked at the impact of warming temperatures on the productivity of workers in Europe. With a distinct spatial gradient, labour productivity in Europe could drop by 1.6% by the 2080s. The South and East are expected to be the most affected regions, with nations like Greece potentially seeing production losses of up to 5.4%. In order to minimize heat-related illnesses, workers are compelled to take more frequent breaks and reduce their work intensity (Kjellstrom et al., 2013). This decrease in hourly labour productivity, therefore, directly leads to a reduction in economic output. This study predicts that by 2050, many outdoor jobs will become "extreme," with temperatures so high that they will drastically impair workers' capacity to execute their tasks.

Our study intends to assess the diverse impacts of severe temperatures on workplace accidents in Italy across several sectors using daily data at the NUTS-3 level, considering the degree of sensitivity and vulnerability of the various sectors. To successfully avoid workplace accidents under heat stress circumstances, this study aims to provide new evidence to guide targeted measures and regulations.

Interestingly, Italy experienced a remarkably high number of deaths between 2003 and 2022, mostly from extreme heat and other natural catastrophes. Nearly USD 60 billion in economic losses and over 38,000 fatalities were reported (CRED, 2024; Adil et al., 2025). Given the likelihood of an increase in the frequency and severity of extreme heat events in the near future, it is crucial to comprehend the likelihood of the effects of extreme temperatures on workers as well as the sensitivity of the sectors for workers' health and safety agenda, taking into account individual and workplace characteristics for appropriate prevention measures (Di Blasi et al., 2023; Gariazzo et al., 2023).

The causal relationship between severe temperatures and accidents at work has been thoroughly examined in many studies. The premise behind casual identification, according to Park et al. (2021), is that the idiosyncratic variation in daily temperature within a given location is plausibly exogenous, and that the resulting influence on injuries is not driven by hypothetical endogenous differences in labour inputs. To reduce the possibility that their estimated impacts were caused by endogenous changes in labour inputs, studies by Marinaccio et al. (2019), Dillender (2021), and Ireland et al. (2023) relied on plausible exogenous temperature shifts in a specific spatial unit.

Unlike earlier research, we quantify the diverse effects of excessive summer temperatures on work-related risks at various levels of occupational exposure to extreme temperatures. Our main contribution is based on the analysis of sectoral heterogeneity in occupational exposure to extreme heat, which provides compelling evidence of the critical significance of working conditions within each sector. In comparison to Marinaccio et al. (2019), who analysed the period 2006-2010, and Filomena and Picchio (2024), who studied 2008-2021 in Italy, our contribution is the use of more recent data on work-related accidents in Italy (2018-2024) and the test the mediating role of workers' workers' exposure to weather conditions using occupational exposure scores.

This paper is structured as follows. The next section provides an overview of the research data and methodologies used in this study. Section 3 describes the empirical techniques, whereas Section 4 presents the main results. Section 5 concludes.

2 Data and descriptive evidence

In our analysis, we focus on the summer months because excessive heat in Italy is only critical from 1st May to 30th September. One major challenge in studying the effect of climate or weather variability on work-related accidents is obtaining granular data on both accidents and climate data to relate the weather variability experienced by workers in a given local area to work-related accidents that occurred on that same day and in that same area (Dillender, 2021; Filomena and Picchio, 2024). In our analysis, we match daily data on work-related accidents from the National Institute of Insurance against Workplace Accidents (*Istituto Nazionale per l'Assicurazione contro gli Infortuni sul Lavoro, INAIL*) with daily meteorological data from Copernicus European-OBS.[2] Because publicly accessible data on workplace accidents only represent the province (equivalent to the NUTS-3 level) where the incident happened, we will analyse temperature days by province by sector.

2.1 Extreme temperatures

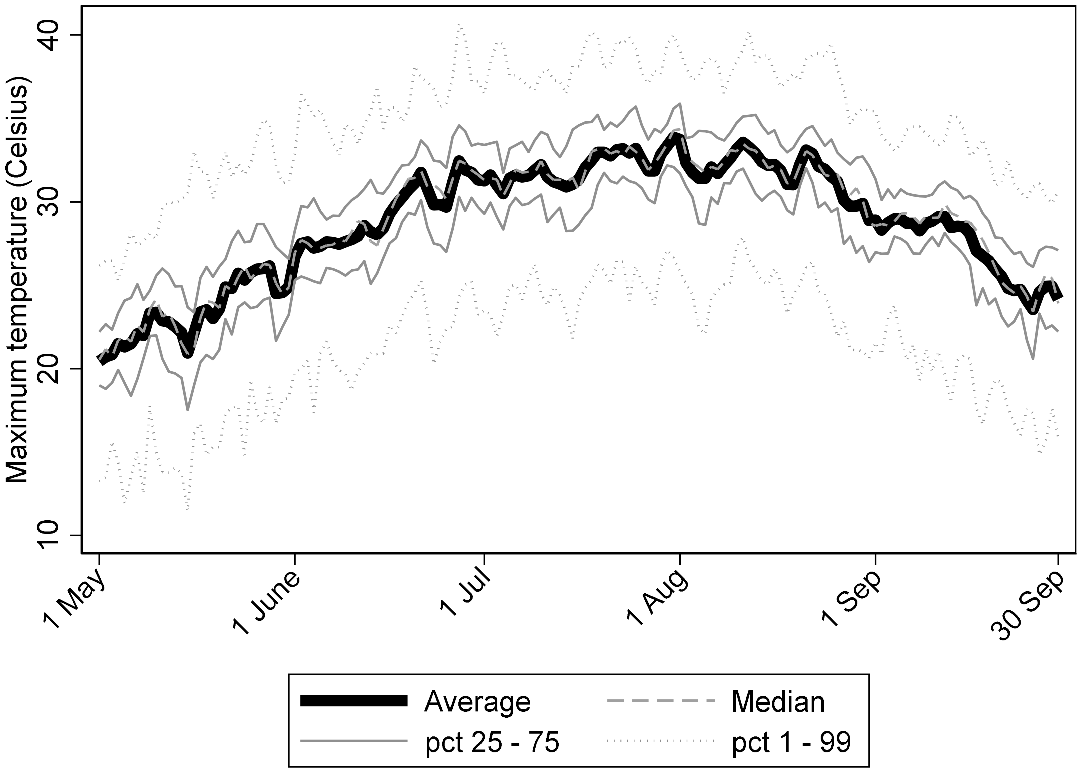
Daily maximum air temperature data were collected from the European-OBS dataset, using a 0.25° x 0.25° grid (version 31.0e).[3] Figure 1 shows maximum daily temperatures in Italy from 1st May 1 to 30th September for 2018-2024, with average, median, and percentile ranges (25th - 75th and 1st - 99th percentiles). Notably, July and August were recognized as the hottest temperature months across these years, with the highest average maximum temperatures. The data highlights the seasonal peak in temperature during mid-summer and the significant fluctuation around central values.[4]

[2] E-OBS is a daily gridded land-only observational dataset over Europe.

[3] Observational station data of the European Climate Assessment & Dataset (ECA&D) and the gridded observational dataset (E-OBS) are made available free of charge from https://www.ecad.eu.

[4] Additional evidence about the trends and geographical distribution of extreme temperatures in Italy is reported in Appendix A.

Figure 1. Maximum daily temperature for summer months in Italy (2018-2024)



Notes: Distribution of maximum temperature in Italian provinces by calendar day (years 2018-2024). Source: European Climate Assessment & Dataset (ECA&D) and the gridded observational dataset (E-OBS)

2.2 Workplace accidents

Event-level data on work-related accidents in Italy from 2018 to 2024 were taken from the archives of the Italian Workers' Compensation Authority (INAIL). Employers in Italy are required by law (Presidential Decree n.1124/1965) to report workplace accidents to INAIL, who records information related to the accident such as the date of the accident, characteristics of the injured person (employer identifier, economic sector), sector, municipality of the event, and severity of the accidents (fatalities, workplace accident, number of work-days lost, severity of the handicap). Anonymization measures were used to preserve privacy. This information enables us to calculate the number and severity of accidents at the provincial (NUTS-3), sectoral, and daily levels for the entire period from 2018 to 2024.[5]

[5] Even though data are collected at the municipality level, they are made public at the NUTS3 (province) level. This aggregation bias represents a limitation in our analysis, especially so for those provinces

Table 1. Trends of workplace accidents, fatality, and worker accidents leading to compensation and handicap from 2018-2024 by yearly and monthly (just considering summer – May-September – months)

Year	Workplace accidents	Workplace accidents leading to compensation	Days of compensation	Workplace accidents leading to a handicap	Fatalities
2018	224,117	128,142	4,421,682	25,890	311
2019	220,651	126,334	4,412,947	25,771	329
2020	161,164	102,162	3,792,564	20,457	308
2021	188,975	110,615	4,008,605	22,950	342
2022	237,793	134,151	4,180,615	23,515	333
2023	206,786	117,886	4,024,381	23,868	355
2024	202,396	112,899	3,679,220	20,460	298
Total	1,441,882	832,189	28,520,014	162,911	2,276
Month	Workplace accidents	Workplace accidents leading to compensation	Days of compensation	Workplace accidents leading to handicap	Fatalities
May	332,647	166,019	5,743,022	34,255	498
June	293,360	171,319	5,837,565	33,491	445
July	300,499	188,572	6,230,146	34,312	490
August	220,349	137,821	4,732,945	26,044	396
September	295,027	168,458	5,976,336	34,809	447
Total	1,441,882	832,189	28,520,014	162,911	2,276

Notes: Own elaboration on INAIL data.

Due to the lack of comprehensive data regarding the geographic distribution of employment levels across provinces, we have excluded two significant sectors from this study: "Public administration and defence; compulsory social security" (NACE code: 84) and "Agriculture, Forestry and Fishing" (NACE codes: 01, 02, 03).[6] Additionally, INAIL

characterized by rather heterogeneous climates. Results of our baseline estimates remain basically identical if we exclude the 10 provinces with the highest within-province heterogeneity (absolute deviation across municipalities) in maximum temperature in summer days. All these provinces are located in the Alps. Results are available upon request.

[6] A summary of the share of workplace accidents considered in our analysis over total workplace accidents is shown in Table A1. Workplace accidents in the agriculture, forestry and fishing sector just account for 0.3% (but 1% of fatalities), while the contribution of workplace accidents in the public sectors is around 2% across different measures. The exclusion of these sectors limits the possibility to fully generalise our results. At the same time, the agriculture, forestry and fishing sector turn out to be a very special case when dealing with the link between extreme heat and workplace accidents (see also: Marinaccio et al., 2019; Ricco et al., 2020; Di Blasi et al., 2023) due to the high incidence of seasonal work, with large heterogeneity in seasonality across different regions.

did not report data on a comparatively high percentage of events: 31% of accidents, 28% of accidents that resulted in disability, and 27% of fatalities, but only 15% of accidents that resulted in compensation and 11.5% of days of compensation.

The yearly data (summer months May-September) from 2018 to 2024 show fluctuations in worker accidents, fatalities, compensation claims, and handicap cases in Italy (see Table 1). The total number of workplace accidents peaked in 2022 at 237,793, with a slight decrease in 2023 and 2024. Fatalities remained relatively low, ranging from 298 to 355, reflecting a chronic but steady risk profile. Compensation claims followed a similar pattern, reaching 134,151 in 2022 before declining to some extent.

2.3 Sectoral exposure to extreme heat

To quantify a worker's exposure to excessive heat, the worker (or particular job post) would be the best unit of analysis. We could calculate extremely detailed exposure indicators if we had data on work lists for each employee and the steps taken by employers to prevent workers from being exposed to excessive heat (e.g., air conditioning, ad hoc shifts, etc.). Yet, such a wealth of information could just be gathered through worker ad hoc surveys, which tend to be costly and impractical. The low accident rate makes surveys inappropriate in this regard, as even large samples may result in only a small percentage of chosen workers being involved in an accident.

Alternatively, the occupation level might be an appropriate compromise. A variety of tasks carried out by incumbent workers can be categorized as occupations. No matter the industry or organization in which they operate, occupations typically have comparable activities, necessary competencies, and work environments. As a result, the occupational level is especially well-suited to quantify exposure to environmental elements like extreme temperatures. For instance, a recent study by Biagetti and Intraligi (2024) examines an occupation-level measure of heat stress exposure, asking how frequently workers are exposed to extremely high temperatures (above 32 °C) or extremely low temperatures (below 0 °C) while performing their duties. Their results show that extreme heat reduces employment rates in heat-exposed occupations more than in other occupations.

With few exceptions, Labour Force Surveys are the main (and almost exclusive) source of data on workers' occupations. These surveys, which are harmonised across countries, acquire precise information on the labour force from large representative samples. Furthermore, there are several sources of information about occupational tasks, required skills and abilities, and work contexts that can be linked to occupational employment data (for example, the Occupational Information Network - O*NET - in the United States and the European Skills, Competences, Qualifications, and Occupations - ESCO). In this instance, the greatest limitation to the direct use of occupation-level indicators of heat exposure is the lack of information regarding the occupation of workers who encountered workplace accidents in administrative data.

Indeed, once a workplace accident is reported to the public authority, just the employer's industry is included. This suggests that sector-level data can be used as the third-best method for developing indicators of extreme temperature exposure. Furthermore, using sector-level measures of exposure becomes particularly effective for implementing sector-specific regulations that can discriminate between sectors based on administrative definitions.

In this study, we use very granular data from the INAPP-ISTAT *Indagine Campionaria sulle Professioni* (ICP-2013), which provides comprehensive information on job tasks, required skills, work contexts, and other occupation-specific details aligned with the Italian classification of occupations, similar to the US O*NET database. This survey employs a comprehensive and detailed structured questionnaire to analyse the features of occupations, providing rich qualitative descriptions of their work activity and context, and providing a thorough grasp of the figures in the Italian labour market. Data are collected for incumbents in all five-digit occupations.[7] We focus on Section H of the ICP-2013 survey, "Information on Working Conditions," which considers the physical environment, methods of performing the job, and the interpersonal relationships involved. Answers are given on a scale of 1 to 5, with 1 meaning 'never' and 5 meaning 'every day'.[8] Based on the review in Section 1, we choose three key variables: (i). working indoors in

[7] The Italian Classification of Occupations (*Classificazione delle Professioni*) is coherent with the ISCO-08 classification. To aggregate scores at the 4-digit of the classification (used in the Italian Labour Force Survey) we take the average across all 5-digit occupations

[8] We rescaled the variable by imposing a theoretical range of 0-1 to ease interpretation.

a controlled environment;[9] (ii). working outdoors in all-weather situations;[10] and (iii). being exposed to extremely hot or cold temperatures.[11] These are alternate proxies for determining workers' possible exposure to excessive heat, allowing us to categorize workers based on their relative vulnerability to extreme temperatures. To assess occupational exposure to extreme heat in various sectors, we computed the weighted average scores of 2-digit NACE Rev. 2 sectors using the average number of workers employed by sector and occupation (4-digit CP 2011) from the Italian Quarterly Labour Force Survey (ISTAT) for the years 2014-2019. Table A3 in Appendix A contains a complete list of sectors and their related values for the three exposure scores.

2.4 Aggregate facts

First, we compare our set of occupational exposure to extreme heat with the frequency of hot days (maximum temperature above 32°C) and actual accident rates (total accidents and accidents leading to compensation) at the aggregate (national) sector-level (Figure 2).[12] According to the left charts of the three panels, there is a generally flat relationship between the incidence of hot days and occupational exposure to extreme heat: sectors with high or low levels of exposure are not systematically present in provinces with a higher frequency of hot days during the summer. Alternatively, if we look at the relationship between occupational exposure to extreme heat and accident rates at the sectoral level (central and right charts in Figure 2), we observe that the sectors with consistently worse working conditions have higher accident rates (i.e., low frequency of work indoors in a controlled environment and high frequency of work outdoors exposed to all weather conditions and high exposure to very hot or very cold temperatures).

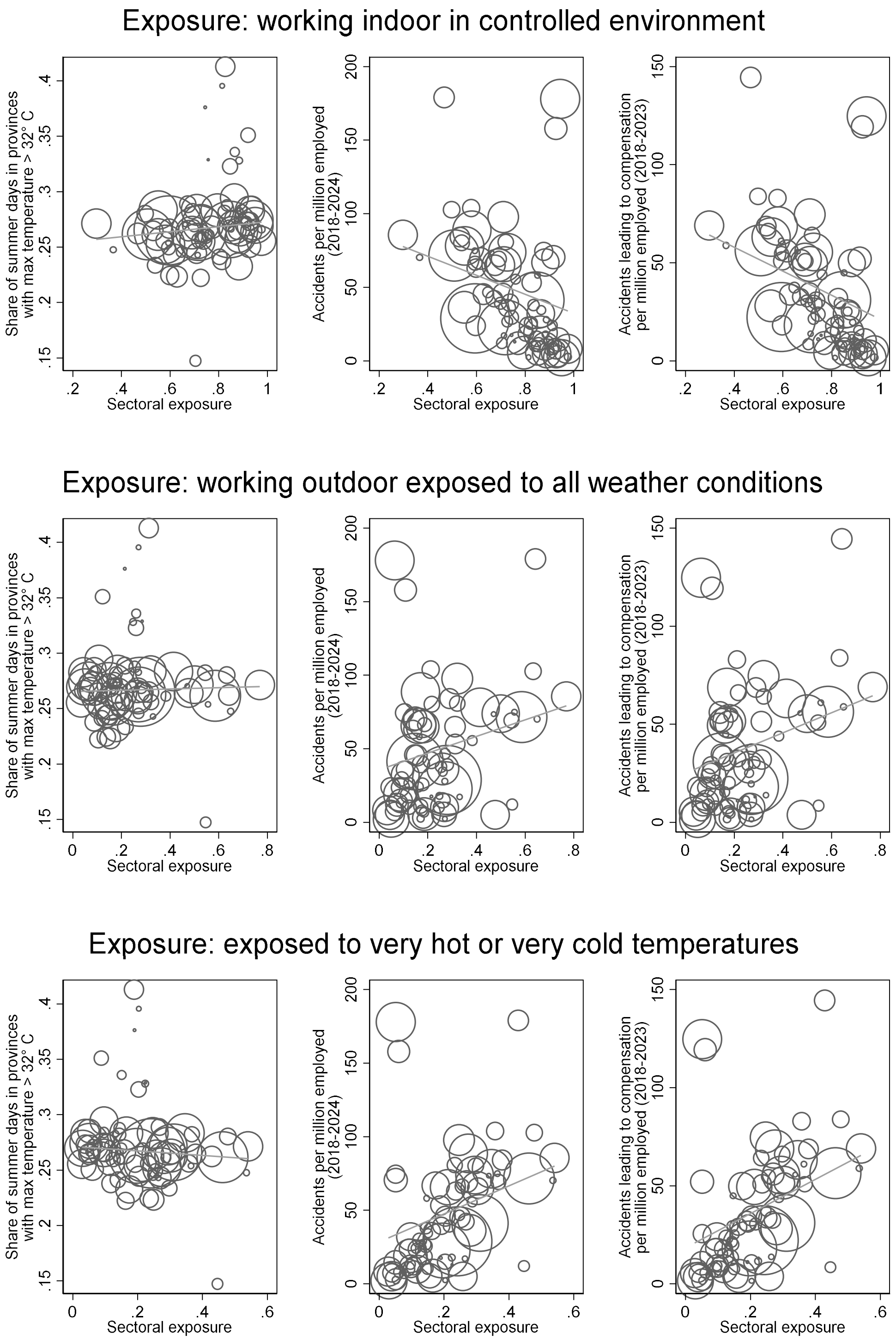
[9] How often does your job require you to work indoors in a controlled environment (e.g., air conditioning)?

[10] How often does your job require you to work outdoors in all weather conditions?

[11] How often are you exposed to very hot (over 32 degrees Celsius) or very cold (below freezing) temperatures in your job?

