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ABSTRACT

Working Under the Sun: The Role of Occupation in Temperature-Related Mortality in Mexico*

We investigate how occupation influences the relationship between temperature and mortality in Mexico. Using multiple decades of nationwide death records---which include information on occupation---linked to local weather data, we find that heat-related mortality risk varies sharply by occupation. Young adults in climate-exposed jobs, especially in agriculture, experience significantly higher death rates from warm and hot temperatures. A 15 to 24 year-old agricultural worker is over 10 times more likely to die from heat exposure than a peer in professional or managerial employment, underscoring the role of occupation in climate vulnerability. These findings show that the burden of extreme heat disproportionately falls on the working poor. Our results suggest that implementing occupational safety measures and targeted heat adaptation policies (such as mandatory rest breaks and early warnings for outdoor workers) are essential to protect vulnerable workers. Furthermore, ongoing economic shifts away from highly exposed sectors may reduce increases in heat-related mortality due to climate change.

JEL Classification: I10, J81, Q54
Keywords: temperature, climate, occupation, health, mortality

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1 Introduction

Climate and weather influence labor markets and human health. Both ambient heat and cold are major causes of global mortality (Gasparrini et al., 2015; Zhao et al., 2021), with climate change projected to increase mortality on net (Carleton et al., 2022). Workers are also affected by heat through reduced work hours (Graff Zivin and Neidell, 2014), decreased productivity (Behrer et al., 2021; Somanathan et al., 2021), and higher levels of workplace injury and illness (Park et al., 2021; Dillender, 2021; Ireland et al., 2023). Until recently, it was thought that climate impacts on mortality are primarily concentrated among older individuals who are less likely to be in the labor force, suggesting that these two sources of climate change impact fall on disjoint groups. Recent work in the context of Mexico, however, shows that young, working-age adults are particularly vulnerable to mortality from heat (Wilson et al., 2024), raising the possibility that young workers are facing a double threat from climate change—both to their health and productivity. This paper explores the extent to which occupation affects heat-related mortality. The goal is to understand whether young workers bear a disproportionate share of climate-related health impacts on top of the productivity impacts they are already suffering.

Determining how much the temperature–mortality pattern is driven by occupation is crucial for characterizing the distributional impacts of climate change and informing policy. If occupations influence heat exposure and heat-related mortality, policies aimed at improving workplace safety—particularly those addressing occupational heat exposure like the recently proposed U.S. rule requiring workplaces to provide breaks and protections during high heat periods (OSHA, 2024)—can complement existing public policy responses to heat such as providing cooling centers, informing the public about upcoming heat waves, and engaging in community health outreach (Sampson et al., 2013; Jay et al., 2021; Shrader et al., 2023). Conversely, if occupation is not a significant factor, current responses may suffice but should be better tailored to the specific heat sensitivity of young individuals (Wilson et al., 2024).

To determine how occupation influences temperature-related mortality, we leverage extensive weather, mortality, and demographic microdata from Mexico spanning more than three decades. We focus on Mexico because it is a large, middle income country that faces high mortality from temperature, a wide diversity of climates and occupations, and it possesses high quality vital statistics and labor force records. Importantly, Mexican death certificates record a decedent's occupation, allowing us to estimate the effect of temperature on mortality stratified by occupation. We combine these data with a flexible fixed effects specification to identify nonlinear patterns in the relationship between excess mortality and temperature deviations relative to location and time averages.

Our first set of results indicates that the temperature–mortality relationship differs significantly across occupations. Workers in the primary sector—those in agriculture, fishing, livestock rearing, and hunting—experience markedly higher mortality rates on both hot and cold days compared to other occupational categories, including those without paid employment. On a day with 32°C temperature (90°F) weather, the mortality rate for workers in the primary sector is about 0.3 deaths per 100,000 people higher than on a day with 23°C temperature (73°F). And this mortality rate is more than double the rate of the next closest group, which is individuals who have no paid employment at the time of death.

We conduct various robustness checks to determine whether omitted variables at both the individual and regional levels confound this result. Through a coarsened exact matching procedure with progressively richer matching variables, we confirm that the key finding regarding primary sector workers remains consistent. This holds true even after accounting for all other observable factors from death certificates, along with a broad range of economic and regional variables, such as area income, poverty measures, climate, and air pollution.

We next examine the interaction between age and occupation. While age does not significantly affect occupational outcomes when precisely controlled for in the coarsened exact matching procedure, economic conditions and other research emphasizing the importance of age in the temperature–health relationship urges us to investigate how age and occupation jointly mediate the effect of temperature on mortality. Younger workers often hold lower-wage, lower-amenity jobs, which limits their ability to invest in goods that aid adaptation to environmental shocks and which might also reduce their workplace flexibility to avoid environmental hazards.

Consistent with this hypothesis, we find that the youngest workers in the primary sector face serious temperature-related mortality risks. Compared to primary sector workers aged 45 to 54, those aged 15 to 24 in the primary sector have a death rate roughly 2.4× higher. Further, a 15 to 24 year-old primary sector worker experiences a roughly 10.5× higher risk of dying from temperature exposure than a professional/managerial worker in the same age group. And as a final comparison, the results indicate that being a 15 to 24 year old worker in the primary sector puts you at higher risk of mortality from heat than being over the age of 75.

Younger, primary sector workers experience relatively elevated mortality across a span of warm and moderately hot temperatures that are very common in Mexico. Thus, among individuals 15 to 74 years old, those under 25 working in the primary sector account for 16% of heat-related deaths during our sample period, despite accounting for only 1.6% of the population (and 0.7% of all deaths).

These stark differences in vulnerability to heat have important implications for policies to address temperature-related mortality and for climate change. Traditionally, groups thought to be vulnerable to heat—and thus the primary targets of information campaigns and public health outreach—have been the elderly, people with chronic health conditions, and impoverished individuals (see Sampson et al., 2013; Jay et al., 2021, for examples of the use of this definition). These definitions have been made based on research conducted largely in high-income, cooler countries. In the hotter, middle-income setting we study, young people who are actively employed—but in a relatively low-paying occupation—are at the highest risk from warm and hot temperatures. Thus, this group should be included in the set of prioritized groups during heat events. In Mexico, this dimension of vulnerability is now being recognized. For example, during heat waves in 2023, the labor ministry in San Luis Potosí urged all employers to follow worker heat protection policies including ensuring rest breaks, maintaining water hydration stations at worksites, and regularly monitoring workers' body temperatures to keep them below 38°C (see Section A for more details on the policy environment in Mexico).

The importance of occupation also has a potential bright side in the form of climate change sensitivity. Over the 20th century, and continuing to today, the Mexican economy has undergone rapid sectoral transition away from agriculture and toward services. And this change has been mirrored broadly around the world. Our results suggest that this transition reduced the sensitivity of mortality to the climate. Continued sectoral transition would further reduce this sensitivity, which could be especially important in low-income countries that continue to have large agricultural labor forces. One area of important uncertainty in climate impacts, however, is that continued productivity losses in the agricultural sector could interact with non-homothetic preferences for agricultural commodities to reverse this trend and instead increase the share of agricultural workers in the countries experiencing the largest climate shocks (Nath, 2025). Given the importance of mortality and agricultural productivity to projected climate damages (EPA, 2023), this type of dual shock could substantially increase the harms from climate change.

The rest of the paper proceeds as follows: Section 2 provides background on heat-related mortality, evidence on the effects of occupational heat exposure on health and productivity, and discusses the setting of this study—which looks at temperature, mortality, and occupations in a middle-income country—in the context of the existing literature. Section 3 describes the data on mortality, weather, and other variables. Section 4 lays out the method and estimating equation used to estimate the effect of temperature on mortality. Section 5 presents results on temperature–mortality response functions by occupation and occupation-by-age as well as total deaths from temperature. Section 6 discusses implications of the results for climate change impacts. Finally Section 7 concludes.

2 Background and Prior Literature

Hot and cold temperatures significantly affect human health. Suboptimal temperatures have been shown to cause mortality around the world (Zhao et al., 2021; Carleton et al., 2022). Morbidity studies are less common due to easier access to mortality data; however, they show health declines on hot days, with mixed results for cold days (White, 2017; Karlsson and Ziebarth, 2018; Gould et al., 2024; Aguilar-Gomez et al., 2025; Sarmiento et al., ming). In Mexico in particular, previous work has shown that temperature has substantial effects on mortality. Cold is especially deadly overall (Cohen and Dechezleprêtre, 2022), and hot and humid conditions have been shown to be especially deadly for younger individuals (Wilson et al., 2024).

Behavioral, physiological, and social mechanisms connect temperature and mortality. These mechanisms evolve throughout life. Older individuals are particularly vulnerable to temperature-related mortality due to physical changes like reduced shivering, altered mobility, and energy poverty (Vassilieff et al., 1995; Zanobetti et al., 2013; Leigh-Hunt et al., 2017; Soriano-Hernandez et al., 2022). Infants also face risks due to their underdeveloped thermoregulatory systems and limited personal control over their adaptive margins (Falk and Dotan, 2008; Graff Zivin and Shrader, 2016). While young adults have a lower overall mortality risk compared to children and older adults, they face unique dangers from increased heat exposure during recreation and work (Ebi et al., 2021; Kjellstrom et al., 2009). We contribute to this literature by documenting differences in the temperature–mortality relationship across different occupations, focusing to the how age and occupation interact and determine the vulnerability of individuals to temperature-related mortality.

Global warming is expected to reduce cold-related deaths while increasing heat-related deaths. The net effect on mortality will vary by location but is projected to result in an overall increase in global mortality (Carleton et al., 2022). The exact change depends on societal adaptation to higher temperatures and the interaction of other factors with mortality. Understanding the differences in the temperature–mortality relationship across occupations is crucial for evaluating the impacts of future climate change. One of the most significant changes in the last century is the structural transformation from agricultural to industrial and service-based societies. This transformation has markedly reduced the share of agricultural workers across high- and middle-income countries. If occupational exposure significantly influences temperature-related mortality, then sectoral reallocation over time will affect society's climate sensitivity, a point we revisit in Section 6.

One reason to suspect that occupational temperature exposure increases mortality is previous research indicating that heat exposure at work leads to shorter work hours (Graff Zivin and Neidell, 2014), decreased labor income (Behrer et al., 2021) and reduced productivity (Somanathan et al., 2021; Foster et al., 2021; LoPalo, 2023). Dillender (2021), Park et al. (2021), and Ireland et al. (2023) further find that occupational injuries rise with increased temperatures. These findings suggest that temperature impacts workers on the job, indicating that occupational temperature exposure could significantly contribute for temperature-related mortality.