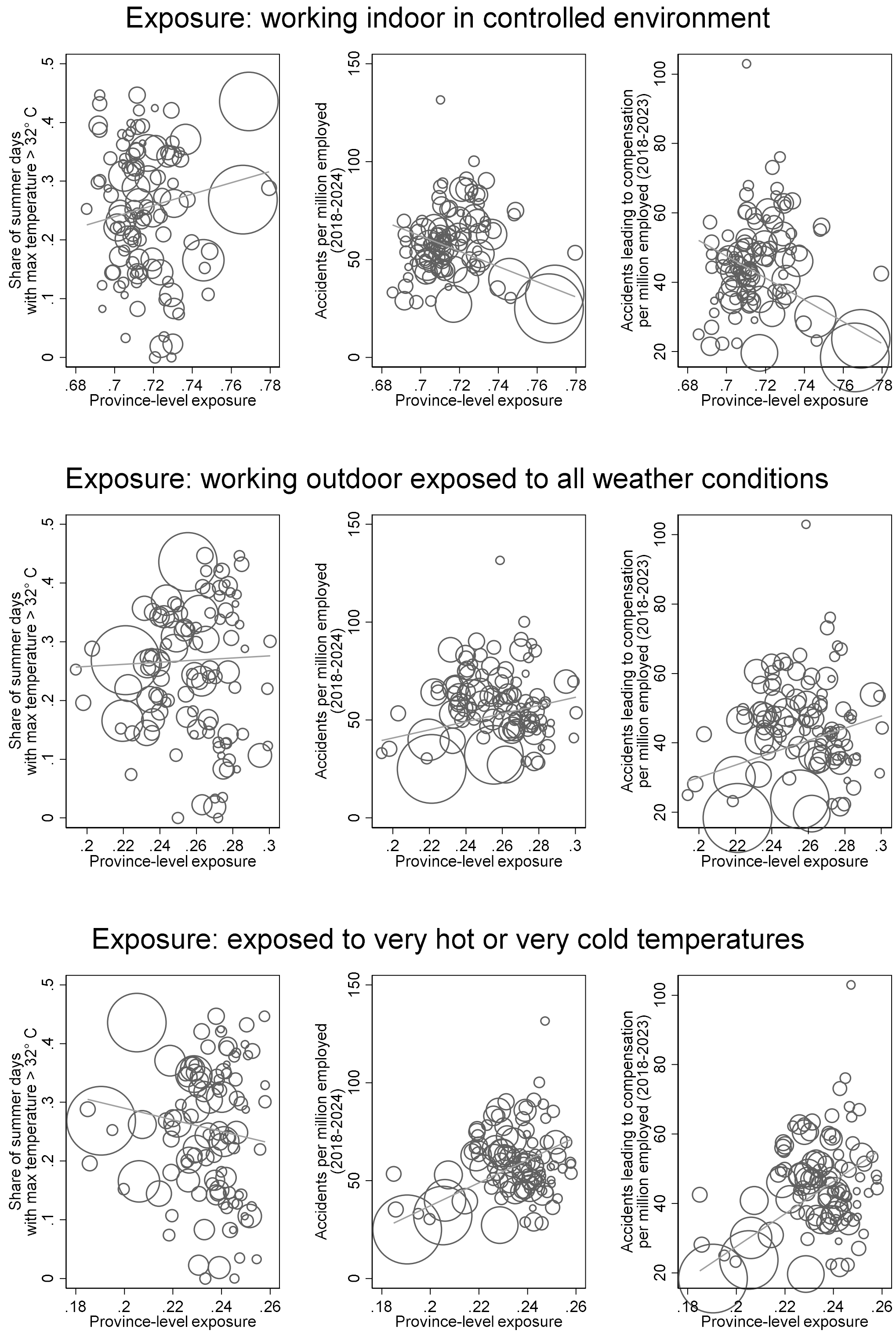
[12] To compute the average incidence of hot days by sector at the national level, we calculate the weighted average of province-level share of hot days using sector-by-province employment (average 2014-2018) as weights.

Figure 2. Sector-level evidence



Notes: The size of bubbles is proportional to the number of employees in the sector.

Figure 3. Province-level evidence



Notes: The size of bubbles is proportional to the number of employees in the province.

We repeat the process, but this time consider the province level rather than the sectoral level (Figure 3).[13] At the provincial level, there is a considerable correlation between occupational exposure to severe heat and accident rates, as expected. When considering the relationship between occupational exposure indicators and the incidence of hot days, we found a positive relationship between the frequency of work indoors in a controlled environment and the incidence of hot days, suggesting a sort of 'good' specialization of provinces exposed to extreme heat. When considering the other two variables of exposure, instead, nor a ‘good’ or a ‘bad’ specialisation is found. On the other hand, however, the expected relationship between average province-level exposure and accident rates is found (central and left charts of Figure 3).

3 Empirical strategy

After flexibly accounting for unobserved heterogeneity, we examine state-of-the-art techniques based on assessing the non-linear relationship between temperature and occupational accidents.[14] Our unit of analysis is the sector-province pair, which is observed on a daily basis. Our dependent variables are rescaled for the average number of employees (including self-employed) working in local branches of firms in 2014-2018 (source: ISTAT) in order to account for the scale of sector-province pairs, or how many workers are potentially vulnerable to suffer a workplace accident.[15] To give a representative image of the Italian context, this variable is also employed as a regression weight.

Our baseline specification for estimating the average impact of extreme heat on workplace incidents is described by the equation:

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[13] In this case, the indicators of occupational exposure to extreme heat are computed as the weighted average of sector-level scores using sector-by-province employment (average 2014-2018) as weights.

[14] In developing our empirical strategy, we consider the recent methodological contributions in the field of ‘climate econometrics’. A review by Hsiang (2016) discussed recent developments, including the use of nonlinear models with spatial and temporal displacement, the parameterization of climate variables from a social perspective, the measurement of adaptation, the characterization of uncertainty, and the projection of the impact of climate change using empirical estimates.

[15] The source is aggregated data on the business registry (*Archivio Statistico delle Imprese Attive*). Unfortunately, these data are released with substantial delay, limiting the possibility of exploiting the time-varying dimension.

$$y_{pst} = \sum_{b \neq 20} \circ \beta_b MaxT\_bin_{pt}^b + \gamma_{ps} + \theta_{mp} + \eta_{yp} + \delta_{st} + \varepsilon_{pst} \quad (1)$$

Where y_{pst} is a series of indicators of workplace accidents occurred in province p, sector *s,* and day t and $MaxT\_bin_{pt}^b$ are 2°C maximum temperature bins (reference: 20-22°C) recorded in province p on day t. Our coefficients of interest are β_b that represent the difference in workplace accident rates for different temperature bins with respect to the bin of reference. A series of fixed effects is included to account for unobserved factors in a flexible way. Firstly, we consider sector-province fixed effects γ_{ps}, to account for time-invariant unobserved factors that do not vary over time within each sector-province combination but could influence workplace accident rates. Secondly, we consider month-by-province (θ_{mp}) and year-by-province (η_{yp}) fixed effects to consider the unobserved factors that vary over time at the regional level. Finally, we also include sector-by-day dummies (δ_{st}) to take into account sector-specific shocks or unobserved heterogeneity that vary across days, which may affect accident risks within sectors. These include, for example, sector-day specific patterns of seasonality, work shifts, peaks of production, or closures for holidays.

The regression of equation 1 is estimated with OLS, and standard errors are clustered at the province level, as temperature just varies across provinces and days (not sectors).

To evaluate the heterogeneous effects of extreme heat for different levels of sectoral exposure, we add a series of interaction terms between temperature bins and indicators of sectoral exposure:

$$y_{pst} = \sum_{b \neq 20-22^\circ} \beta_b MaxT\_bin_{pt}^b + \sum_{b \neq 20-22^\circ} \psi_b Exposure_s \times MaxT\_bin_{pt}^b + \gamma_{ps} + \theta_{mp} + \eta_{yp} + \delta_{st} + \varepsilon_{pst} \quad (2)$$

Sectoral exposure variables ($Exposure_s$) are time-invariant and measured at the national level. To ease interpretation, the exposure variables are measured as the deviation from the national (weighted) median. Moreover, we report marginal effects at the 10th, 50th and 90th percentiles of exposure variables.

Similar to Picchio and van Ours (2024), we carefully excluded particular dates and time periods from the data filtering process to improve the sample's robustness and relevance. Recognizing that public holidays and classical vacation times can induce sector-specific biases, we eliminated observations that occurred on these dates. We specifically removed all national holidays (Labour's Day, 1st May; Republic's Day, 2nd June; *Ferragosto*, 15th August). This focused exclusion method tries to improve the quality of our study by focusing on periods with more usual behavioural patterns, removing the distinctive effects of major holidays.

4 Results

4.1 Average effect of extreme heat

Figure 4 displays the baseline data for the estimated average effects of extreme heat on workplace accident indicators.[16] The number of workplace accidents (total and compensation-related) appears to be positively connected with elevated maximum temperatures, although the difference from the baseline maximum temperature bin (22-24°C) is not statistically significant. On the contrary, no consistent trend is detected for any indicators of accident severity.

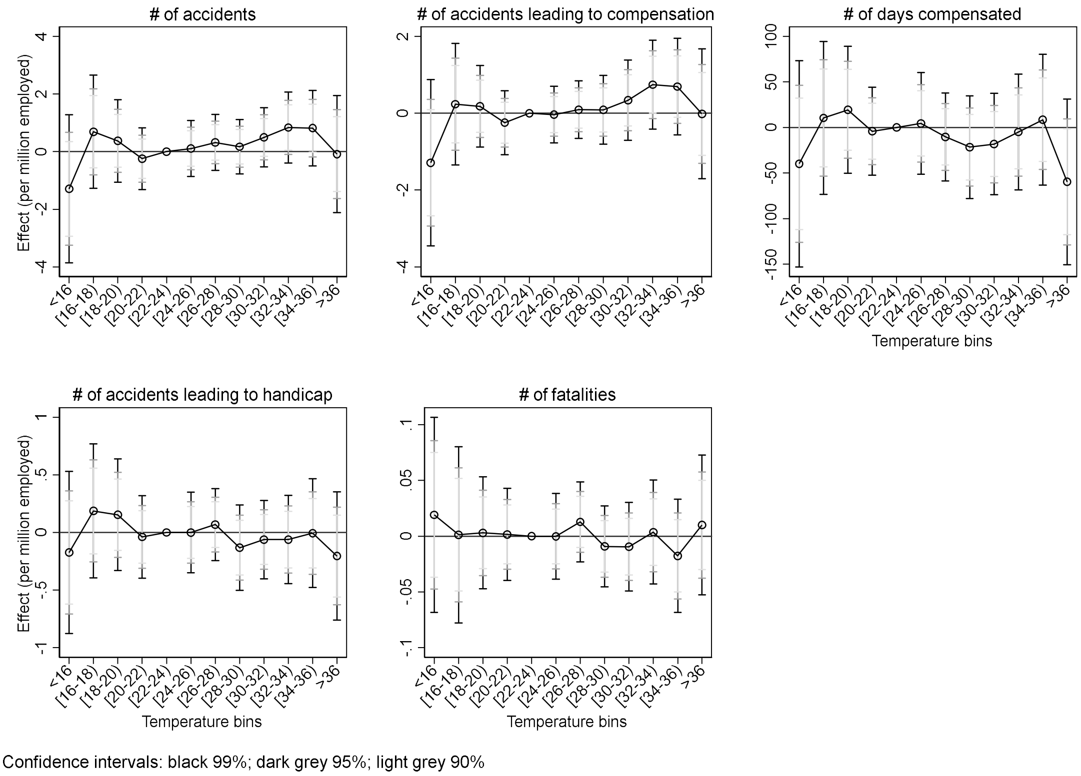
Overall, these findings indicate a typically weak average influence of extreme heat on accidents in the Italian case. Interestingly, we find consistent evidence of a reduction in accidents (both total and compensation-related) and days compensated for the highest temperature bin (>36°C, accounting for 3.9% of our sample), coupled with wider confidence intervals. This result appears to hint at avoidance behaviours: on very hot days, labour input may have been reduced, particularly in the most vulnerable sectors, to avoid the adverse effects of elevated temperatures. It should also be mentioned that local and regional governments had the authority to issue decrees prohibiting work activities on exceptionally hot days in sectors typically thought to be the most vulnerable to excessive heat (agriculture and construction sectors). Unfortunately, it is not possible to directly quantify avoidance behaviours: to do so, we would ideally need information on hours worked by day, province, and sector, or credible proxies of this measure.

The absence of significant average effects, however, may conceal enormous heterogeneity across workers, occupations, and sectors as a result of diverse exposure to extreme heat. We explicitly explore the possibility of heterogeneous impacts in the next

[16] Three confidence intervals depicted in different shades of grey (black 99%, dark grey 95% and light grey 90%). Table B1 in Appendix B summarise the results of Figure 6.

part, where we consider a number of sectoral occupation-based metrics of exposure of workers executing different occupations.

Figure 4. Baseline results



Notes: OLS regressions weighted by average employment 2014-2018 in province-sector. Standard errors clustered by province. Additional control variables: province-by-sector fixed effects, sector-by-day fixed effects, province-by-year fixed effects, province-by-month fixed effects.

4.2 Heterogeneous effects by sectoral exposure

Figure 5 depicts the relationship between maximum temperature (binned using the 22-24°C range as the baseline) and the frequency of workplace accidents during the extended summer months, based on our measurements of sectoral exposure to extreme heat. [17] We find that as maximum temperatures rise above the baseline, there is a significant increase in accidents across all three exposure dimensions: working indoors in a controlled

[17] To simplify the presentation of results, we report in the main text plots of the marginal effect of different temperature bins for different levels (10th percentile, median and 90th percentile) of sectoral exposure. Detailed results for the estimated interaction terms are reported in Tables B2-B4 in Appendix B.

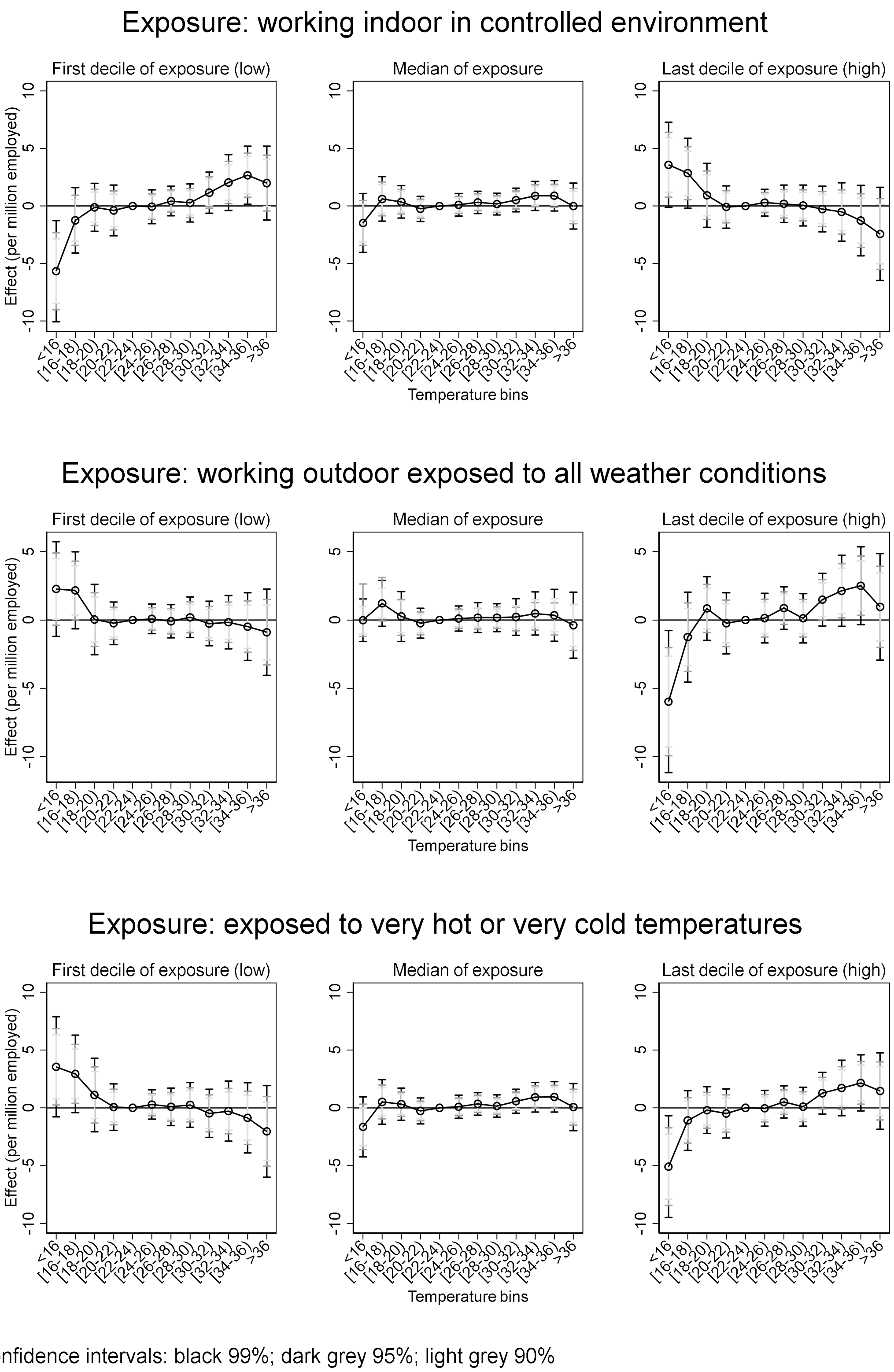
environment (reverse), working outdoors in all weather conditions, and working in extremely hot and cold temperatures. The number of incidents for workers who were working outside in all types of weather and extremely hot or cold temperatures increases significantly as the temperature rises above the baseline, indicating that workers who are working outdoors and in extremely hot or cold temperatures are particularly susceptible to heat-related incidents and hazards. Although the slight increase in accidents among workers in sectors where it is uncommon to work indoors in controlled environments, these workers nevertheless follow the upward trend as temperatures rise. Confidence intervals support the findings' robustness by verifying that these increases are statistically significant at higher confidence levels.

Figure 6 depicts the number of accidents at work that resulted in compensation for various temperature ranges. According to the estimation, more accidents resulting in compensation for workers in industries with high exposure scores occur when maximum temperatures soar. The findings clearly show a correlation between a higher incidence of compensable accidents and higher temperature thresholds. This data implies that in more exposed industries, heat stress and thermal discomfort play a substantial role in more serious injuries that necessitate compensation.

Figure 7 takes leave days into account. There is an associated increase in accidents that result in employee absences due to high levels of sectoral exposure when temperatures rise above the mild range. Additionally, it implies that elevated temperatures not only increase the likelihood of accidents in sectors that are exposed but also lead to more severe or debilitating injuries that necessitate workers taking leave days. Hotter weather or rising temperatures may make workplace injuries more severe, requiring longer leave days, prolonging recovery times, and affecting the labour productivity of the most exposed sectors.

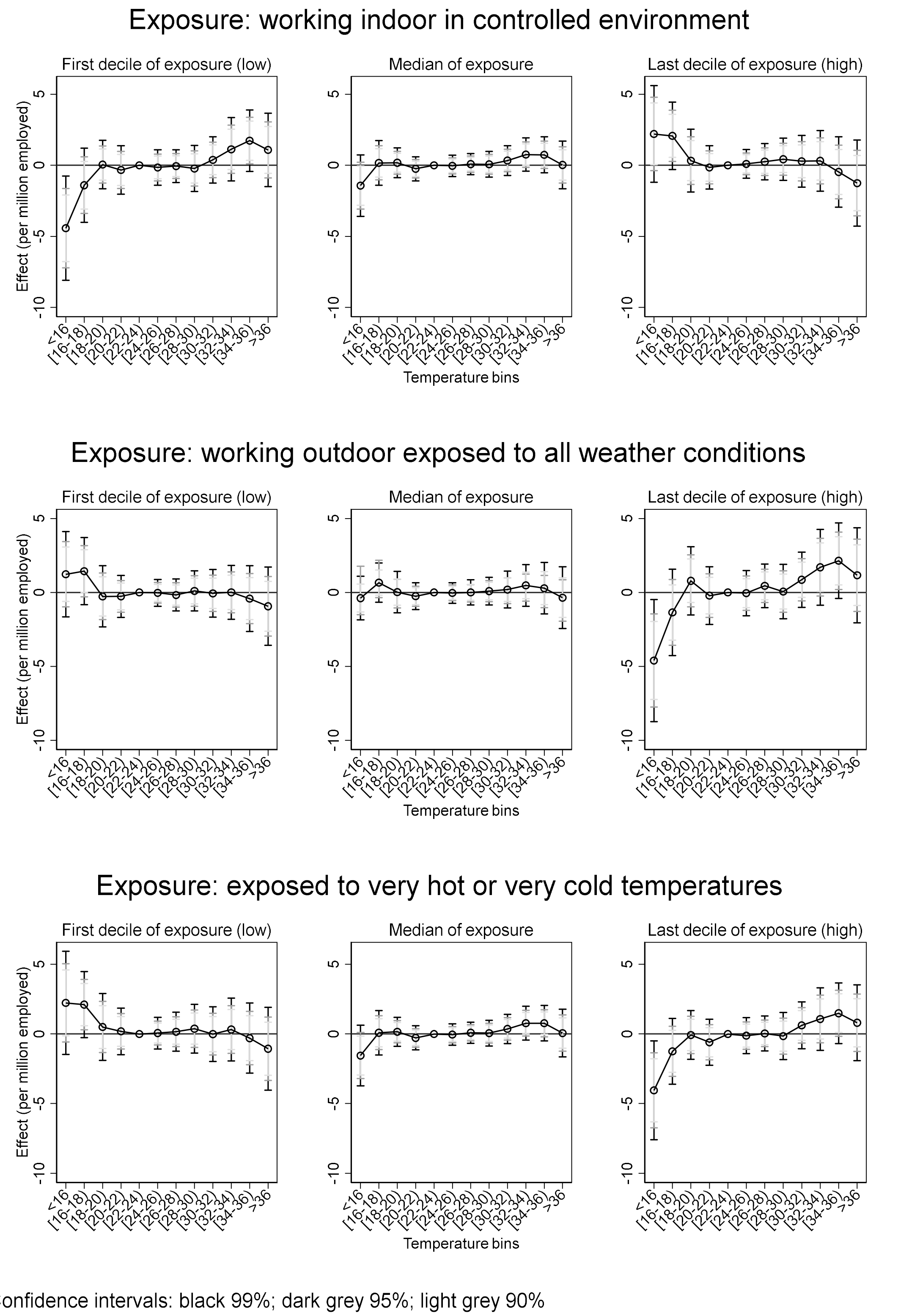
Figure 8 indicates the number of workplace accidents that result in handicap status. We also find substantial heterogeneity across sectors based on occupational exposure, with more exposed sectors experiencing the highest number of accidents with permanent repercussions during periods of extreme maximum temperatures. Due to an irreversible degradation of labour capital, this outcome also has substantial long-term productivity consequences.