Many prior studies on mortality and the effects of occupational heat focus on high-income countries. This emphasis arises from better access to detailed mortality records with granular sociodemographic characteristics. Bureaucratic burdens and limited public resources often hinder data collection and measurement of mortality outcomes in developing countries (Landrigan et al., 2018). This situation underscores the need to study the temperature–mortality relationship on these regions. There are also reasons to believe that the effects may differ in middle- or lower-income countries. A larger proportion of workers in these countries are employed in climate-exposed sectors (International Labour Organization, 2024). These nations also have lower rates of worker protection and higher rates of occupational mortality (Boudreau, 2024). Additionally, many workers are informal, which offers flexibility to avoid temperature extremes but limits essential protections for adaptation. Understanding mortality in middle- and low-income countries is crucial for assessing climate change impacts, as comprehensive global analyses of mortality often lack information for many such countries, although Mexico is regularly included in these analyses.

Mexico is uniquely positioned to provide evidence on occupational channels of temperature-related mortality for four main reasons:

High Exposure Workforce: A significant portion of Mexico's labor force works in temperature-exposed sectors, particularly agriculture, construction, mining, and informal commerce. Millions of Mexican workers operate outdoors or in hot indoor environments, such as uncooled factories. This includes 15% of workers in agriculture and many others in outdoor urban jobs (Climate Resilience, 2024). During heat waves, these workers face direct thermal stress. Crucially, a majority of outdoor laborers belong to the informal sector, often lacking formal employer oversight or social protection. This high level of informality parallels that of other large low- and middle-income economies in warm climates, like Brazil, India, and China. For instance, street vendors, day laborers, and certain construction crews may not receive mandated rest breaks or water provisions. This combination of high heat exposure and limited protection increases the vulnerability of working-age adults.

Climate and Geography: Mexico's geographic diversity includes regions that frequently experience extreme heat and cold. Northern states like Sonora and Nuevo León see summer highs exceeding 40°C and winter lows below -5°C. Coastal tropical areas combine heat with high humidity. In recent years, Mexico has been one of the few countries where wet-bulb temperatures approached 35°C, the threshold of human survivability (Raymond et al., 2020; Humberto Basilio, 2025). These extremes are rare globally, positioning Mexico as a crucial example of potential, future, heat-stressed climates. The country also faces frequent heat waves; for instance, in 2023, it experienced three record-breaking heat waves between April and June, with temperatures reaching up to 45°C, resulting on numerous confirmed heatstroke deaths (Humberto Basilio, 2025). In short, Mexico offers a preview of the climate challenges many countries will confront, serving as a "natural laboratory" for studying heat–health impacts on workers.

Policy Environment and Data Availability: Mexico's situation allows researchers to assess outcomes within a comprehensive policy framework. The country has implemented heat exposure standards and labor protections, but important questions remain about the enforcement and effectiveness of these policies. This is a common challenge for worker protection law across middle- and low-income countries (Boudreau, 2024). Additionally, Mexico has one of the best public databases on heat-related deaths and maintains detailed climate records. Every death is documented in a national database, giving researchers access to over 30 years of mortality data alongside weather information. Thus, Mexico provides the necessary real-world conditions and data to thoroughly investigate occupational temperature risks within a middle-income country framework.

Economic Context: Mexico is an upper-middle-income country with the second-largest economy in Latin America. It combines modern industrial sectors with traditional, labor-intensive ones. This economic mix presents challenges typical of both high- and low/middle-income nations. For instance, some areas feature modern infrastructure and climate-controlled workplaces, while large rural and informal economies still rely on outdoor labor. Moreover, despite significant resources and institutional capacity, economic inequality leaves many workers without adequate protections.

In summary, Mexico's population age structure, high-exposure workforce, extreme climate events, and developed policy framework with extensive data make it a valuable case study for occupational temperature-related mortality. Insights from Mexico can inform national efforts, such as strengthening enforcement and tailoring adaptation programs for vulnerable workers, as well as international strategies to protect workers in a time of changing temperatures.

3 Data

Mortality: Mortality data comes from the Mexican National Institute of Geography and Statistics (INEGI). The dataset includes information on all recorded death-certificates in Mexico since 1990. We conclude our sample in 2023.

Occupation and sociodemographic characteristics in the death certificates: Each recorded mortality event includes the individual's occupation, which is crucial for our analysis. We categorize occupations into five groups: primary sector, technical/manual, sales/personal services, professional/managerial, and no paid work. Primary sector workers engage in agriculture, livestock farming, fishing, and hunting. Technical/manual occupations include industrial workers, construction workers, and artisans. Sales/personal services encompass vendors, merchants, and personal services, such as surveillance and domestic work. Professional/managerial work includes professionals, technicians, control personnel, and office workers. Death certificates capture both formal and informal workers without distinguishing between them. For instance, a construction worker, whether formal or informal, is classified under technical/manual, regardless of their informality status. Table A1 presents the intertemporal concordance between the INEGI labor groups and our categories. We also have access to sociodemographic characteristics, such as sex, age, and education. Table A2 includes information on the distribution of these sociodemographics across occupations in all death certificates. We exclude death records lacking information on the date of death, the individual's age, occupation, or location of death. Records for deaths occurring outside Mexico are also excluded. These exclusions account for less than 0.92% of the data.