Figure 5. Number of accidents



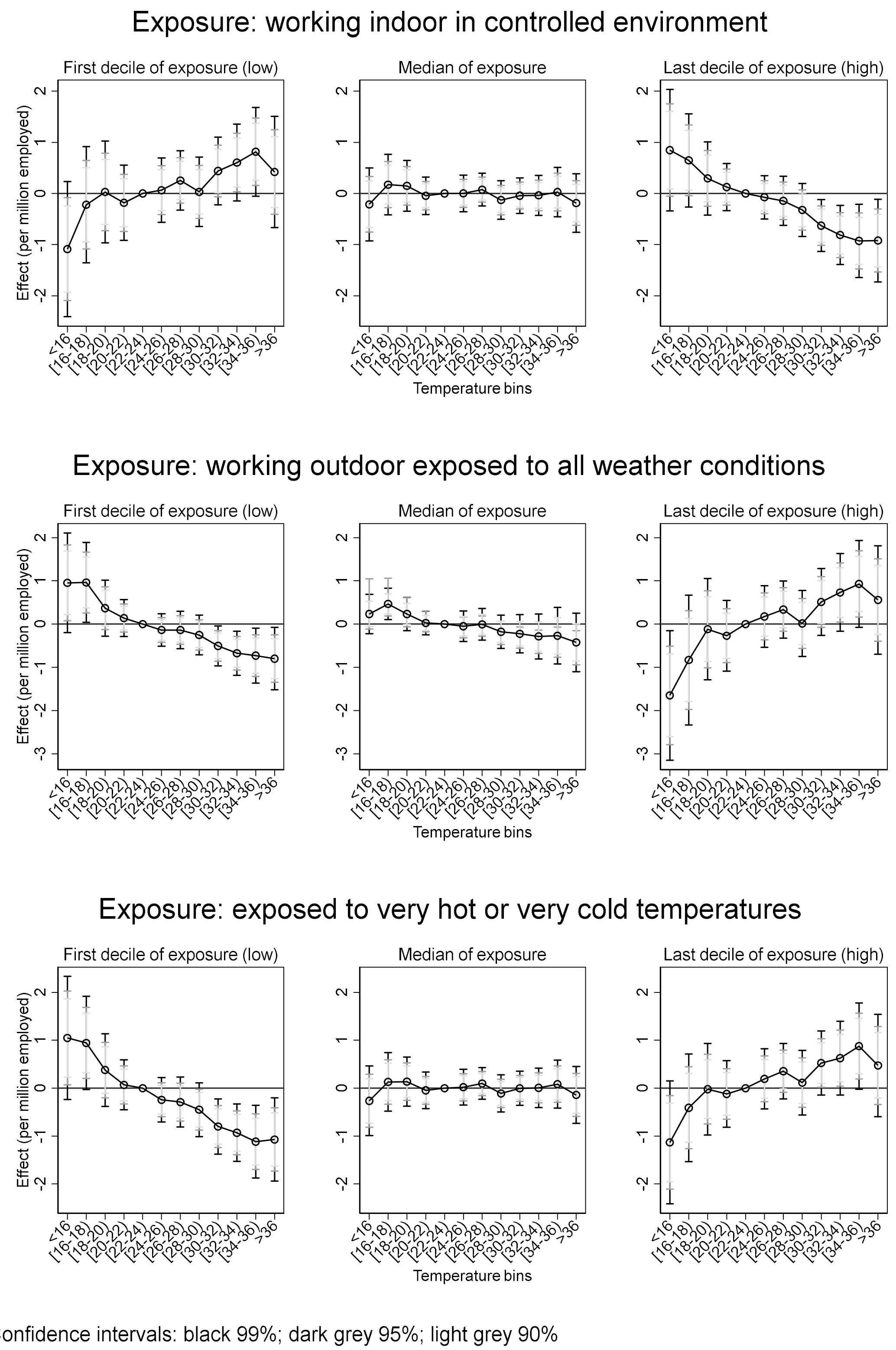
Notes: OLS regressions weighted by average employment 2014-2018 in province-sector. Standard errors clustered by province. Additional control variables: province-by-sector fixed effects, sector-by-day fixed effects, province-by-year fixed effects, province-by-month fixed effects.

Figure 6. Number of accidents leading to compensation



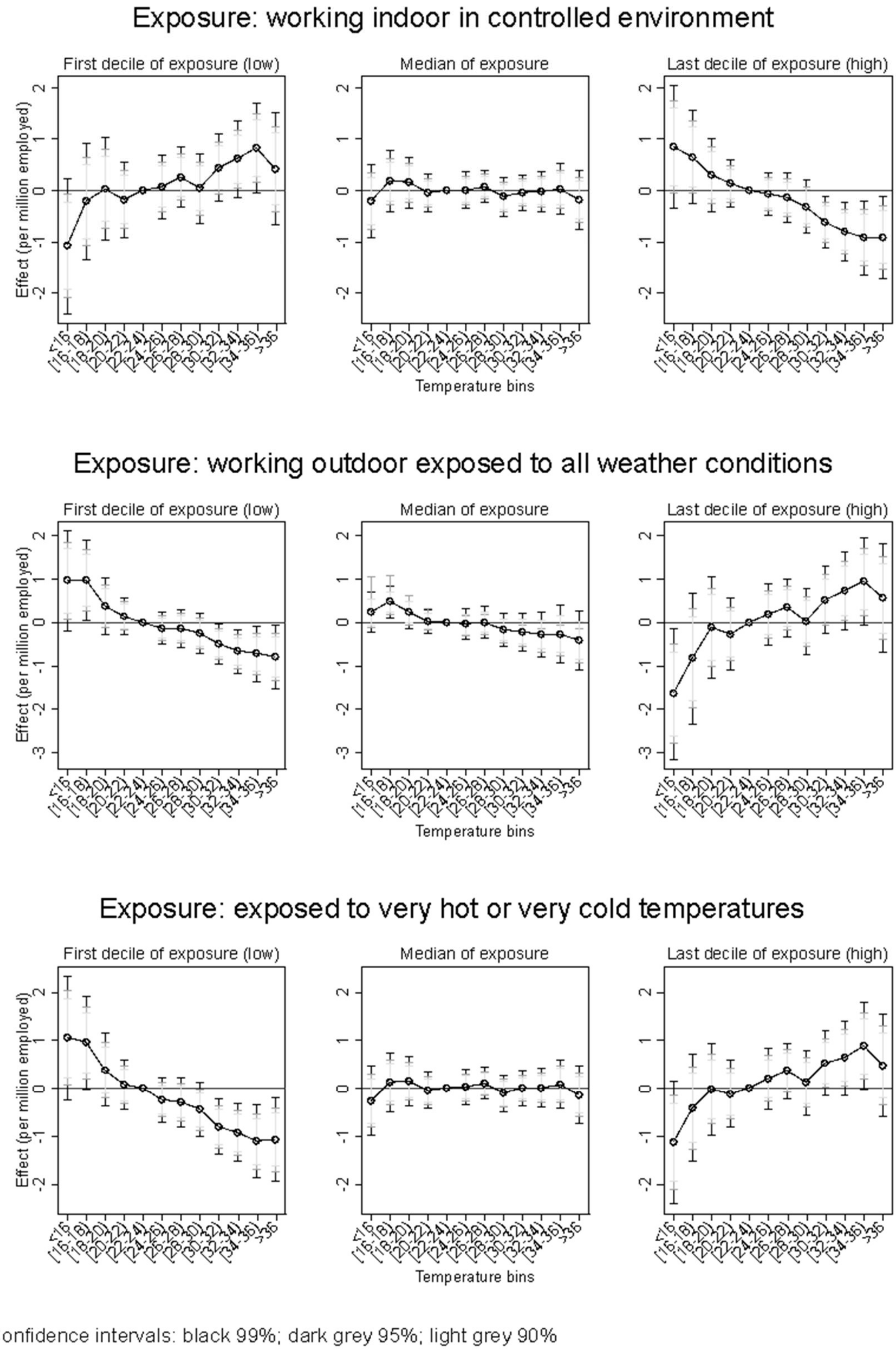
Notes: OLS regressions weighted by average employment 2014-2018 in province-sector. Standard errors clustered by province. Additional control variables: province-by-sector fixed effects, sector-by-day fixed effects, province-by-year fixed effects, province-by-month fixed effects.

Figure 7. Days of leave due to accidents



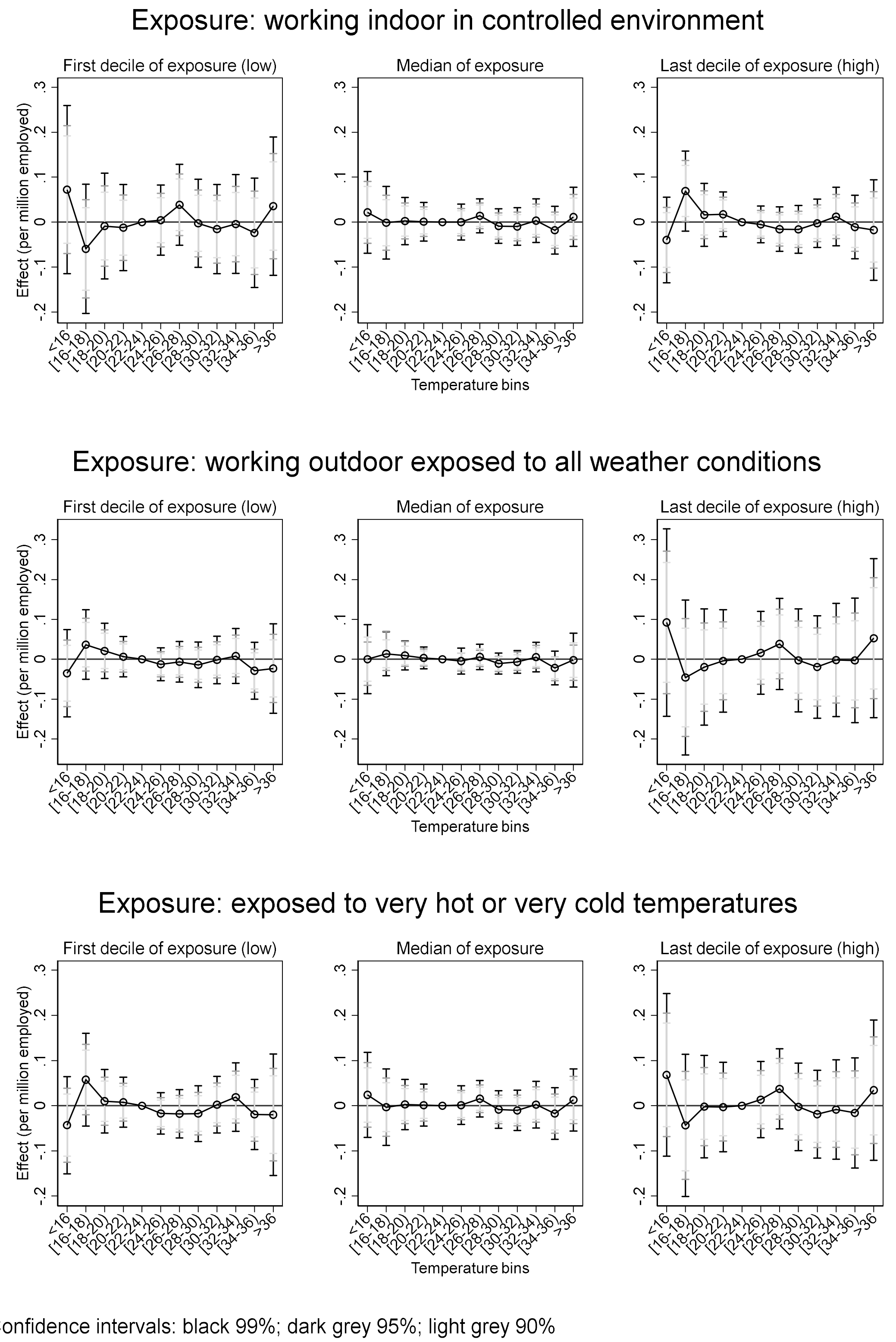
Notes: OLS regressions weighted by average employment 2014-2018 in province-sector. Standard errors clustered by province. Additional control variables: province-by-sector fixed effects, sector-by-day fixed effects, province-by-year fixed effects, province-by-month fixed effects.

Figure 8. Accidents leading to handicap



Notes: OLS regressions weighted by average employment 2014-2018 in province-sector. Standard errors clustered by province. Additional control variables: province-by-sector fixed effects, sector-by-day fixed effects, province-by-year fixed effects, province-by-month fixed effects.

Figure 9. Workplace accidents leading to fatality



Notes: OLS regressions weighted by average employment 2014-2018 in province-sector. Standard errors clustered by province. Additional control variables: province-by-sector fixed effects, sector-by-day fixed effects, province-by-year fixed effects, province-by-month fixed effects.

Figure 9 displays the findings of the estimation of workplace fatalities. In contrast to the other accident severity metrics that have been discussed thus far, fatalities appear to be unrelated to exceptionally high temperatures, even for the most exposed sectors.

The analysis demonstrates that workplace accidents due to extreme heat depend almost entirely on the sectoral working conditions. For outdoor workers and those with high temperature exposure, the risk to safety increases across all measures of accident severity (excluding fatal accidents). Looking at Figure 5, the total number of accidents for these highly exposed groups rises sharply, peaking between 34°C and 36°C with up to 3.5 additional accidents per million workers compared to the comfortable 22-24°C baseline. This increase in frequency translates directly into greater severity, where compensated accidents (Figure 6) mirror this trend, also peaking at approximately 3.5 additional injuries per million workers in the 34-36°C bin. The days of leave due to accidents (Figure 7) also show a significant rise, increasing by roughly 1.5 additional days per million employed in extreme heat. The risk of handicap accidents (Figure 8) is also clearly elevated, rising by up to 1.5 per million in the hottest bins for outdoor workers. This confirms that intense heat is a factor not just in causing more injuries, but in causing more serious, disabling injuries.

In contrast, workers in controlled indoor environments show a remarkable level of protection. For these groups, the effect on total accidents remains negligible, close to zero. Furthermore, the highest-exposed indoor workers show a surprising reduction in accident severity as heat rises, possibly due to increased caution or stricter employer controls. In extreme heat (>36°C), these workers experienced a reduction in workplace accidents (-2.5 accidents per million), compensated accidents (Figure 6) by up to -2.0 per million and a reduction in days of leave (Figure 7) by up to -1.5 per million employed.

Crucially, while heat significantly increases the frequency and severity of injuries (Figures 5-8), the risk of accidents leading to fatality (Figure 9), remains statistically unchanged across all groups. Although the average annual number of total accidents is an average of 325 during the 2018-2024 period, the data shows that high heat does not increase the already low probability of an incident becoming fatal.

4.3 Robustness checks

We additionally run a series of checks to make sure that our results were robust to alternative specifications. We first explicitly take into account the count nature of workplace accidents and use the pseudo-Poisson maximum likelihood estimator to ensure that the statistical model selection has no influence on our findings. While results for heterogeneous effects across sectors with different exposure (Figures C2-C6 in Appendix C) are consistent with our main results in terms of both magnitude and statistical significance, this alternative approach confirmed that the positive association between high temperatures and workplace accidents is, on average, at best "weak" (Figure C1 in Appendix C).

Second, we extended the list of holiday periods that were excluded from the analysis. Eliminating these days helps control for potential biases associated with reduced or altered work activity, as holidays can have a considerable impact on work patterns, with crucial sectoral and regional specificities. This might happen when companies or firms, in particular sectors, cut back on their workload during particular times, which is somewhat correlated with sectoral exposure, or when the hours worked by specific sectors are focused on holidays more than by other sectors. All Saturdays, Sundays, and the week including 15th August were excluded for this purpose.[18] Excluding these days, results (see Figures D1-D6 in Appendix D) confirm our baseline evidence and, in most cases, standard errors are smaller, suggesting large sectoral heterogeneity in labour input during weekends and holidays.

Lastly, we employed the average Wet Bulb Globe Temperature (WBGT) index to take into consideration humidity and other environmental factors that affect heat stress. We establish the wet-bulb globe-temperature for each province and day by taking into account the mean air temperature, relative humidity, vapour pressure, wind speed, and total precipitation data from Copernicus, the environmental monitoring program of the European Union. Results employing the WBGT index (see Figures E1-E6 in Appendix E) are in line with those from a surface air temperature analysis alone.

[18] It is common in Italy that many companies stop their production during the week including 15th August.

5 Conclusions

In this study, we assessed how much extreme temperatures affect workplace accidents across various Italian sectors. The study highlights how crucial it is to take into consideration workers' exposure to acquire a comprehensive picture of the relationship between temperature and accidents. Based on a solid panel data framework, our estimation results show that, for the most exposed sectors, there is a significant positive correlation between rising temperatures and the frequency and severity of workplace accidents (except for fatal accidents), yet not for low-exposure sectors. The stability and dependability of these findings are further supported by extensive robustness checks that examine alternative model specifications. Thus, the results show that employees who work in physically demanding workplaces or are exposed to hot or cold weather have a disproportionate burden of heat-related risks.

Considering these findings, policymakers should prioritize developing and implementing tailored measures to protect workers from heat stress. It is particularly important to consider sector (or, even better, workplace) specificities in implementing measures. Indeed, implementing measures that limit work activities in all sectors in very hot days would result in very large costs in terms of reduced output and productivity as climate change will increase the frequency of very hot days in Italy. Selective measures, instead, would limit output and productivity losses to the most exposed sectors.

Measures involve implementing sector-specific safety practices, including enforced cooling breaks, flexible working hours during heatwaves, heat-resistant equipment, and increased access to hydration and shaded rest places. Promoting climate-adaptive workplace improvements, such as enhancing green space surrounding businesses and in urban areas, can also help to reduce heat exposure. Furthermore, improving legal frameworks to enforce heat stress management and raising awareness among employers and workers about the risks posed by extreme temperatures are important initiatives. In light of the continuous challenges posed by climate change, it will be imperative to proactively include climate adaptation measures into occupational health policy in order to protect vulnerable labour populations and guarantee safe, sustainable working conditions.

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Appendix A – Additional descriptive evidence

Figure A1 depicts the distribution of daily maximum temperatures across Italian municipalities during the extended summer months (May-September) from 2018 to 2024, highlighting regional variability in thermal extremes. This figure also emphasizes the range and frequency of high-temperature events, illustrating how certain areas experience more intense heat at higher percentiles, consistent with ongoing climate warming trends. Figure A2 indicates that the average maximum temperature for the bottom half of the distribution (below median) is approximately 21.8°C, followed by about 28.1°C for the 50^{th} to 75^{th} percentiles, around 31°C for the 75^{th} to 90^{th} percentiles, and approximately 34.2°C for the top decile. This illustrates the increasing trend of maximum temperatures across higher percentile ranges during the extended summer months in Italy.