Mortality Rates: We calculate monthly municipal mortality rates by dividing the number of deaths on a specific day by the municipality's population. We source municipal population data from the 1990, 2000, 2010, and 2020 national censuses, applying linear interpolation for the intervening years. We assume linear population growth between observations, and no population change after 2020. This assumption may introduce measurement error in the dependent variable, reducing model efficiency but not the consistency of our estimates (Cohen and Dechezleprêtre, 2022). This approach allows us to estimate annual population values for each municipality, occupation, and age group.[1]

Occupational characteristics (ENOE): We use data on occupational characteristics from the quarterly National Survey of Occupation and Employment (ENOE) conducted by INEGI. We collect data for 2013–2023 on the main occupations of respondents and match them to the five categories outlined above (the labor groups are the same across death certificates and ENOE). We have access to various occupational and household characteristics, such as employment formality, whether the respondent has a contract at work, hours worked in the reference week before the survey data, the start date of their current job, and the workforce participation of household members. We calculate an occupational flexibility index based on these characteristics.[2]

Weather Data: Weather data comes from European Centre for Medium-range Weather Forecasting Reanalysis 5 - Land (ERA5-Land) dataset. The dataset includes hourly estimates of air temperature and precipitation at a 0.25 by 0.25-degree resolution globally. A key strength of ERA5 is its integration of extensive observational data from satellites, weather balloons, and ground stations with a numerical weather prediction model. This integration provides a consistent and comprehensive depiction of weather conditions across Mexico. For this study, we extracted average daily air temperature and precipitation from January 1990 to December 2021. We aggregated the hourly gridded data into population-weighted averages for each municipality using population rasters from the Global Human Settlement Layer Project curated by the Emergency Management Services of Copernicus. Distributions of temperature, weighted by person-days in each occupation category, are shown in Figure A1. Temperatures in Mexico center around 20°C with a 5$^{\text{th}}$ percentile of 11°C and a 95$^{\text{th}}$

[1] Across both mortality and population data, we account for 67 municipal boundary changes occurring between 1998 and 2019 by assigning values reported for modified units to an aggregate set of 2,402 municipal units that is stable across all years of our study.

[2] We calculate this 0–1 measure as the average of the employment formality, sole breadwinner status, employment contract, and the standard deviation of hours worked as a percentage of average weekly hours worked (normalized to range from 0–1). A higher score in this measure corresponds to more occupational flexibility.

percentile of 27°C. The primary sector is exposed to warmer temperatures than other sectors, on average, but all occupations are well represented across the temperature distribution.

Measuring Temperature: Humid heat poses significant risks for human health because humans rely on sweating for thermoregulation, and humid air decreases sweating efficiency. Despite this mechanism, existing studies that compare the effect of humid and dry heat on mortality do not find a clear difference in effects (Baldwin et al., 2023). In Mexico, humid heat, as measured by wet-bulb temperature, leads to only about 10% more heat-related deaths than dry-bulb temperature (temperature measured without accounting for humidity), and the overall difference across the temperature distribution is small (Wilson et al., 2024). Given these findings, our main results focus on dry-bulb temperature, which is easier and more widely measured. We also conduct a sensitivity analysis using wet-bulb temperature, calculated using the method from Davies-Jones (2008).

4 Estimation Method

4.1 Estimating Baseline Effect of Temperature on Mortality Across Groups

We initially examine the effects of temperature on mortality across different groups using the following estimating equation:

$$D_{aimy} = g_a(T_{it}, \ldots, T_{it_m}) + q_a(\mathbf{p}_{im}) + \delta_{aiy} + \theta_{aim} + \varepsilon_{aimy} \tag{1}$$

where D_{aimy} denotes the mortality rate for a population group a in municipality i during month m of year y. We examine two distinct dimensions of a: in one set of results, we estimate effects across occupation groups; in another, we estimate effects across age groups. Throughout, we focus on individuals ages 15 to 74.

The main right-hand-side variables of interest are distributed lags of temperature exposure, indicated by the T variables. This paper focuses on the cumulative effect of plausibly random temperature shocks. Temperature exposure affects mortality dynamically: hot temperatures lead to an acute increase in mortality, followed by a decline in subsequent days, while cold temperatures exhibit an opposite pattern (generally, a short-term reduction in mortality followed by a cumulating effect that grows over the course of a few weeks) (Deschenes and

Moretti, 2009; White, 2017). We aggregate temperatures over the month, in essence allowing temperature exposure at any time in a month to affect mortality with an average effective lag period of one half of a typical month. Previous research shows that mortality rises on both hot and cold days, globally and in Mexico (Gasparrini et al., 2015; Carleton et al., 2022; Cohen and Dechezleprêtre, 2022; Wilson et al., 2024). To correctly resolve the nonlinear effect of weather, we aggregate vectors representing nonlinear functions of weather metrics by population-weighted sums across space and time (Hsiang, 2016). In our main results, we focus on dry-bulb temperature, for which we use polynomial transformations up to the fourth order following Carleton et al. (2022). We present results for wet-bulb temperature in the appendix.

The remaining elements of the estimating equation are control variables. Daily total precipitation, $\mathbf{p}_{it}$ is included in a similar way to temperature, though we use a quadratic specification. We also include fixed effects to account for both cross-sectional and time-series confounders: δ_{aiy} at the level of municipality-year, which addresses location-specific fixed factors such as topography, governance, differences in access to healthcare or mortality reporting, as well as secular trends in mortality rates and climate; and θ_{aim}, which account for municipality-level seasonal patterns.

The term ϵ_{aimy} represents the remaining error term. In all results, we present confidence intervals around our estimates derived from a 1000-draw bootstrap applied at the state level to account for arbitrary correlation in terms across municipalities within a state ($N = 32$) and across sample months. We discuss potential additional omitted variable bias and other confounding in the next section.