INAIL, Italy's national agency, monitors workplace accidents and work-related illnesses, covering about 75-80% of the workforce, excluding certain professions like police, servicemen, journalists and firefighters. The dataset used in this paper includes details on accidents, worker demographics, injury type, and workplace information, distinguishing between workplace and commuting accidents. In this paper, the term 'workplace accident' is used to refer specifically to incidents that are directly related to work and did not occur during the worker's commute.

Table A1 reports the distribution of days/provinces by year and maximum temperature bins, weighted by average province employment.

Table A2 summarises the share of workplace accidents considered in our analysis once we excluded accidents for which the sector was not reported or for which no information on provincial employment of the sector was not available.

Table A3 presents the scores and deciles for various NACE Rev. 2 sectors based on their exposure to different working environments.

Table A4 presents the correlation analysis between measures of workplace accidents (in rates) and the incidence of extreme summer temperature by sector-province. As expected, there is a strong positive correlation between accidents and compensation received, as well as with leave days taken, indicating that higher accident numbers are associated with increased injuries and related compensations. Fatalities are moderately correlated with accidents but show larger correlations with handicap and durations involved.

Temperature variables display weak correlations with accidents and the other measures of severity.

Figure A1. Daily maximum temperature for Italian municipalities by different percentiles (extended summer month May-September 2018-2024)

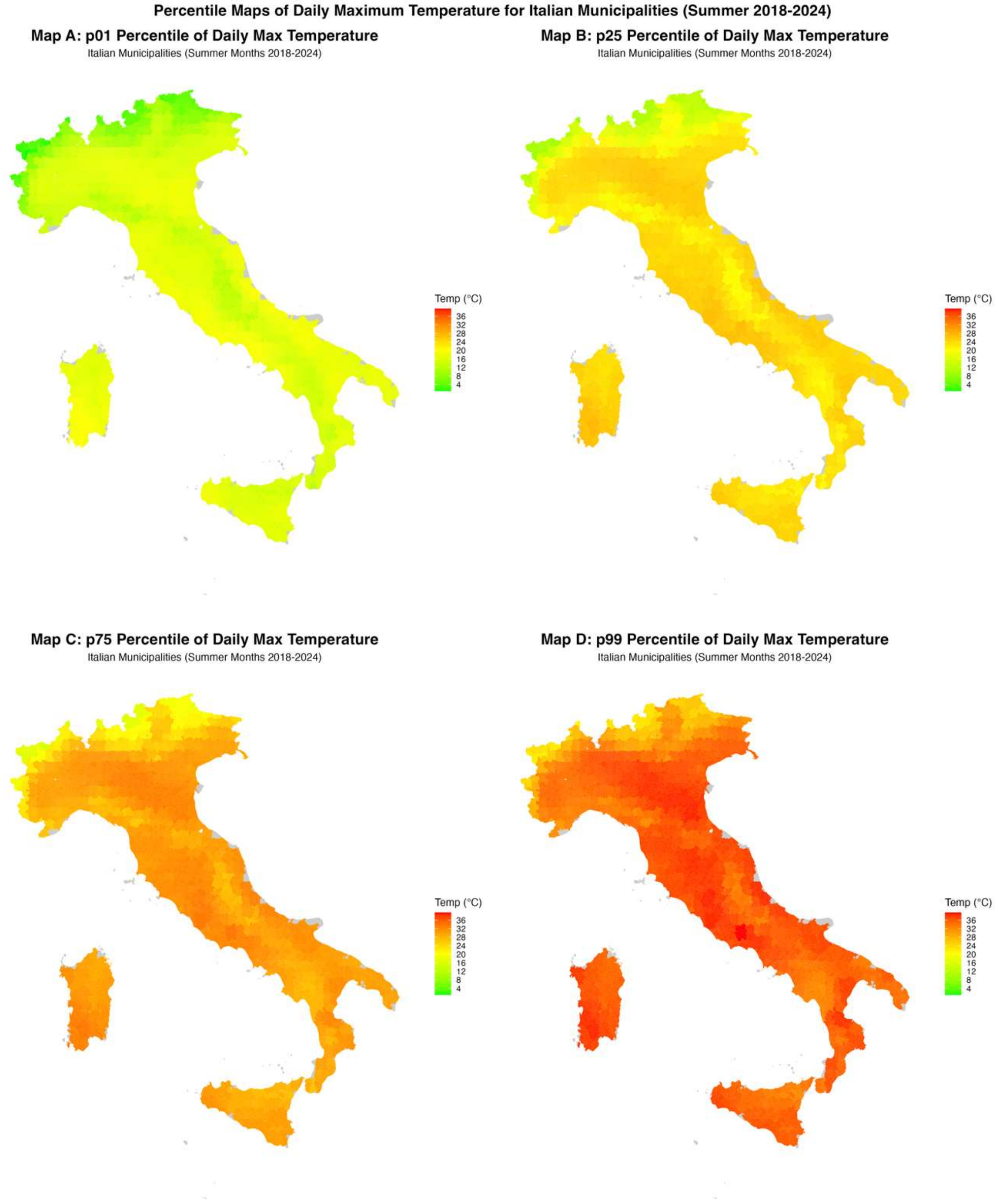


Figure A2. Daily maximum temperature for Italian municipalities by different percentile ranges (extended summer months May-September 2018-2024) (note: the value of the temperature percentile was presented as the average maximum temperature for each percentile range)

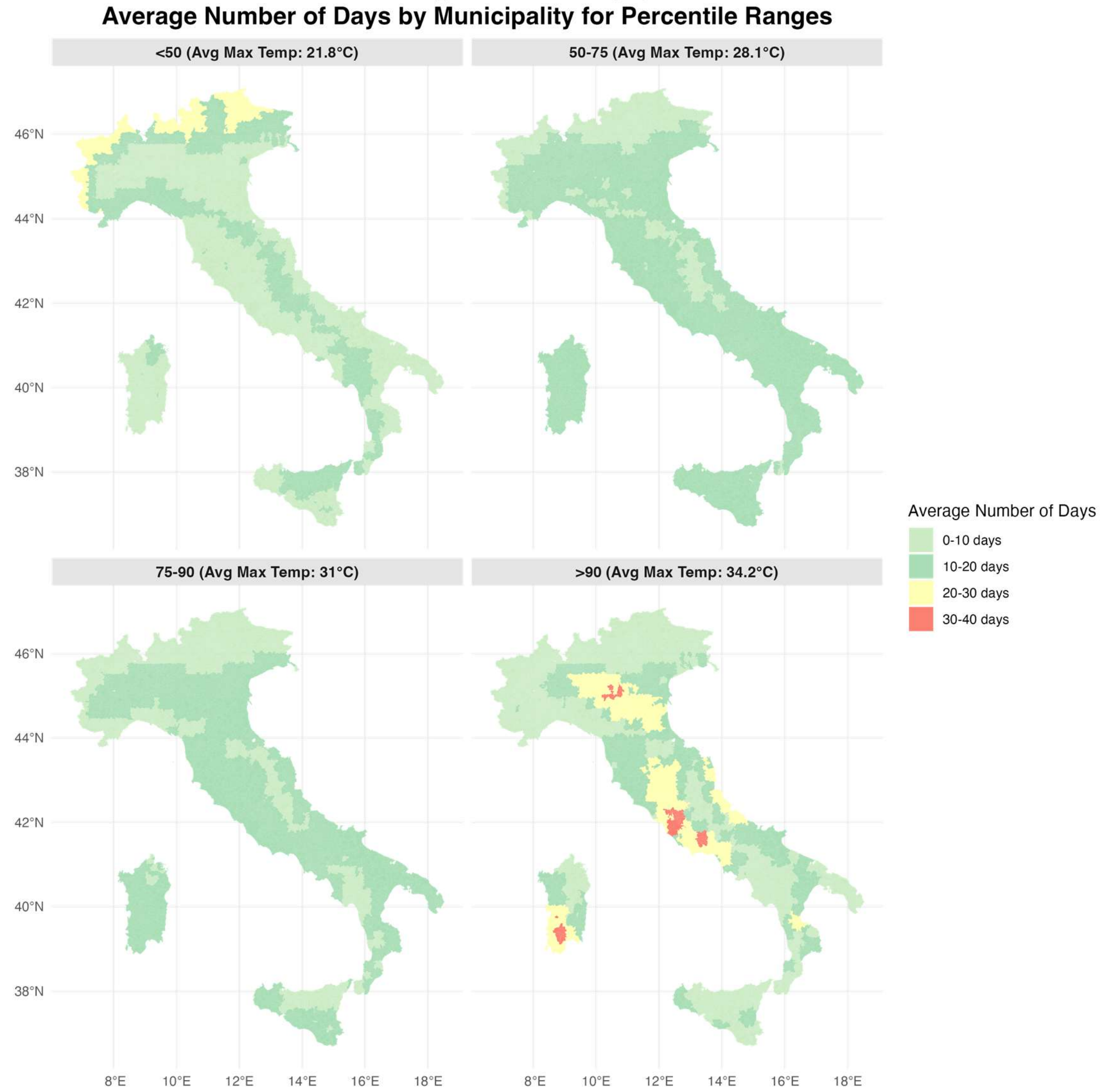


Table A1 – Distribution of days/provinces by year and maximum temperature bin

Max temperature bin (°C)	2018	2019	2020	2021	2022	2023	2024	Total
<16	0.004	0.025	0.003	0.005	0.004	0.006	0.006	0.007
[16-18)	0.007	0.029	0.006	0.010	0.012	0.018	0.013	0.014
[18-20)	0.023	0.055	0.019	0.023	0.020	0.030	0.027	0.028
[20-22)	0.032	0.057	0.045	0.052	0.038	0.043	0.058	0.046
[22-24)	0.062	0.059	0.092	0.075	0.056	0.049	0.114	0.072
[24-26)	0.101	0.077	0.143	0.112	0.059	0.094	0.140	0.103
[26-28)	0.151	0.096	0.161	0.136	0.092	0.171	0.100	0.129
[28-30)	0.217	0.145	0.150	0.175	0.159	0.170	0.103	0.160
[30-32)	0.208	0.181	0.173	0.177	0.183	0.167	0.110	0.171
[32-34)	0.133	0.165	0.132	0.128	0.177	0.108	0.167	0.145
[34-36)	0.056	0.078	0.055	0.073	0.118	0.082	0.126	0.084
>36	0.007	0.034	0.020	0.032	0.082	0.062	0.036	0.039

Table A2 – Relevance of excluded accidents

Sector	Accidents	Accidents with compensation	Days compensated	Accidents with handicap	Fatalities
Agriculture, Forestry, and Fishing	0.3%	0.4%	0.5%	0.4%	1.0%
Public administration and defence; compulsory social security	1.9%	2.1%	2.3%	1.9%	1.9%
Sector not available	31.0%	14.9%	11.5%	27.7%	27.3%
All other sectors (our sample)	66.9%	82.6%	85.7%	69.9%	69.7%

Notes: own elaboration on INAIL data for summer months (May-September) for years 2018-2024. Accidents that occurred during commuting are excluded

Table A3 – Sectoral exposure to extreme heat

NACE Rev. 2		Working indoors in controlled environment		Working outdoors, exposed to all weather conditions		Exposed to very hot or very cold temperatures	
		Score	Decile	Score	Decile	Score	Decile
01	Crop and animal production, hunting, and related service activities	0.272	1	0.831	10	0.568	10
02	Forestry and logging	0.174	1	0.866	10	0.629	10
03	Fishing and aquaculture	0.139	1	0.907	10	0.819	10
05	Mining of coal and lignite	0.645	4	0.524	9	0.429	9
06	Extraction of crude petroleum and natural gas	0.814	6	0.271	7	0.204	5
07	Mining of metal ores	0.564	2	0.197	6	0.209	5
08	Other mining and quarrying	0.366	1	0.649	10	0.535	10
09	Mining support service activities	0.757	5	0.286	8	0.225	6
10	Manufacture of food products	0.690	4	0.179	5	0.303	8
11	Manufacture of beverages	0.647	4	0.271	7	0.247	7
12	Manufacture of tobacco products	0.744	5	0.214	6	0.191	5
13	Manufacture of textiles	0.726	5	0.105	3	0.163	4
14	Manufacture of wearing apparel	0.770	5	0.073	2	0.098	4
15	Manufacture of leather and related products	0.597	3	0.047	1	0.092	3
16	Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles of straw and plaiting materials	0.539	2	0.216	6	0.298	8
17	Manufacture of paper and paper products	0.594	3	0.187	6	0.255	7
18	Printing and reproduction of recorded media	0.744	5	0.092	2	0.124	4

NACE Rev. 2		Working indoors in controlled environment		Working outdoors, exposed to all weather conditions		Exposed to very hot or very cold temperatures	
		Score	Decile	Score	Decile	Score	Decile
19	Manufacture of coke and refined petroleum products	0.713	5	0.330	9	0.264	7
20	Manufacture of chemicals and chemical products	0.737	5	0.171	5	0.192	5
21	Manufacture of basic pharmaceutical products and pharmaceutical preparations	0.824	6	0.178	5	0.144	4
22	Manufacture of rubber and plastic products	0.617	4	0.141	4	0.270	7
23	Manufacture of other non-metallic mineral products	0.531	2	0.290	8	0.379	9
24	Manufacture of basic metals	0.578	2	0.211	6	0.358	9
25	Manufacture of fabricated metal products, except machinery and equipment	0.581	2	0.170	5	0.275	7
26	Manufacture of computer, electronic, and optical products	0.803	6	0.120	3	0.139	4
27	Manufacture of electrical equipment	0.709	4	0.146	4	0.204	5
28	Manufacture of machinery and equipment n.e.c.	0.712	4	0.162	5	0.212	5
29	Manufacture of motor vehicles, trailers, and semi-trailers	0.628	4	0.154	4	0.250	7
30	Manufacture of other transport equipment	0.673	4	0.214	6	0.268	7
31	Manufacture of furniture	0.599	3	0.138	4	0.236	6
32	Other manufacturing	0.813	6	0.087	2	0.117	4
33	Repair and installation of machinery and equipment	0.676	4	0.311	8	0.304	8
35	Electricity, gas, steam and air conditioning supply	0.847	6	0.260	6	0.203	5
36	Water collection, treatment and supply	0.761	5	0.383	9	0.287	8
37	Sewerage	0.593	2	0.556	9	0.365	9
38	Waste collection, treatment and disposal activities; materials recovery	0.467	1	0.642	10	0.429	9
39	Remediation activities and other waste management services	0.662	4	0.471	9	0.338	9
41	Construction of buildings	0.297	1	0.769	10	0.541	10
42	Civil engineering	0.498	1	0.633	10	0.478	10
43	Specialised construction activities	0.508	1	0.586	9	0.462	9
45	Wholesale and retail trade and repair of motor vehicles and motorcycles	0.550	2	0.262	6	0.280	8
46	Wholesale trade, except for motor vehicles and motorcycles	0.718	5	0.270	7	0.196	5
47	Retail trade, except for motor vehicles and motorcycles	0.594	2	0.279	7	0.241	6
49	Land transport and transport via pipelines	0.552	2	0.414	9	0.346	9
50	Water transport	0.704	4	0.547	9	0.446	9
51	Air transport	0.884	8	0.248	6	0.224	6
52	Warehousing and support activities for transportation	0.710	4	0.321	8	0.246	7
53	Postal and courier activities	0.827	6	0.313	8	0.189	4
55	Accommodation	0.883	8	0.178	5	0.174	4
56	Food and beverage service activities	0.845	6	0.147	4	0.311	8
58	Publishing activities	0.901	9	0.184	6	0.077	3

NACE Rev. 2		Working indoors in controlled environment		Working outdoors, exposed to all weather conditions		Exposed to very hot or very cold temperatures	
		Score	Decile	Score	Decile	Score	Decile
59	Motion picture, video and television programme production, sound recording and music publishing activities	0.866	7	0.261	6	0.151	4
60	Programming and broadcasting activities	0.887	8	0.270	6	0.132	4
61	Telecommunications	0.921	9	0.123	3	0.088	3
62	Computer programming, consultancy and related activities	0.928	9	0.044	1	0.039	1
63	Information service activities	0.928	9	0.064	2	0.039	1
64	Financial service activities, except insurance and pension funding	0.975	10	0.033	1	0.028	1
65	Insurance, reinsurance and pension funding, except compulsory social security	0.914	9	0.176	5	0.062	3
66	Activities auxiliary to financial services and insurance activities	0.934	9	0.181	6	0.051	3
68	Real estate activities	0.882	8	0.269	6	0.118	4
69	Legal and accounting activities	0.950	10	0.049	1	0.030	1
70	Activities of head offices; management consultancy activities	0.935	9	0.088	2	0.051	1
71	Architectural and engineering activities; technical testing and analysis	0.888	8	0.477	9	0.258	7
72	Scientific research and development	0.912	9	0.161	5	0.114	4
73	Advertising and market research	0.855	7	0.171	5	0.106	4
74	Other professional, scientific and technical activities	0.852	7	0.267	6	0.156	4
75	Veterinary activities	0.976	10	0.170	5	0.052	3
77	Rental and leasing activities	0.699	4	0.281	8	0.216	5
78	Employment activities	0.794	6	0.185	6	0.165	4
79	Travel agency, tour operator and other reservation service and related activities	0.841	6	0.245	6	0.149	4
80	Security and investigation activities	0.692	4	0.545	9	0.367	9
81	Services to buildings and landscape activities	0.727	5	0.500	9	0.294	8
82	Office administrative, office support and other business support activities	0.864	7	0.108	3	0.096	3
84	Public administration and defence; compulsory social security	0.851	6	0.299	8	0.218	5
85	Education	0.876	7	0.104	2	0.051	1
86	Human health activities	0.944	9	0.064	1	0.051	2
87	Residential care activities	0.926	9	0.108	3	0.060	3
88	Social work activities without accommodation	0.916	9	0.148	4	0.051	2
90	Creative, arts and entertainment activities	0.834	6	0.254	6	0.144	4
91	Libraries, archives, museums and other cultural activities	0.851	7	0.165	5	0.147	4
92	Gambling and betting activities	0.895	9	0.091	2	0.096	3
93	Sports activities and amusement and recreation activities	0.720	5	0.321	9	0.233	6
94	Activities of membership organisations	0.862	7	0.160	5	0.107	4
95	Repair of computers and personal and household goods	0.726	5	0.124	3	0.143	4
96	Other personal service activities	0.863	7	0.087	2	0.096	3
97	Activities of households as employers of domestic personnel	0.893	8	0.125	3	0.069	3

NACE Rev. 2		Working indoors in controlled environment		Working outdoors, exposed to all weather conditions		Exposed to very hot or very cold temperatures	
		Score	Decile	Score	Decile	Score	Decile
98	Undifferentiated goods- and services-producing activities of private households for own use	0.682	4	0.389	9	0.252	7
99	Activities of extraterritorial organisations and bodies	0.873	7	0.141	4	0.115	4

Table A4. Correlation between accident-related variables and extreme temperatures

	Accidents	Compensated accidents	Days compensated	Handicap	Fatalities	Max temp >32°C	Max temp >34°C	Max temp >36°C
Accidents	1.000							
Compensated accidents	0.986	1.000						
Days compensated	0.885	0.917	1.000					
Handicap	0.768	0.806	0.912	1.000				
Fatalities	0.163	0.180	0.267	0.293	1.000			
Max temp >32°C	-0.078	-0.084	-0.050	-0.033	0.014	1.000		
Max temp >34°C	-0.073	-0.078	-0.034	-0.009	0.028	0.965	1.000	
Max temp >36°C	-0.070	-0.072	-0.020	0.012	0.037	0.896	0.973	1.000

Notes. Correlations weighted by average employment in province-by-sector. All variables on accidents are expressed as the ratio of events (or days) per million/day. Summer days only (May-September) are included.

Appendix B – Tables of main results

This appendix presents tables corresponding to Figures 1-9 in the main text. Table B1 examines the average effect of maximum temperature across the various outcomes using the 22-24°C temperature bin as the baseline. Tables B2, B3, and B4 show the interaction effects between temperature bins and the measures of sectoral exposure: indoor controlled environments, outdoor work, and exposure to very hot or cold temperatures, respectively.

Table B1. Average effect of maximum temperature on accidents

	(1)	(2)	(3)	(4)	(5)
	Accidents per million workers per day	Accidents with compensation per million workers per day	Days compensated per mission workers per day	Accidents with handicap per million workers per day	Fatalities per million workers per day
<16	-1.292	-1.289	-39.89	-0.174	0.0191
	(0.998)	(0.841)	(43.92)	(0.273)	(0.0340)
[16-18)	0.690	0.236	10.49	0.187	0.00122
	(0.762)	(0.613)	(32.63)	(0.226)	(0.0307)
[18-20)	0.375	0.180	19.41	0.153	0.00295
	(0.556)	(0.412)	(27.06)	(0.188)	(0.0195)
[20-22)	-0.245	-0.246	-4.140	-0.0389	0.00154
	(0.416)	(0.323)	(18.75)	(0.139)	(0.0160)
[22-24)	[reference cat]	[reference cat]	[reference cat]	[reference cat]	[reference cat]
[24-26)	0.107	-0.0357	4.450	-0.000476	-0.000175
	(0.376)	(0.286)	(21.72)	(0.136)	(0.0149)
[26-28)	0.320	0.0917	-10.35	0.0682	0.0128
	(0.377)	(0.291)	(18.76)	(0.121)	(0.0139)
[28-30)	0.170	0.0867	-21.53	-0.132	-0.00918
	(0.365)	(0.348)	(21.89)	(0.144)	(0.0141)
[30-32)	0.494	0.337	-18.23	-0.0618	-0.00947
	(0.399)	(0.405)	(21.63)	(0.132)	(0.0154)
[32-34)	0.838*	0.744	-4.966	-0.0618	0.00363
	(0.479)	(0.449)	(24.65)	(0.149)	(0.0181)
[34-36)	0.816	0.693	8.495	-0.00595	-0.0177
	(0.508)	(0.488)	(27.88)	(0.183)	(0.0197)
>36	-0.0865	-0.0163	-59.66*	-0.205	0.00998
	(0.789)	(0.656)	(35.30)	(0.216)	(0.0243)
N	8159394	8159394	8159394	8159394	8159394

Notes. OLS regressions weighted by average employment 2014-2018 in province-sector. Standard errors clustered by province in parenthesis. * p<0.1, ** p<0.05; *** p<0.01. Additional control variables: province-by-sector fixed effects, sector-by-day fixed effects, province-by-year fixed effects, province-by-month fixed effects.

Table B2. Interaction terms between temperature and sectoral exposure: working indoors in controlled environment

Interaction between temperature bin and exposure:	(1) Accidents per million workers per day	(2) Accidents with compensation per million workers per day	(3) Days compensated per mission workers per day	(4) Accidents with handicap per million workers per day	(5) Fatalities per million workers per day
<16°C	23.38***	16.78***	673.9	4.897**	-0.284
	(6.314)	(5.552)	(426.1)	(2.059)	(0.242)
[16-18°C)	10.36**	8.792**	159.0	2.198	0.326*
	(4.351)	(3.845)	(276.6)	(1.690)	(0.181)
[18-20°C)	2.650	0.698	37.48	0.669	0.0630
	(3.873)	(3.244)	(227.6)	(1.437)	(0.166)
[20-22°C)	0.774	0.455	-103.7	0.780	0.0752
	(3.431)	(2.745)	(163.4)	(1.001)	(0.129)
[22-24°C)	[reference cat]	[reference cat]	[reference cat]	[reference cat]	[reference cat]
[24-26°C)	0.905	0.638	-63.44	-0.349	-0.0242
	(1.811)	(1.707)	(129.8)	(0.808)	(0.0990)
[26-28°C)	-0.610	0.782	41.66	-1.008	-0.138
	(2.122)	(1.870)	(142.1)	(0.855)	(0.127)
[28-30°C)	-0.554	1.655	-2.209	-0.896	-0.0339
	(2.811)	(2.501)	(161.5)	(0.949)	(0.140)
[30-32°C)	-3.613	-0.246	-172.1	-2.705***	0.0331
	(3.104)	(2.691)	(149.9)	(0.964)	(0.139)
[32-34°C)	-6.471	-2.057	-301.2*	-3.581***	0.0427
	(4.200)	(3.635)	(178.4)	(1.093)	(0.155)
[34-36°C)	-9.973**	-5.587	-459.7**	-4.414***	0.0325
	(4.829)	(3.820)	(193.2)	(1.267)	(0.172)
>36°C	-11.19*	-5.915	-289.3	-3.391**	-0.134
	(5.921)	(4.414)	(220.1)	(1.548)	(0.236)
Observations	8159394	8159394	8159394	8159394	8159394

Notes. OLS regressions weighted by average employment 2014-2018 in province-sector. Standard errors clustered by province in parenthesis. * p<0.1, ** p<0.05; *** p<0.01. Additional control variables: temperature bins, province-by-sector fixed effects, sector-by-day fixed effects, province-by-year fixed effects, province-by-month fixed effects.

Table B3. Interaction terms between temperature and sectoral exposure: working outdoors exposed to all weather conditions

	(1)	(2)	(3)	(4)	(5)
Interaction between temperature bin and exposure:	Accidents per million workers per day	Accidents with compensation per million workers per day	Days compensated per mission workers per day	Accidents with handicap per million workers per day	Fatalities per million workers per day
<16°C	-18.92***	-13.38***	-606.0	-5.972***	0.293
	(6.231)	(4.922)	(394.8)	(1.997)	(0.273)
[16-18°C)	-7.850*	-6.407*	-146.8	-4.116**	-0.189
	(4.156)	(3.654)	(270.0)	(1.901)	(0.216)
[18-20°C)	1.861	2.423	192.2	-1.115	-0.0933
	(3.636)	(3.410)	(228.9)	(1.389)	(0.174)
[20-22°C)	0.0132	0.120	246.8	-0.935	-0.0236
	(2.770)	(2.586)	(159.7)	(0.928)	(0.149)
[22-24°C)	[reference cat]	[reference cat]	[reference cat]	[reference cat]	[reference cat]
[24-26°C)	0.126	-0.0424	221.4*	0.714	0.0657
	(1.925)	(1.733)	(125.4)	(0.752)	(0.116)
[26-28°C)	2.201	1.413	97.65	1.086	0.103
	(1.745)	(1.830)	(146.4)	(0.803)	(0.138)
[28-30°C)	-0.152	-0.105	81.76	0.612	0.0257
	(2.399)	(2.361)	(164.7)	(0.870)	(0.159)
[30-32°C)	4.024	2.106	251.3	2.331**	-0.0408
	(2.574)	(2.474)	(161.4)	(0.926)	(0.157)
[32-34°C)	5.272	3.890	379.8**	3.225***	-0.0229
	(3.388)	(3.308)	(175.6)	(1.058)	(0.173)
[34-36°C)	6.874*	5.885	510.6***	3.805***	0.0597
	(4.128)	(3.608)	(179.3)	(1.195)	(0.187)
>36°C	4.260	4.822	328.3	3.116**	0.174
	(5.117)	(4.244)	(220.8)	(1.468)	(0.257)
Observations	8159394	8159394	8159394	8159394	8159394

Notes. OLS regressions weighted by average employment 2014-2018 in province-sector. Standard errors clustered by province in parenthesis. * p<0.1, ** p<0.05; *** p<0.01. Additional control variables: temperature bins, province-by-sector fixed effects, sector-by-day fixed effects, province-by-year fixed effects, province-by-month fixed effects.

Table B4. Interaction terms between temperature and sectoral exposure: exposed to very hot or very cold temperatures

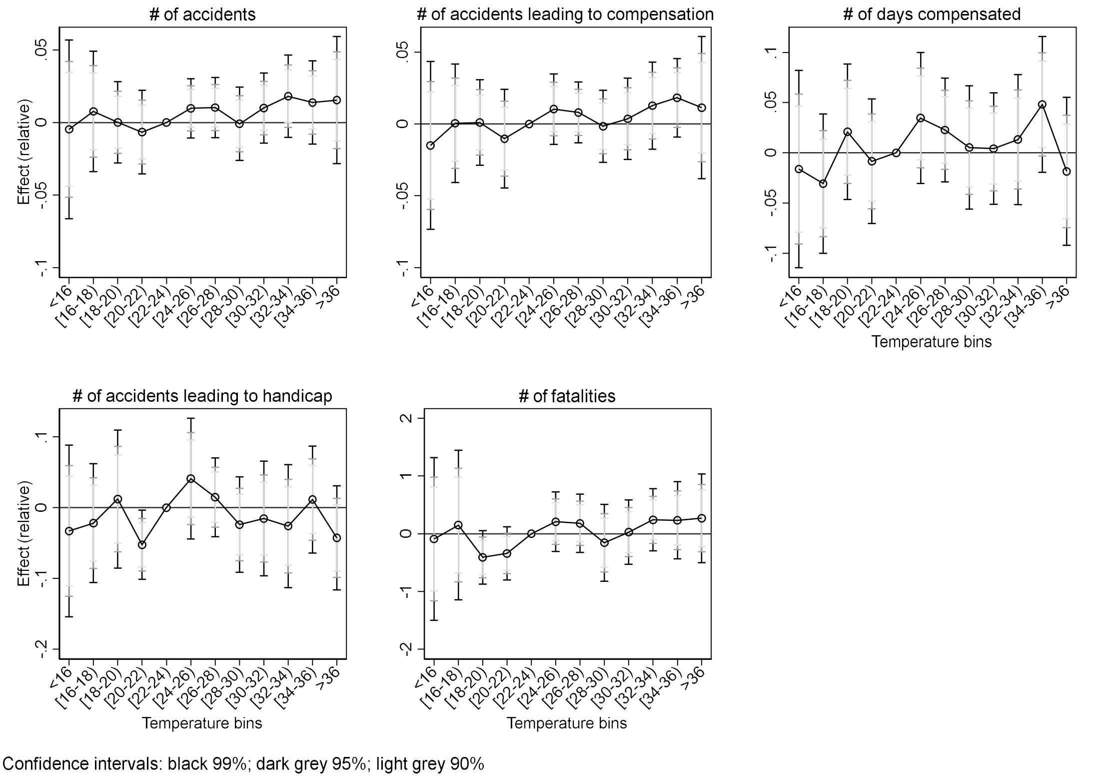
	(1)	(2)	(3)	(4)	(5)
Interaction between temperature bin and exposure:	Accidents per million workers per day	Accidents with compensation per million workers per day	Days compensated per mission workers per day	Accidents with handicap per million workers per day	Fatalities per million workers per day
<16°C	-27.34***	-19.87***	-730.3	-6.890**	0.352
	(8.850)	(7.219)	(534.8)	(2.650)	(0.309)
[16-18°C)	-12.75**	-10.62**	-214.8	-4.283*	-0.320
	(5.492)	(4.404)	(347.9)	(2.191)	(0.273)
[18-20°C)	-4.129	-1.814	124.7	-1.265	-0.0380
	(5.403)	(4.397)	(299.0)	(1.801)	(0.205)
[20-22°C)	-1.759	-2.487	221.9	-0.597	-0.0342
	(4.389)	(3.552)	(215.7)	(1.266)	(0.176)
[22-24°C)	[reference cat]	[reference cat]	[reference cat]	[reference cat]	[reference cat]
[24-26°C)	-1.027	-0.578	210.2	1.385	0.0969
	(2.606)	(2.412)	(175.0)	(1.074)	(0.144)
[26-28°C)	1.338	-0.381	86.01	2.042*	0.175
	(2.798)	(2.689)	(195.6)	(1.129)	(0.164)
[28-30°C)	-0.477	-1.677	116.8	1.785	0.0477
	(3.813)	(3.629)	(218.5)	(1.248)	(0.185)
[30-32°C)	5.528	1.986	359.7*	4.195***	-0.0666
	(4.043)	(3.662)	(202.3)	(1.309)	(0.182)
[32-34°C)	6.334	2.376	452.8*	4.923***	-0.0875
	(5.326)	(4.763)	(234.7)	(1.442)	(0.208)
[34-36°C)	9.548	5.654	709.6***	6.311***	0.0103
	(5.854)	(4.853)	(243.8)	(1.713)	(0.226)
>36°C	11.06	5.902	484.5	4.890**	0.172
	(7.382)	(5.635)	(298.7)	(2.002)	(0.327)
Observations	8159394	8159394	8159394	8159394	8159394

Notes. OLS regressions weighted by average employment 2014-2018 in the province-sector. Standard errors clustered by province in parenthesis. * p<0.1, ** p<0.05; *** p<0.01. Additional control variables: temperature bins, province-by-sector fixed effects, sector-by-day fixed effects, province-by-year fixed effects, province-by-month fixed effects.

Appendix C – Poisson pseudo maximum likelihood estimator

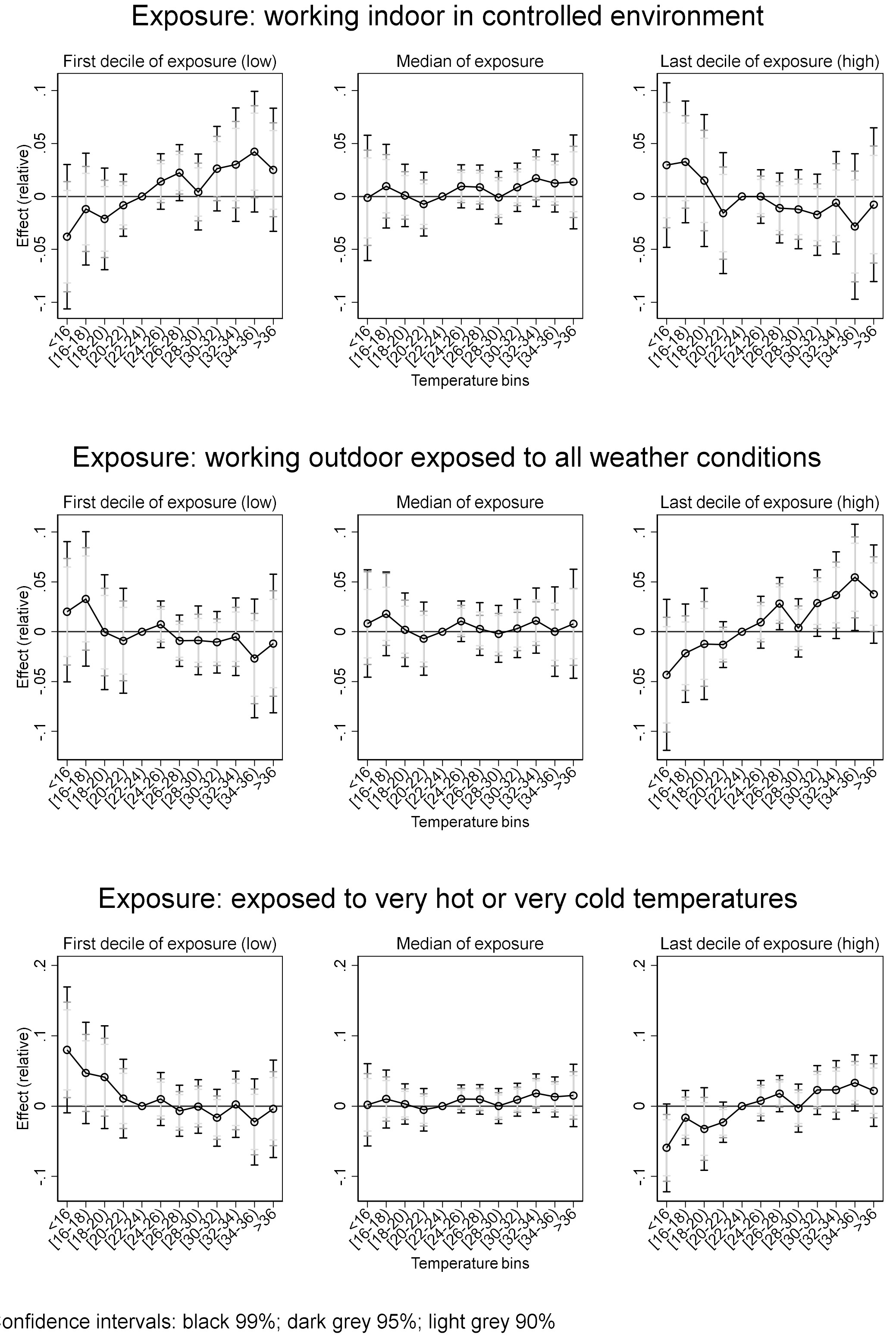
This appendix presents baseline results using the Poisson pseudo maximum likelihood (PPML) estimator. Figures C1 to C6 show various outcomes related to workplace accidents, incorporating fixed effects and clustering standard errors by province. These statistics not only offer robust sensitivity checks but also complement the OLS findings, confirming the study's key results.

Figure C1. Baseline results based on the Poisson pseudo maximum likelihood model



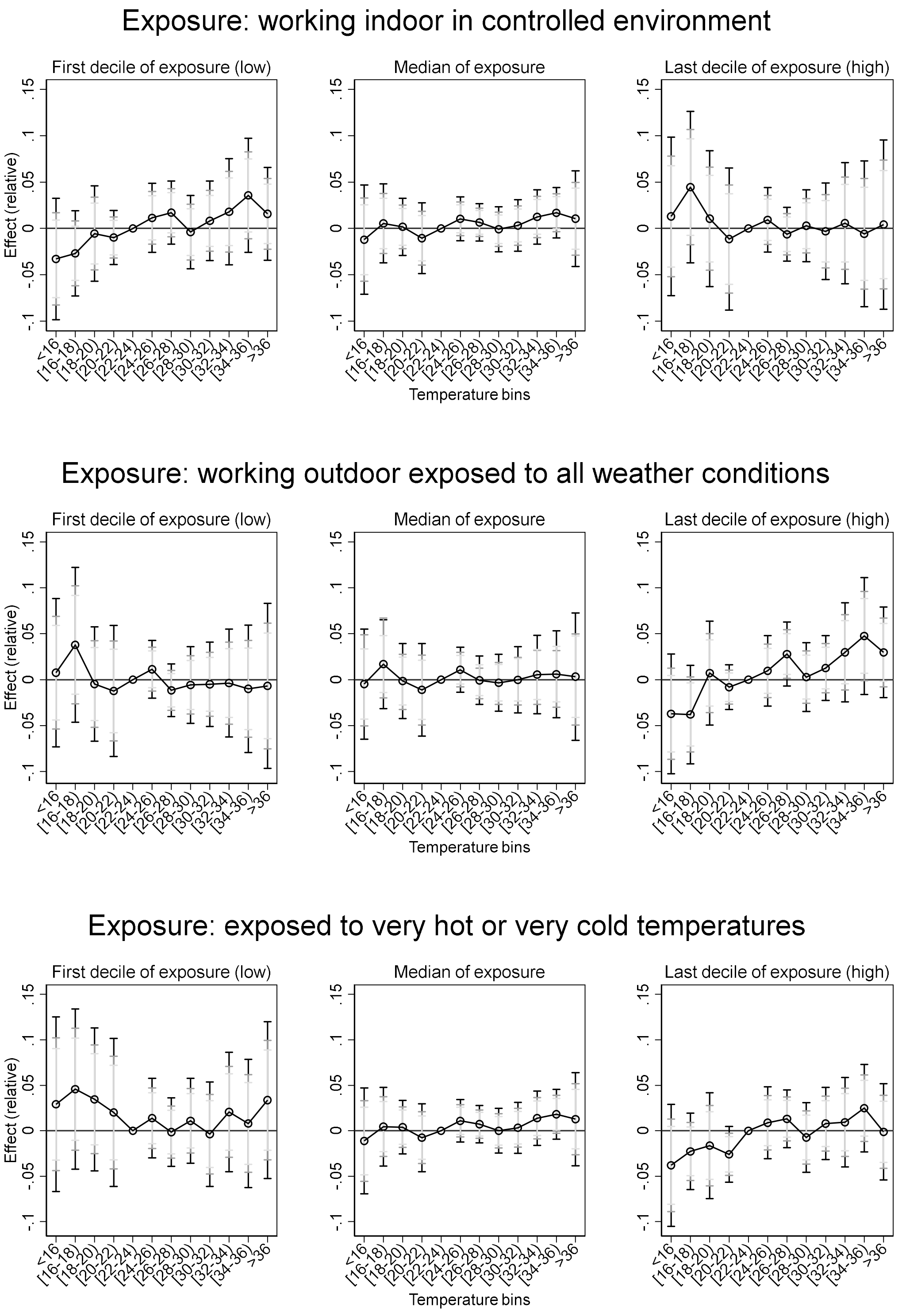
Notes: PPML estimator weighted by average employment 2014-2018 in province-sector. Standard errors clustered by province. Additional control variables: province-by-sector fixed effects, sector-by-day fixed effects, province-by-year fixed effects, province-by-month fixed effects.