Finally, we apply regression weights based on monthly municipality-level populations of group a, linearly interpolated from population counts in the 1990, 2000, 2010, and 2020 Mexican Censuses. For years 2020 through 2023, we assume population remains constant. These weights improve spatial representativeness and address heteroskedasticity. Models are fit using `R` software version 4.4.1 and the `fixest` package (Bergé, 2018), version 0.12.1.

4.2 Adjusting for Correlated Factors

If workers differ fundamentally between occupational groups, heterogeneity in the effects of temperature on mortality may arise from these differences. Mortality records show that primary sector workers are older, predominantly male, less likely to be covered by social security institutions, live in more marginalized rural communities, and cluster in tropical regions in the southern part of the country. The specification above characterizes the variation in mortality responses to temperature exposure across age and occupation groups. However, we also aim to understand how much of these relationships are explained by these factors *per se* versus correlated attributes of individuals and regions. Consider the differences across occupations. Suppose heat-related mortality is higher among agricultural workers and younger individuals. We want to determine how much of the occupation-related mortality arises from difference in the age distribution of individuals within that occupation, compared to difference across occupations after adjusting for age.

We implement this analysis using a coarsened exact matching (CEM) procedure. We leverage the universe of death certificates to match elementary, sales, and white-collar workers with primary sector workers based on age, sex, access to social security, the municipal marginalization index, the share of rural households, and state of residence. After matching, we employ the CEM weights to aggregate the data into the weighted number of deaths per municipality across occupations for workers most similar to primary sector workers.

Selection on unobservables might still be operating after the matching. For example, workers who find it easier to work in relatively hot or cold conditions might select into occupations that are more exposed to those temperatures, and that worker type might not be correlated with the observables in our CEM. This form of selection would mean that our estimates are underestimates of the true effect of temperature on mortality within occupations. For overestimates, the selection story would need to be less plausible. Namely, workers who are relatively unsuited for a climate-exposed job would need to be more likely to work in such a job.

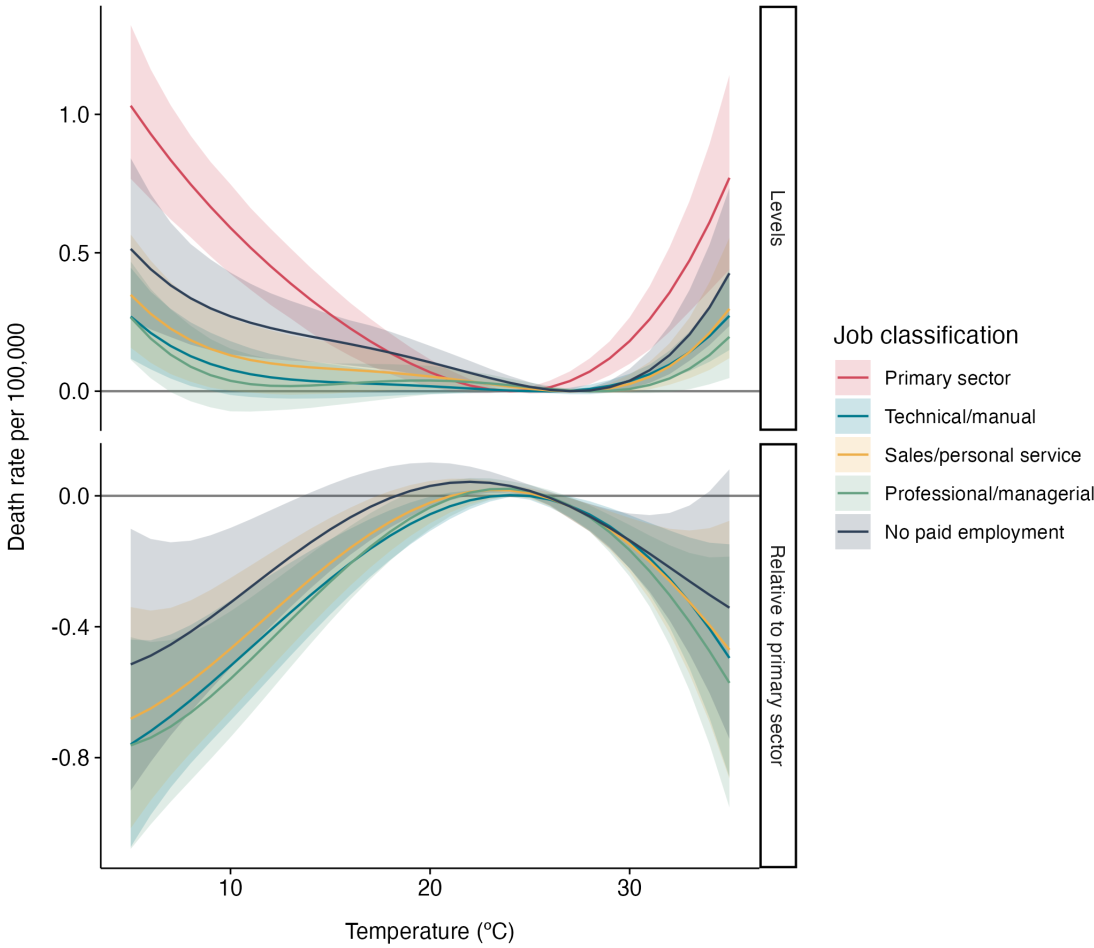
5 Results

5.1 Occupations and Temperature-Related Mortality

Figure 1 displays initial results on the relationship between temperature and mortality rates across occupational groups. The top panel illustrates this relationship for all five occupational classifications, including those not working. For all occupational groups, both hot and cold temperatures increase mortality rates. These findings align with previous studies documenting a clear link between non-optimal temperatures and mortality.