Figure C2. Heterogeneous effects based on the Poisson pseudo maximum likelihood model: workplace accidents



Notes: PPML estimator weighted by average employment 2014-2018 in province-sector. Standard errors clustered by province. Additional control variables: province-by-sector fixed effects, sector-by-day fixed effects, province-by-year fixed effects, province-by-month fixed effects.

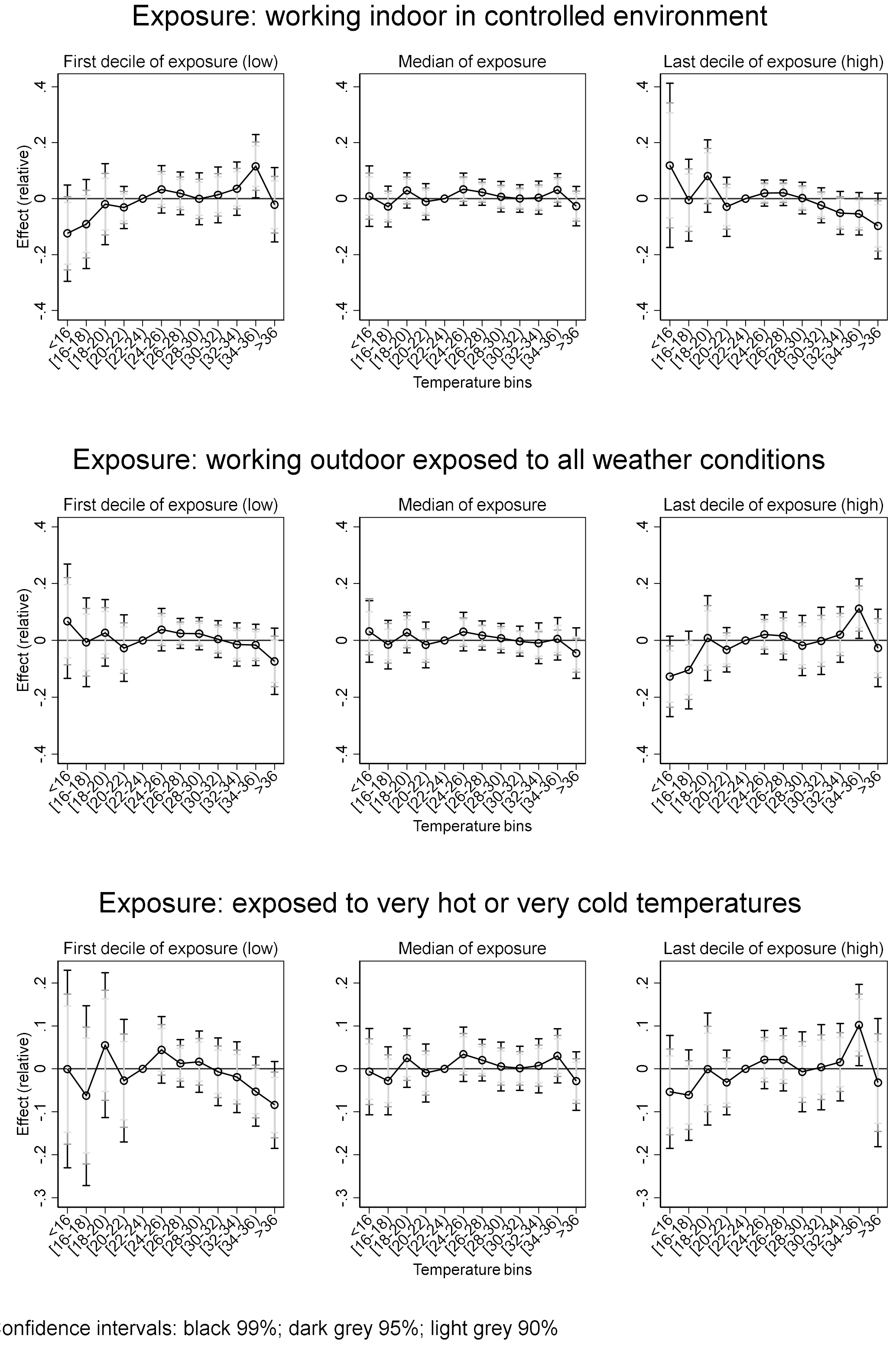
Figure C3. Heterogeneous effects based on the Poisson pseudo maximum likelihood model: workplace accidents leading to compensation



Confidence intervals: black 99%; dark grey 95%; light grey 90%

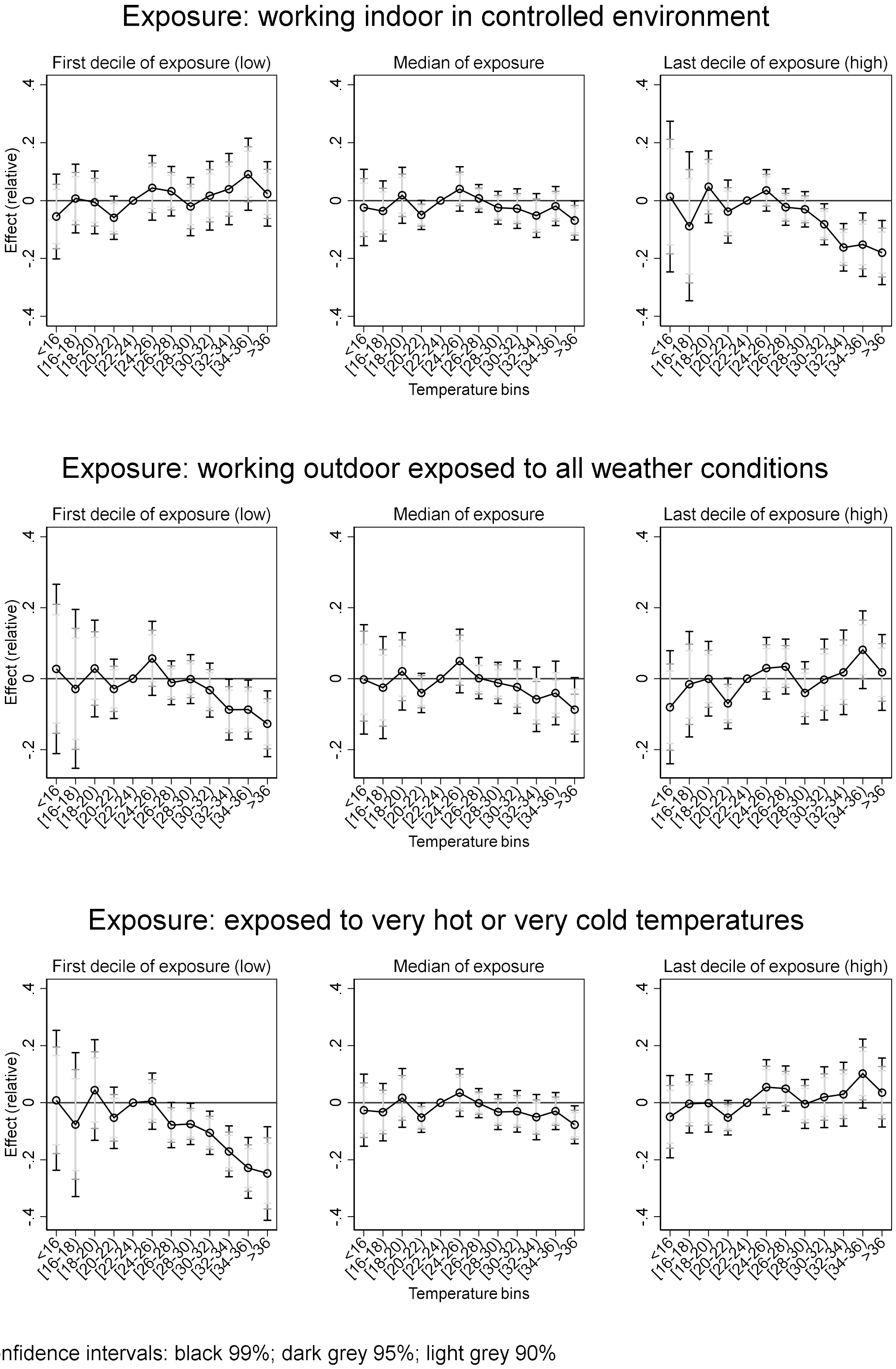
Notes: PPML estimator weighted by average employment 2014-2018 in province-sector. Standard errors clustered by province. Additional control variables: province-by-sector fixed effects, sector-by-day fixed effects, province-by-year fixed effects, province-by-month fixed effects.

Figure C4. Heterogeneous effects based on the Poisson pseudo maximum likelihood model: days compensated due to workplace accidents



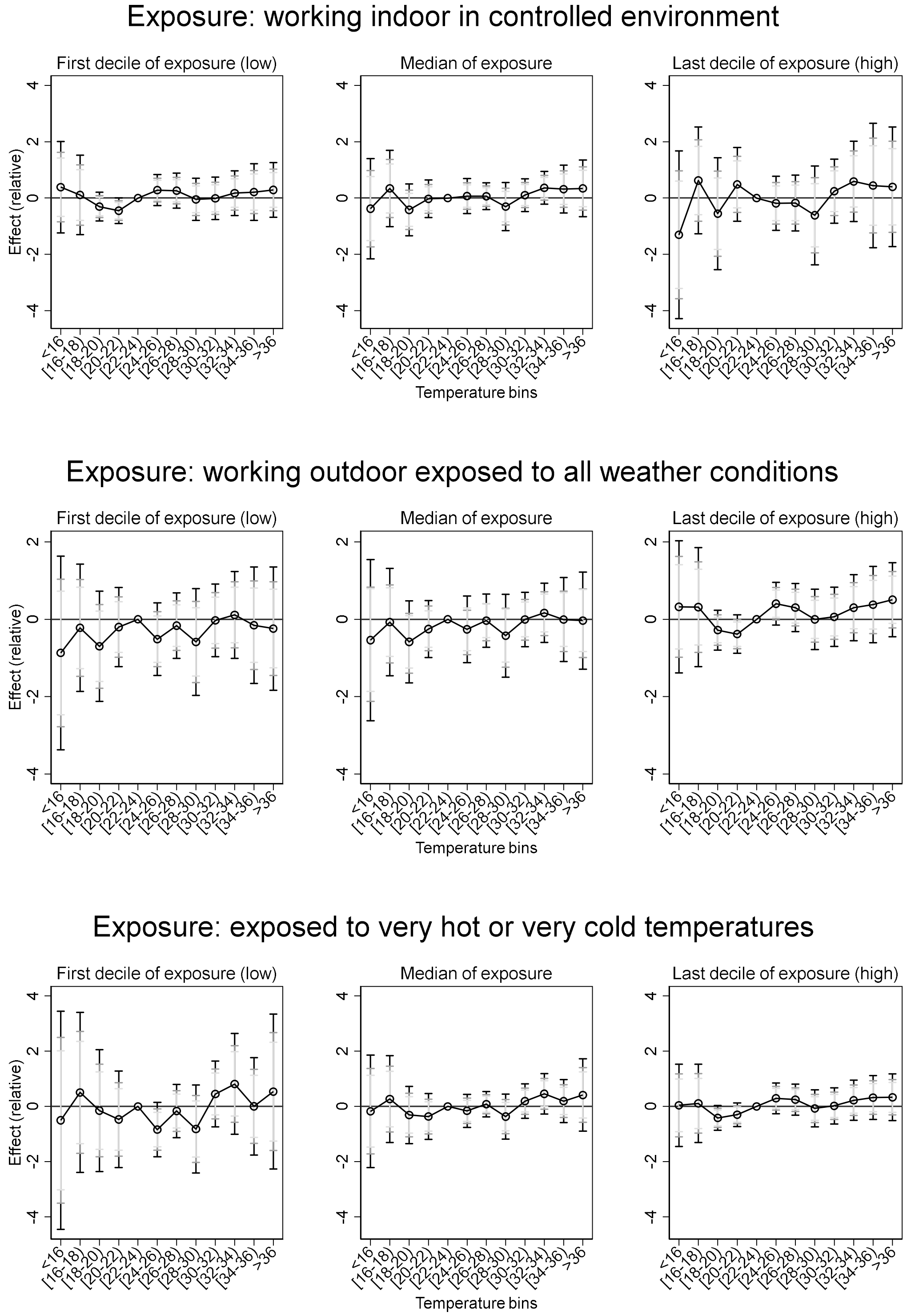
Notes: PPML estimator weighted by average employment 2014-2018 in province-sector. Standard errors clustered by province. Additional control variables: province-by-sector fixed effects, sector-by-day fixed effects, province-by-year fixed effects, province-by-month fixed effects.

Figure C5. Heterogeneous effects based on the Poisson pseudo maximum likelihood model: workplace accidents leading to handicap



Notes: PPML estimator weighted by average employment 2014-2018 in province-sector. Standard errors clustered by province. Additional control variables: province-by-sector fixed effects, sector-by-day fixed effects, province-by-year fixed effects, province-by-month fixed effects.

Figure C6. Heterogeneous effects based on the Poisson pseudo maximum likelihood model: workplace accidents leading to fatality



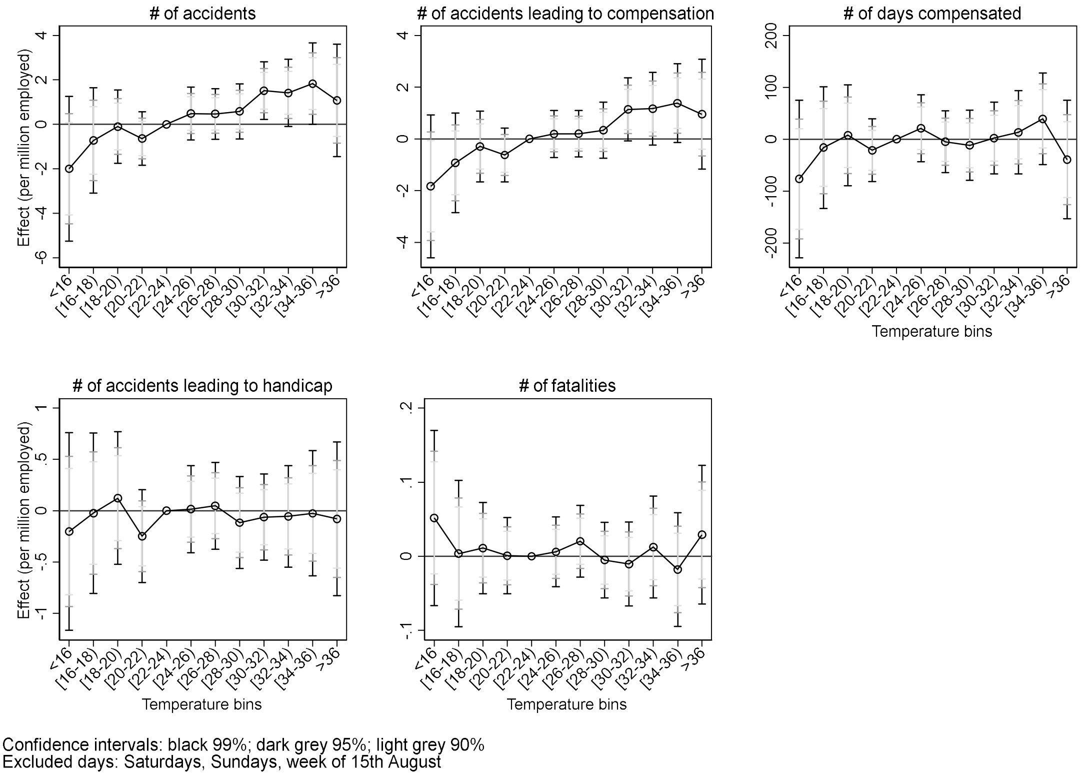
Confidence intervals: black 99%; dark grey 95%; light grey 90%

Notes: PPML estimator weighted by average employment 2014-2018 in province-sector. Standard errors clustered by province. Additional control variables: province-by-sector fixed effects, sector-by-day fixed effects, province-by-year fixed effects, province-by-month fixed effects.

Appendix D – Excluding holidays

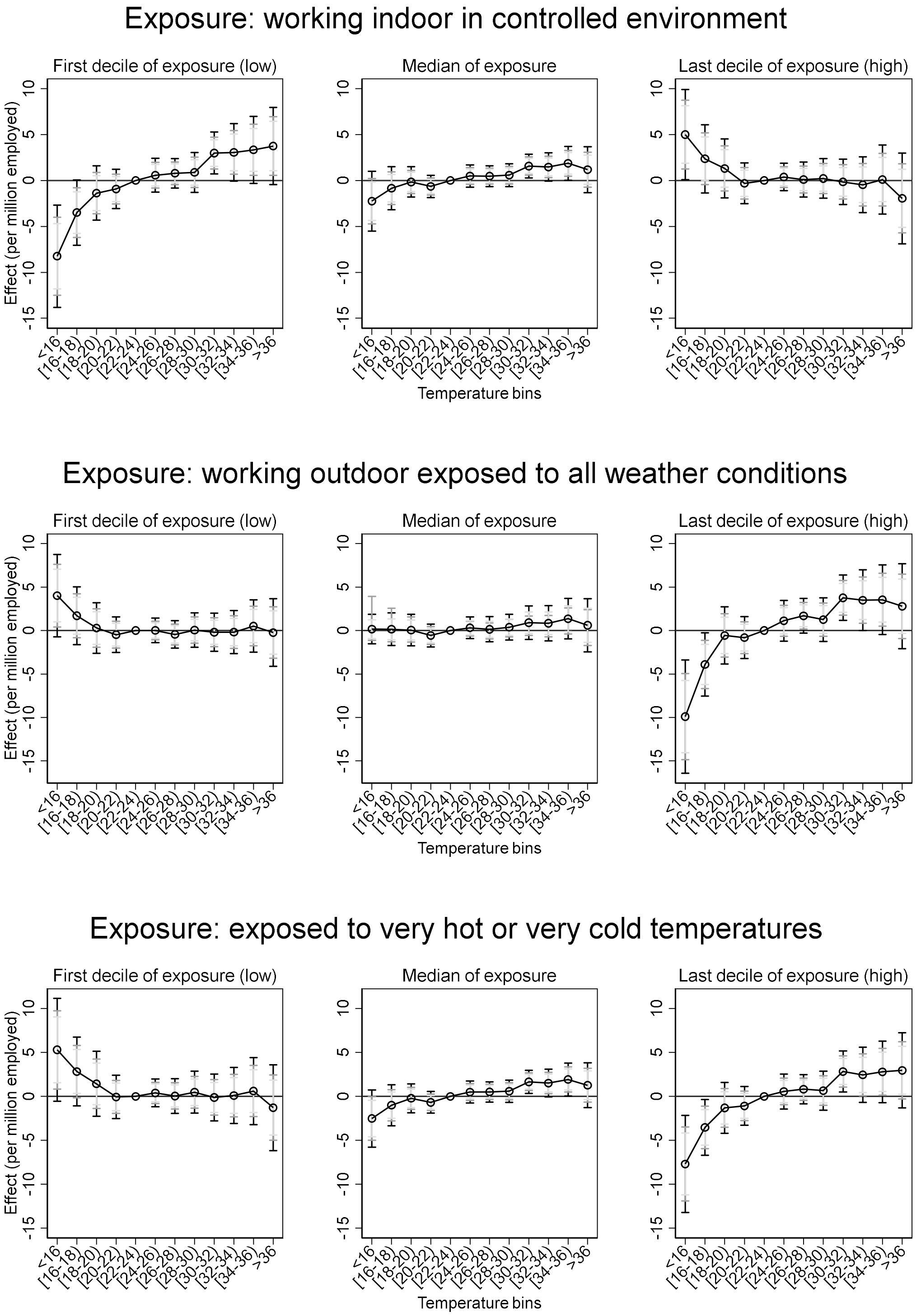
Figures D1 to D6 illustrate heterogeneous effects related to workplace accidents, excluding Saturdays and Sundays and the week of *Ferragosto*. Specifically, Figure D1 represents the baseline results, while Figures D2 to D6 explore heterogeneous effects of extreme temperature across different measures of sectoral exposure. The findings consistently reinforce the main conclusions.

Figure D1. Baseline results excluding holidays



Notes: OLS regressions weighted by average employment 2014-2018 in province-sector. Standard errors clustered by province. Additional control variables: province-by-sector fixed effects, sector-by-day fixed effects, province-by-year fixed effects, province-by-month fixed effects.

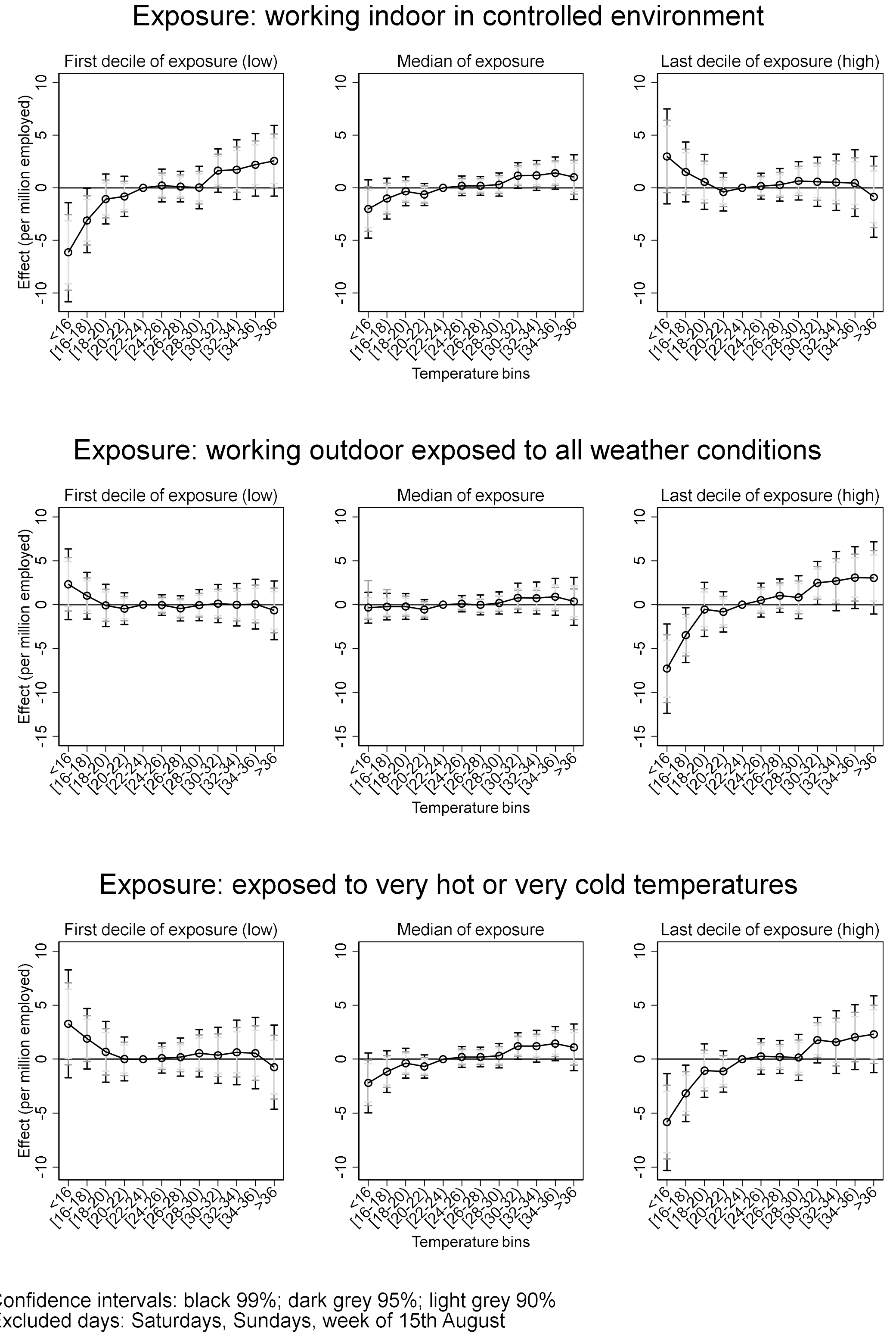
Figure D2. Heterogeneous effects excluding holidays: workplace accidents



Confidence intervals: black 99%; dark grey 95%; light grey 90%
Excluded days: Saturdays, Sundays, week of 15th August

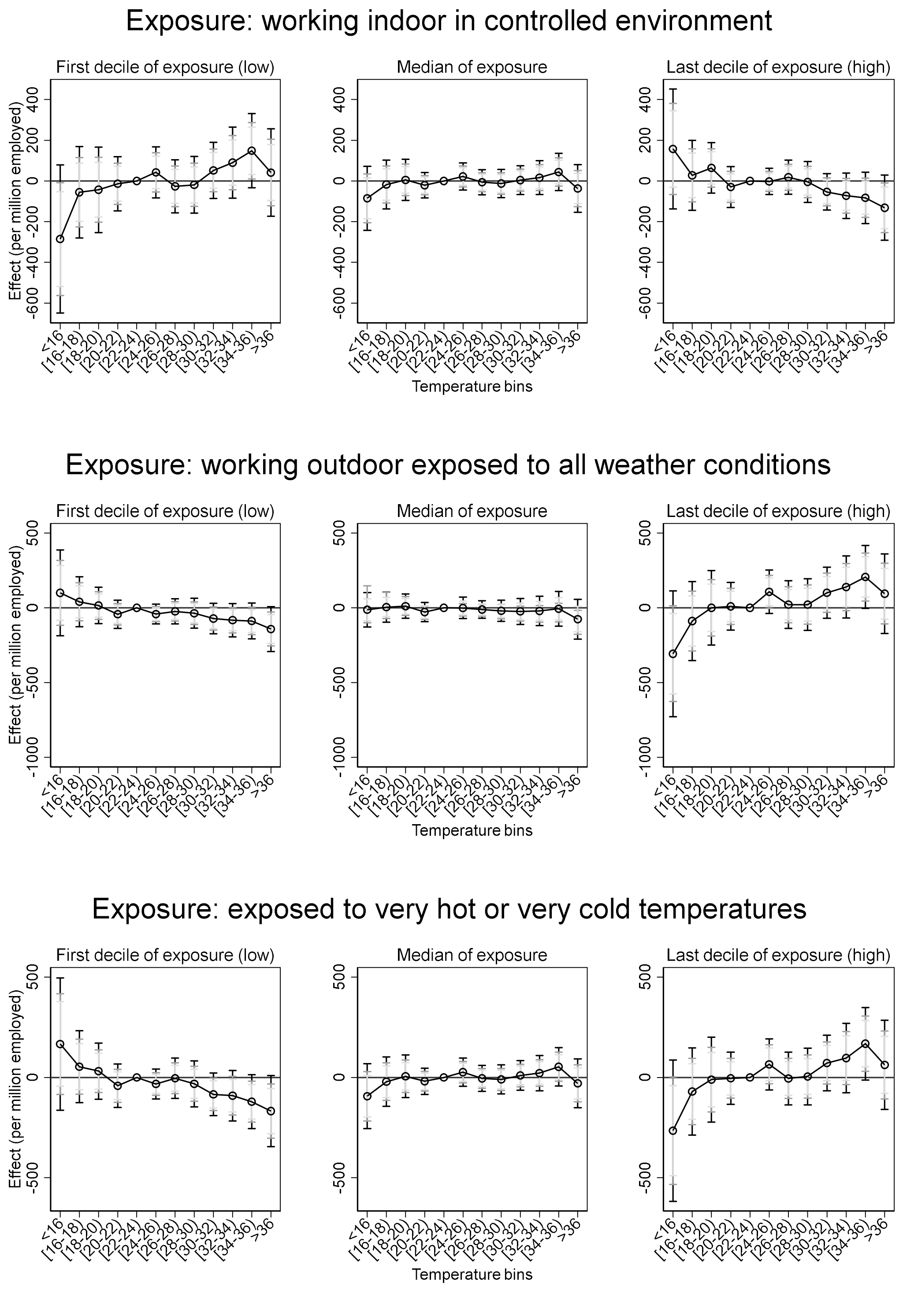
Notes: OLS regressions weighted by average employment 2014-2018 in province-sector. Standard errors clustered by province. Additional control variables: province-by-sector fixed effects, sector-by-day fixed effects, province-by-year fixed effects, province-by-month fixed effects.

Figure D3. Heterogeneous effects excluding holidays: workplace accidents leading to compensation



Notes: OLS regressions weighted by average employment 2014-2018 in province-sector. Standard errors clustered by province. Additional control variables: province-by-sector fixed effects, sector-by-day fixed effects, province-by-year fixed effects, province-by-month fixed effects.

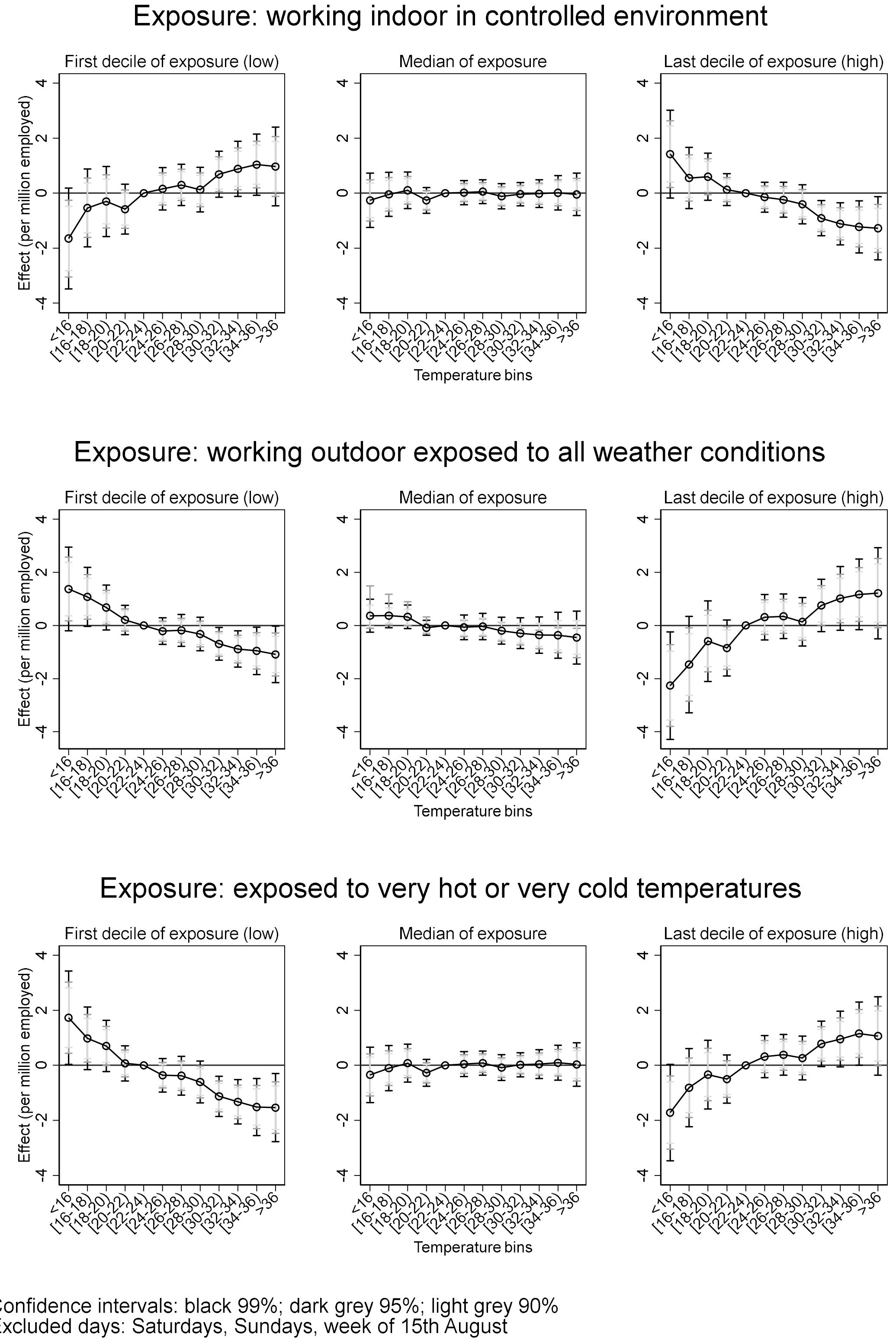
Figure D4. Heterogeneous effects excluding holidays: days compensated due to workplace accidents



Confidence intervals: black 99%; dark grey 95%; light grey 90%
Excluded days: Saturdays, Sundays, week of 15th August

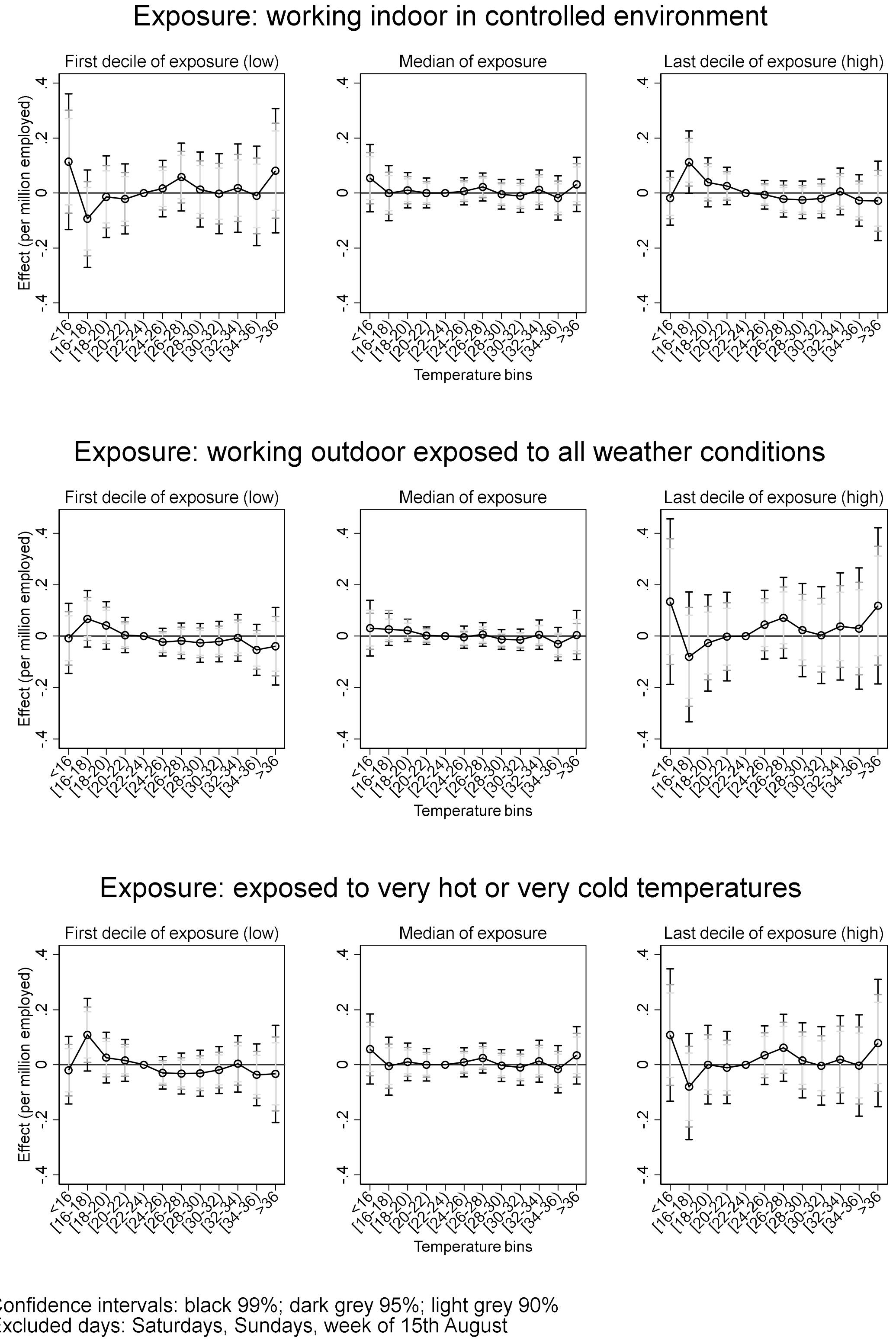
Notes: OLS regressions weighted by average employment 2014-2018 in province-sector. Standard errors clustered by province. Additional control variables: province-by-sector fixed effects, sector-by-day fixed effects, province-by-year fixed effects, province-by-month fixed effects.

Figure D5. Heterogeneous effects excluding holidays: workplace accidents leading to handicap



Notes: OLS regressions weighted by average employment 2014-2018 in province-sector. Standard errors clustered by province. Additional control variables: province-by-sector fixed effects, sector-by-day fixed effects, province-by-year fixed effects, province-by-month fixed effects.

Figure D6. Heterogeneous effects excluding holidays: workplace accidents leading to fatality

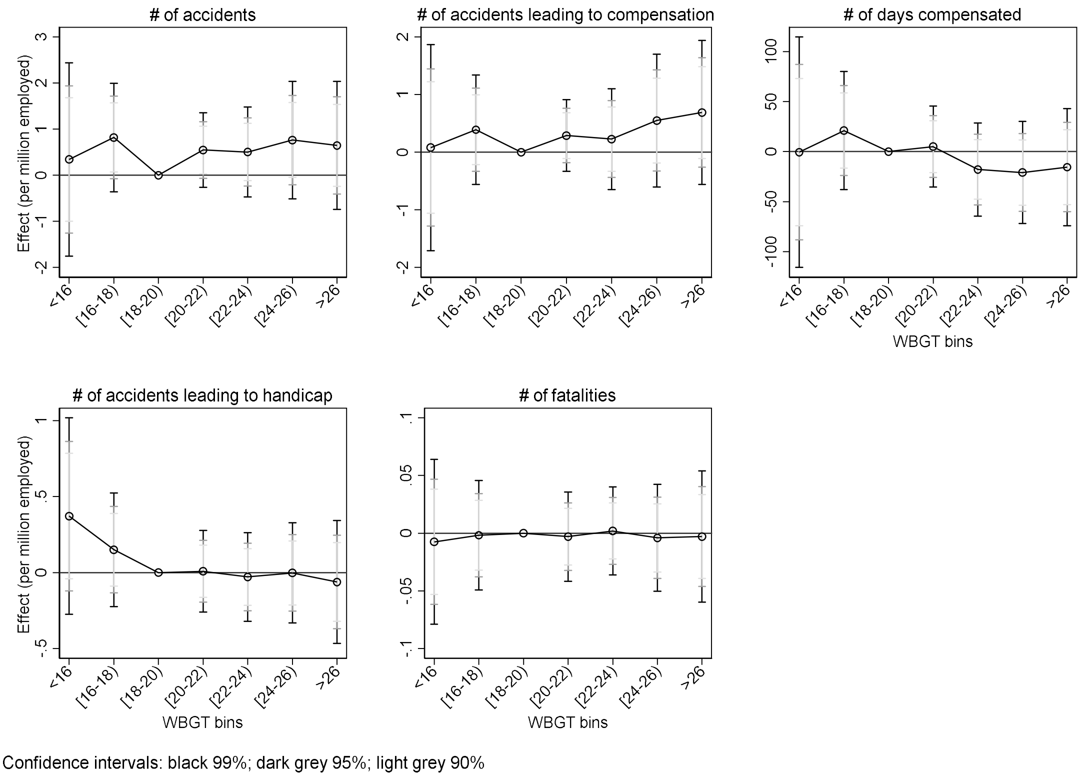


Notes: OLS regressions weighted by average employment 2014-2018 in province-sector. Standard errors clustered by province. Additional control variables: province-by-sector fixed effects, sector-by-day fixed effects, province-by-year fixed effects, province-by-month fixed effects.