Our results indicate that primary sector mortality has the strongest relationship with temperature. At all temperature levels, except for a narrow range around 20°C, higher temperatures correlate with greater excess mortality rates for primary sector workers compared to other sectors. The next most affected group consists of individuals who were not engaged in paid

Figure 1: Mortality-temperature exposure response by occupation



Notes: The top panel shows estimates from fitting versions of Equation (1) separately for each of the given occupation groups using the baseline sample. The estimates are conditional on controls for precipitation as well as fixed effects for municipality by year and municipality by month. Shaded areas show 95% confidence intervals based on bootstrapped standard errors clustered at the state level. The bottom panel shows the results of hypothesis tests of the difference in temperature–mortality response between primary sector workers and workers in other sectors.

work at the time of their death. Professional and managerial workers experience the weakest temperature–mortality relationship, although it is similar in magnitude to the relationships observed for sales/service and technical/manual workers.

The bottom panel of Figure 1 highlights the difference between the primary and other sectors by normalizing effects relative to the primary sector. This figure confirms that the primary sector exhibits the strongest exposure-response function. Moreover, it shows that the response from primary sector workers significantly differs from that of other sectors, as indicated by the 95% confidence intervals (the shaded areas) not crossing the zero line across a wide range of hot and cold temperatures.

Figure 1 clearly shows that the mortality minimizing temperature (MMT) for primary sector workers is lower than for those in other sectors. The MMT helps distinguish between "hot" and "cold" temperatures. Temperatures below the MMT are sub-optimally cold for minimizing mortality, while those above it are sub-optimally warm. (Gasparrini et al., 2015) The MMT significantly influences temperature-related mortality for two reasons. First, a lower MMT indicates that primary sector workers experience heat-related mortality at lower temperatures than workers in other sectors. Second, because moderate temperatures occur more frequently than extreme temperatures (see Figure A1), they have a more relevant impact on total temperature-related mortality than the extremes. Mortality from warm and hot temperatures in the primary sector presents a unique and common risk for these workers compared to other groups.

5.1.1 Robustness

We conduct several robustness and sensitivity analyses on these initial results. A primary concern is that occupation correlates with multiple factors that could serve as risk factors for heat-related mortality. Age is among the strongest determinants of mortality risk, and occupational age profiles differ. Recognizing the significance of age to both occupational and mortality patterns, we explore the interaction between age and occupation in detail in Section 5.2.

For other factors, we work to address potential confounding through a coarsened exact matching exercise, discussed further in Section D. We progressively add more matching variables to more aggressively control for possible confounders by matching on: (1) age group; (2) previous plus sex, education, and marital status; (3) previous plus municipality-level average income, rural population share (as of 2020), share using wood or coal as fuel, and the NASA gridded deprivation index (Center For International Earth Science Information Network-CIESIN-Columbia University, 2022); and (4) previous plus municipality-level average household size, share speaking an indigenous language, and Köppen climate classification. As shown in Figure A6, the results are mixed. Adjusting for age addresses, in part, differences between the temperature-sensitivity of primary sector workers versus those in other sectors: at moderate temperatures, which are quite common, effects are reduced by up to half; at extreme temperatures, which are very rare but relatively more harmful, differences are nearly eliminated. When matching on the full set of individual-level covariates, differences are reduced further, though sizable gaps remain for all but the most extreme temperatures. Matching on occupation-related municipality-level covariates, differences collapse to zero for heat exposure, but persist for a broad range of cold temperatures; this pattern holds when adjusting for the full set of municipality-level covariates. primary sector workers are relatively more vulnerable to hot temperatures holds across these specifications, though the matching does cause primary sector workers and matched other workers to begin to exhibit similar sensitivities to extremely cold and hot temperatures (indicating that these temperatures are dangerous for all groups). In our most aggressive matching specification, though, around 30% of primary sector workers cannot be matched to similar workers in other sectors. Noting in Figure A1 that different occupation groups have distinct temperature exposure profiles across Mexico, it is not necessarily the case that convergence in exposure–response functions indicates convergence in overall mortality risk, though nonetheless it appears a meaningful fraction of sensitivity differences between primary sector workers and those employed in other sectors can be explained by non-occupation and non-age individual characteristics and the sociodemographic characteristics of a worker's municipality of residence.

Physiologically, both heat and humidity affect the human body's ability to thermoregulate. Humans primarily cool themselves through sweating. High humidity reduces sweating's effectiveness, hindering thermoregulation in hot temperatures. The results presented above show the effect of temperature on mortality without considering humidity. Figure A2 illustrates the relationship between a measure that incorporates both heat and humidity—wet-bulb temperature—and mortality across different occupational groups. The results are qualitatively and quantitatively similar to those in Figure 1: primary sector workers are most strongly affected across the entire range of wet-bulb temperatures. This aligns with previous literature indicating that the overall temperature–mortality relationship in Mexico remains consistent whether taking wet-bulb temperature into account or using temperature measures that exclude humidity (Wilson et al., 2024). Further details on wet-bulb temperature and additional results can be found in Section E.

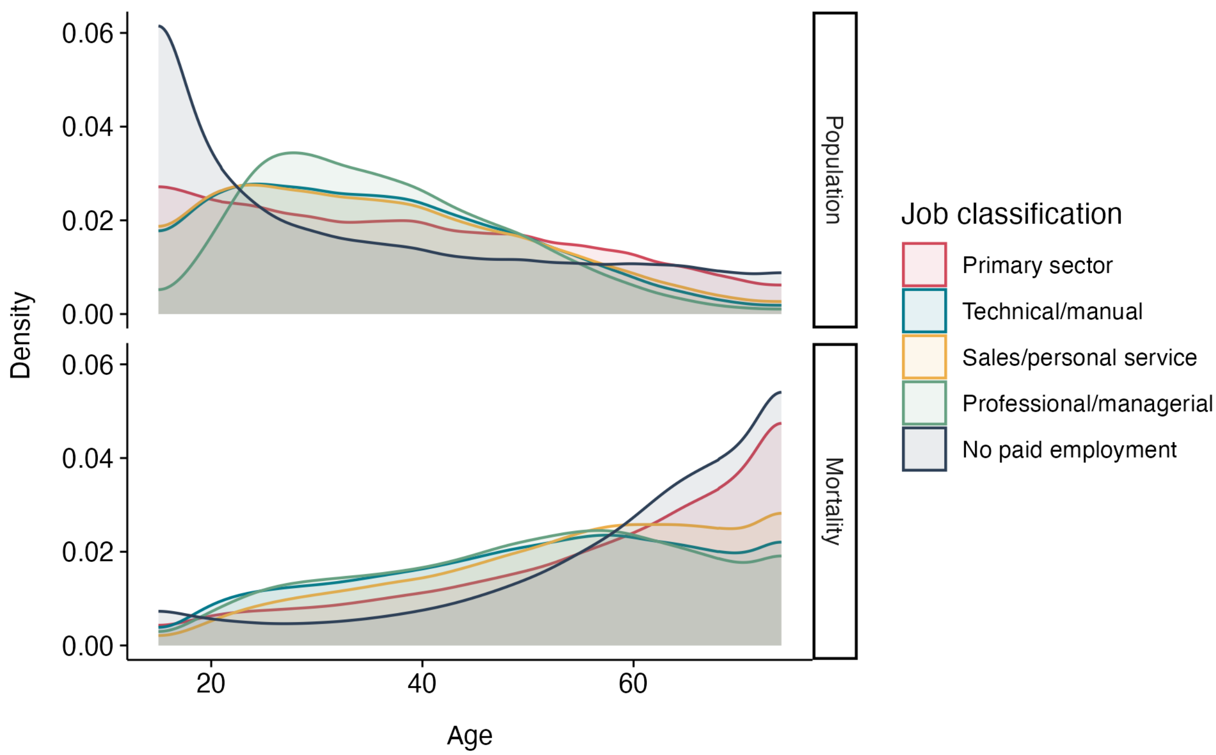
We also test whether pollution confounds our results. Figure A7 adds flexible controls for nine pollutants, revealing that occupation-specific temperature–mortality responses remain unchanged.

Section E conducts a sensitivity analysis on occupational classifications. As noted in Section 3, the detailed occupational categories in the mortality records evolve over time. This requires a cross-walk to broader categories that remain consistent throughout the sample period. This cross-walk may combine both highly exposed and less exposed occupations. In the appendix, we present results using an alternative three-group classification. We again find that mortality among agricultural workers exhibits the highest temperature sensitivity.

5.2 Interaction of Age and Occupation

People's likelihood of being in different occupational groups changes throughout their lives, and mortality is closely linked to age.Figure 2 presents the evolution of occupation and age in our sample. The top panel shows the age distribution across different occupational groups. Primary sector workers, represented in red, are evenly distributed across all age ranges, including young, middle-aged, and older workers. In contrast, workers in other sectors have distinct peaks in their age distribution, particularly in their 20s and 30s. Non-workers predominantly fall into the very young or relatively old categories.