Appendix E – WBGT-based analysis yielded results

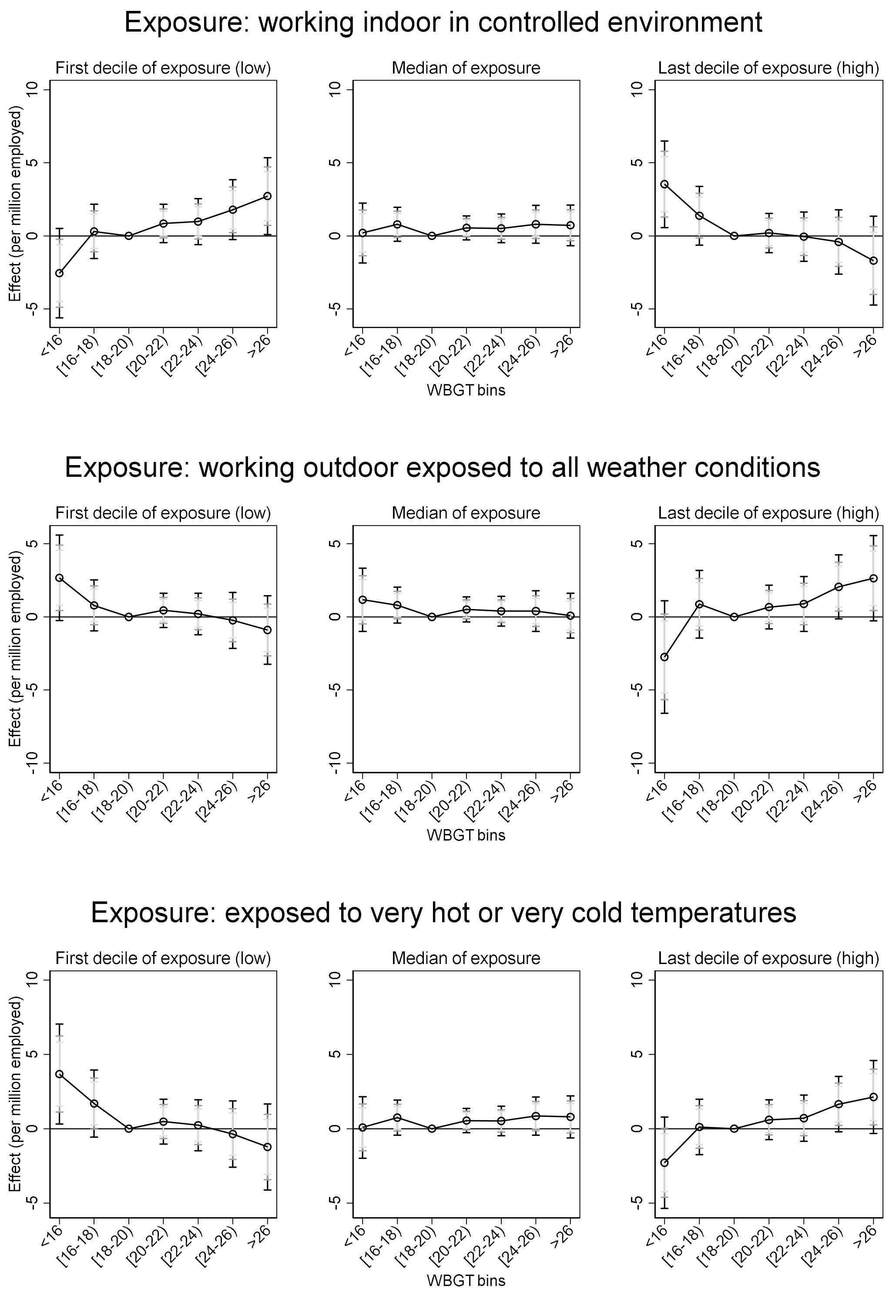
This appendix presents WBGT-based analysis of workplace accidents, with Figure- E1 showing baseline results and Figures E2 to E6 illustrating heterogeneous effects depending on the sectoral exposure variables. The findings consistently indicate significant temperature-related impacts on workplace accidents and their outcomes.

Figure E1. Baseline results WBGT-based analysis



Notes: OLS regressions weighted by average employment 2014-2018 in province-sector. Standard errors clustered by province. Additional control variables: province-by-sector fixed effects, sector-by-day fixed effects, province-by-year fixed effects, province-by-month fixed effects. WBGT temperature bins were similarly aggregated, with base category representing a moderate temperature range (22-24°C). And extreme temperature bins (above 30°C and below 14°C) were combined into single categories, focusing on low versus extreme temperatures.

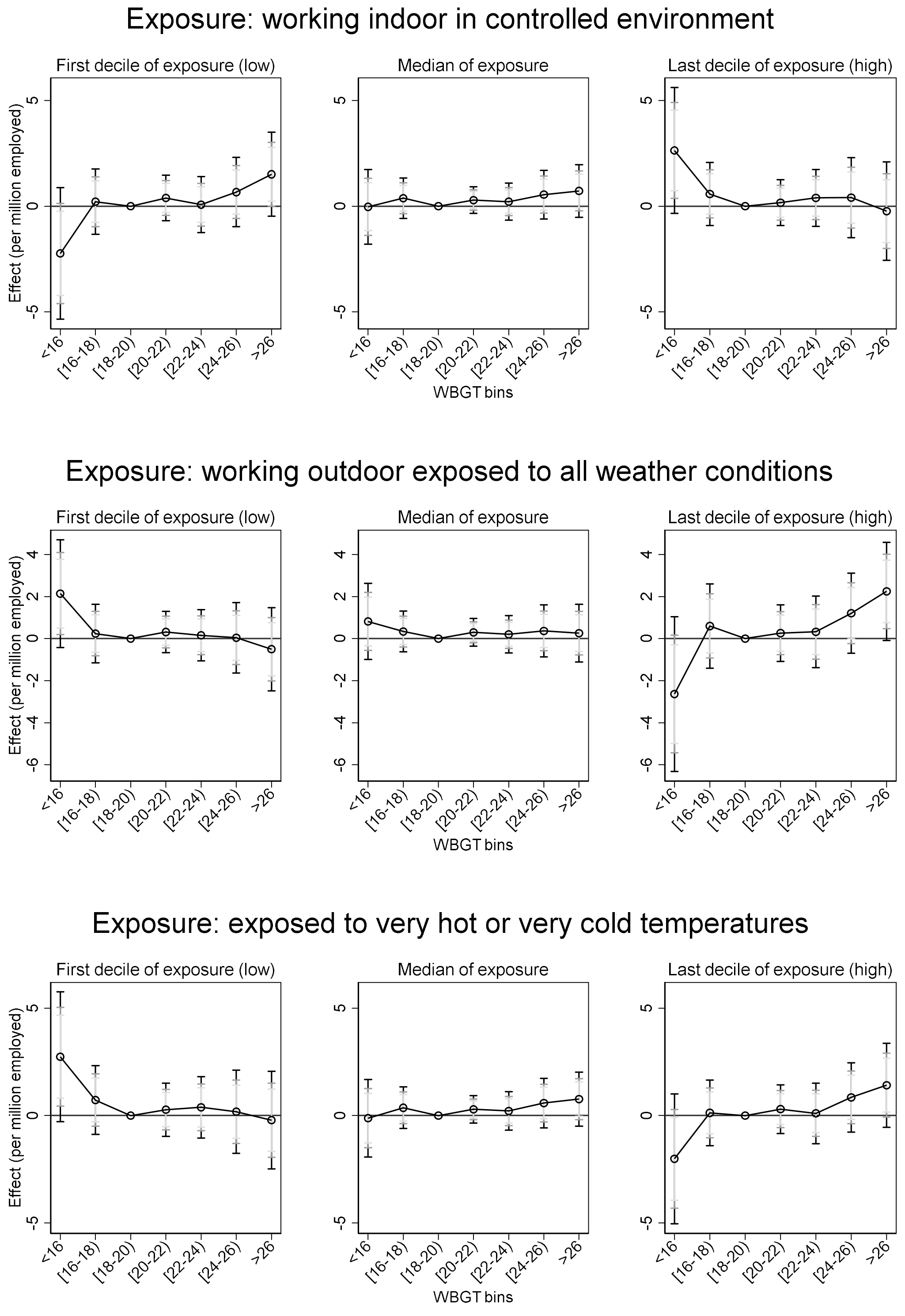
Figure E2. Heterogeneous effects by WBGT-based analysis: workplace accidents



Confidence intervals: black 99%; dark grey 95%; light grey 90%

Notes: OLS regressions weighted by average employment 2014-2018 in province-sector. Standard errors clustered by province. Additional control variables: province-by-sector fixed effects, sector-by-day fixed effects, province-by-year fixed effects, province-by-month fixed effects.

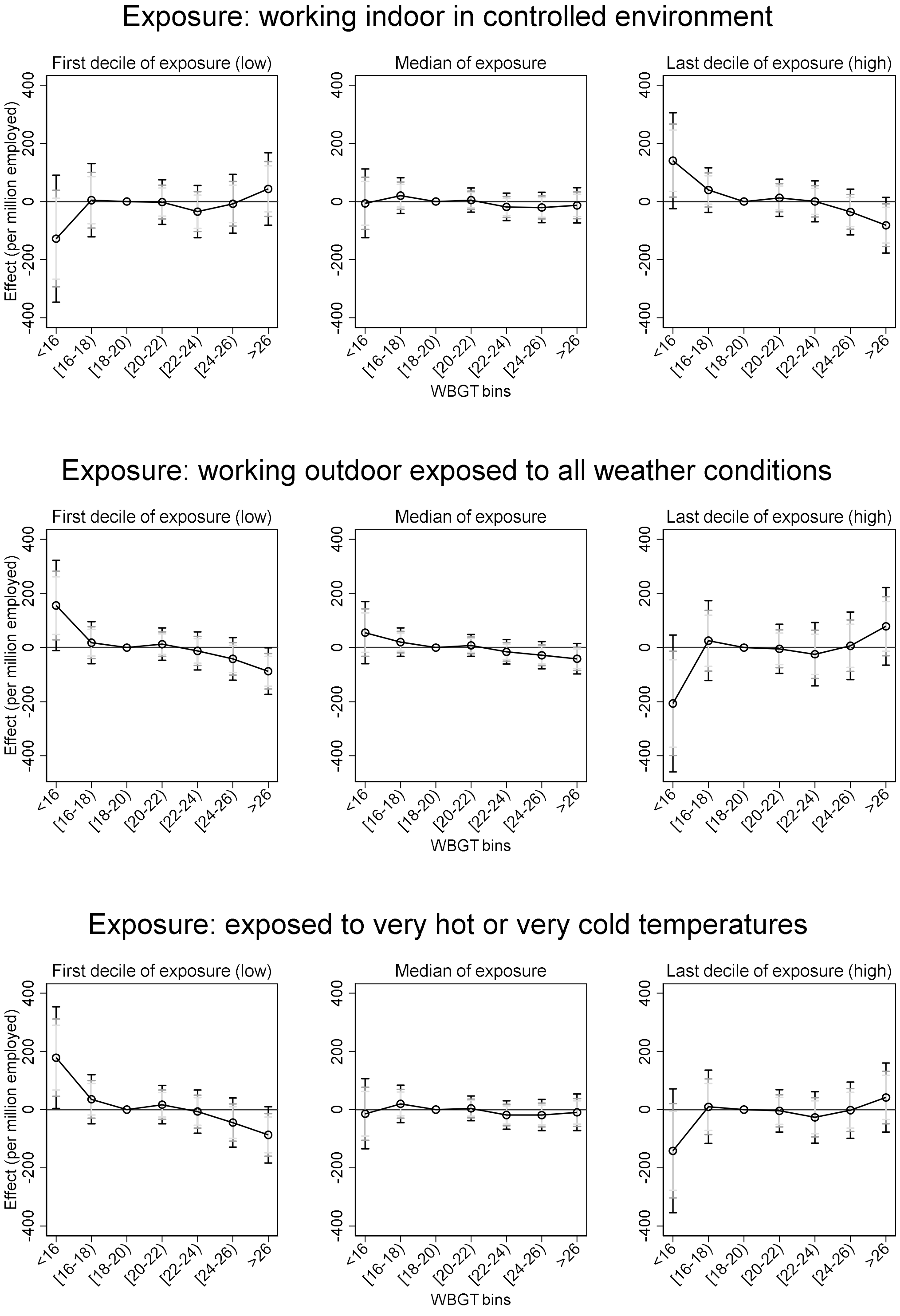
Figure E3. Heterogeneous effects by WBGT-based analysis: workplace accidents leading to compensation



Confidence intervals: black 99%; dark grey 95%; light grey 90%

Notes: OLS regressions weighted by average employment 2014-2018 in province-sector. Standard errors clustered by province. Additional control variables: province-by-sector fixed effects, sector-by-day fixed effects, province-by-year fixed effects, province-by-month fixed effects.

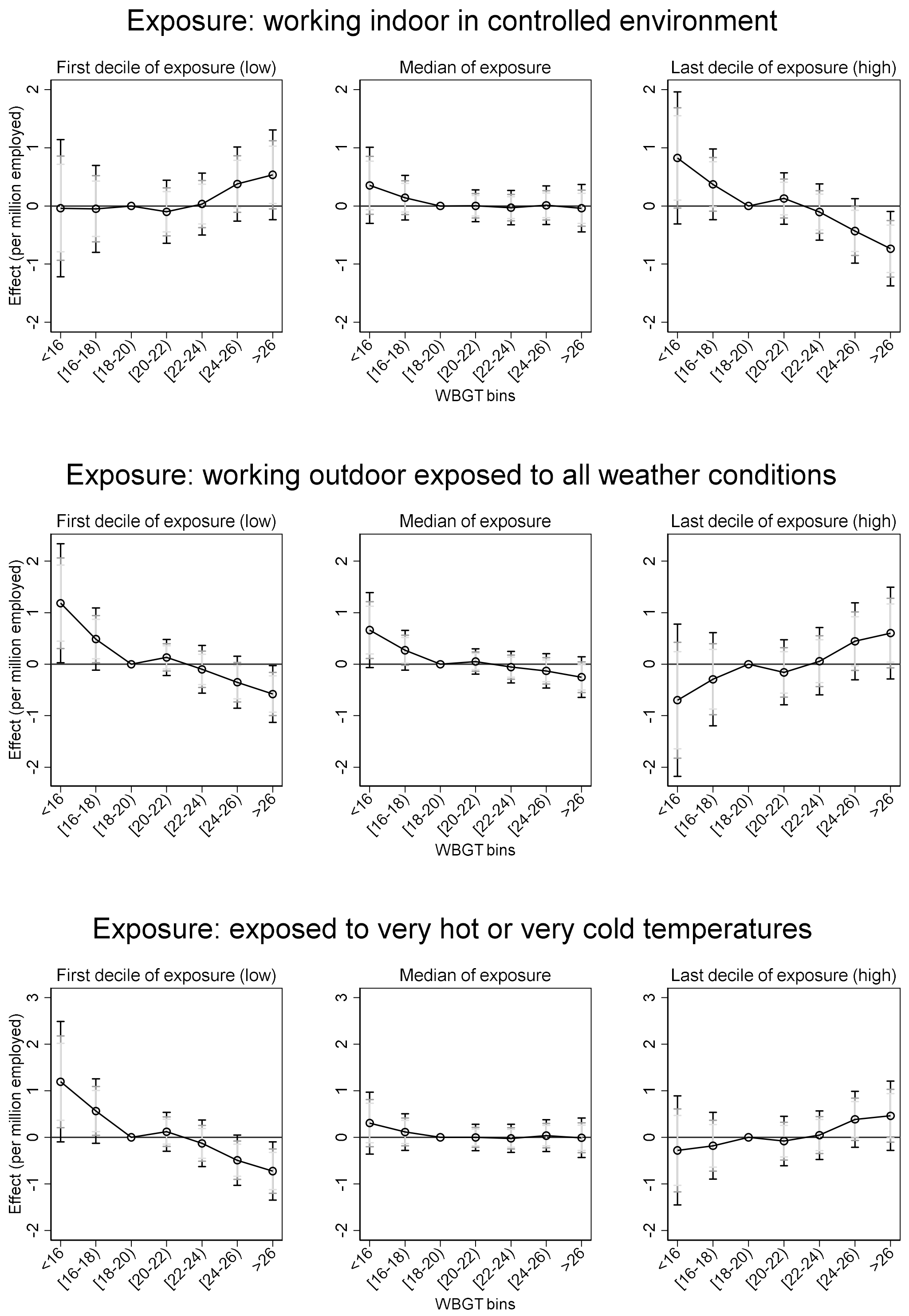
Figure E4. Heterogeneous effects by WBGT-based analysis: days compensated due to workplace accidents



Confidence intervals: black 99%; dark grey 95%; light grey 90%

Notes: OLS regressions weighted by average employment 2014-2018 in province-sector. Standard errors clustered by province. Additional control variables: province-by-sector fixed effects, sector-by-day fixed effects, province-by-year fixed effects, province-by-month fixed effects.

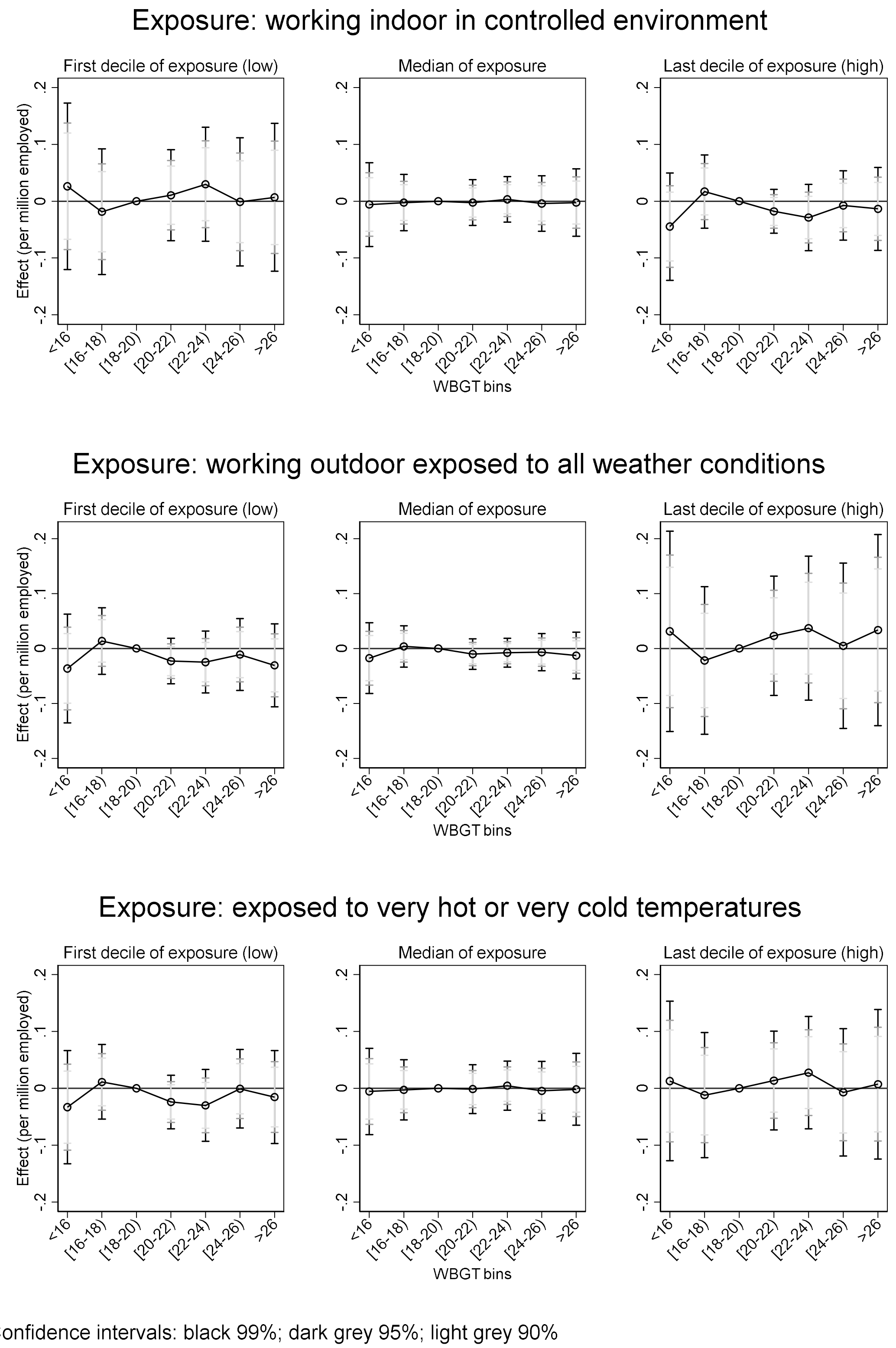
Figure E5. Heterogeneous effects by WBGT-based analysis: workplace accidents leading to handicap



Confidence intervals: black 99%; dark grey 95%; light grey 90%

Notes: OLS regressions weighted by average employment 2014-2018 in province-sector. Standard errors clustered by province. Additional control variables: province-by-sector fixed effects, sector-by-day fixed effects, province-by-year fixed effects, province-by-month fixed effects.

Figure E6. Heterogeneous effects by WBGT-based analysis: workplace accidents leading to fatality



Notes: OLS regressions weighted by average employment 2014-2018 in province-sector. Standard errors clustered by province. Additional control variables: province-by-sector fixed effects, sector-by-day fixed effects, province-by-year fixed effects, province-by-month fixed effects.