Figure 2: Distribution of Mexican residents and deaths by occupation and age

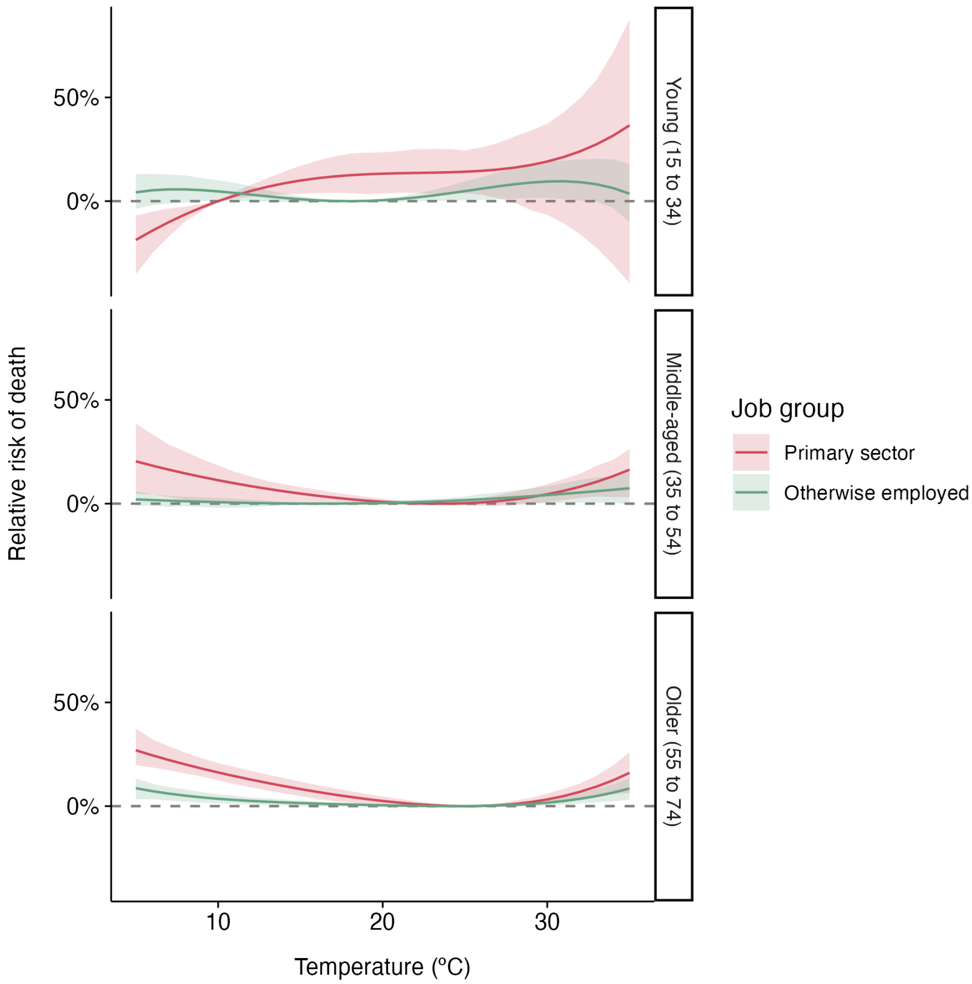


Notes: Both figures show the distributions of ages stratified by 5 occupational categories. The top panel shows the age distribution of the population of Mexico. The bottom panel shows the distribution of age at death.

The bottom panel of Figure 2 plots the distribution of mortality by age and occupation. The figure underscores the significant impact of age on mortality risk, with the share of mortality events increasing sharply with age. This rise is most pronounced for primary sector workers and non-workers. In addition to this unconditional relationship, age is also a strong mediator of the temperature–mortality relationship. Figures A3 and A4 show the effects of dry and wet-bulb temperatures on mortality, stratified by 10-year age groups. The results show that different age groups have markedly different temperature–mortality relationships.

Older individuals, especially those over 65, are especially vulnerable to extreme heat and cool temperatures. In contrast, younger people, especially those under 35, face increased mortality at moderately hot and hot temperatures. These findings align with those reported in Wilson et al. (2024).

Figure 3: Relative risk of temperature-related mortality: primary sector versus other occupations by age



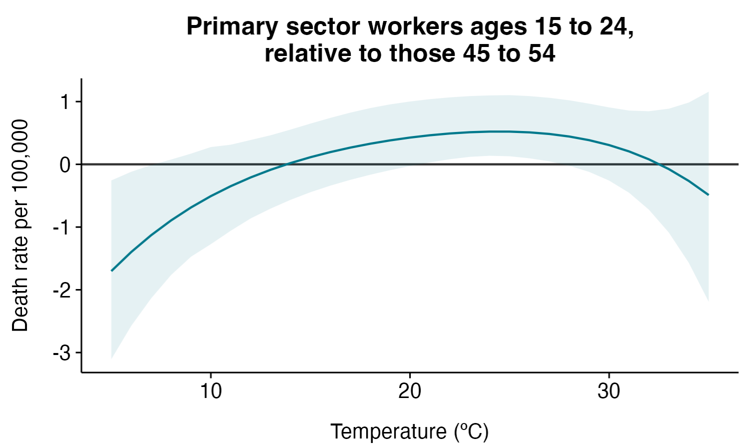
Notes: The figure shows estimates from fitting versions of Equation (1) separately for each of the given occupation-by-age groups using the baseline sample. The dependent variable is relative risk or mortality risk normalized by the unconditional mortality rate within each age-by-occupation group. The estimates are conditional on controls for precipitation as well as fixed effects for municipality by year and municipality by month. Shaded areas show 95% confidence intervals based on bootstrapped standard errors clustered at the state level. The red line and shared areas are the estimates for primary sector workers and the gray line is for all other individuals.

Overall, these figures and results suggest that occupational outcomes displayed in Figure 1 may stem, at least in part, from differences in the age distribution across occupations. To test this, Figure 3 analyzes whether the primary/non-primary sector difference remains within age groups.[3] The figure shows the relative risk of mortality as a function of temperature, using the unconditional mortality rate within each age and occupation cell as the denominator for the relative risk calculation.

The figure presents two main findings. Within each age group, primary sector workers show greater temperature–mortality sensitivity than workers in other sectors. In other words, the occupational results depicted in Figure 1 remain qualitatively consistent across each age group. The difference in the effect of heat is more muted for older workers. But for younger individuals between 15 and 34, primary sector workers are substantially more vulnerable to temperature.

The elevated mortality rate for these younger, primary sector workers shown in Figure 3 also, in one way, masks the extent to which this group is disproportionately affected compared to older groups. The temperature range over which the youngest age group exhibits a significantly higher mortality rate represents a substantial fraction of the total temperature distribution in Mexico (recall that the 5th percentile of temperature is around 11°C; see Figure A1). So younger primary sector workers are at higher risk of temperature-related mortality precisely on those days that are most common. This has implications for the total mortality attributable to temperature, a point we return to when estimating total deaths from temperature in Section 5.3.

Figure 4: Comparison of mortality-temperature exposure response for primary workers aged 15–24 versus 45–54

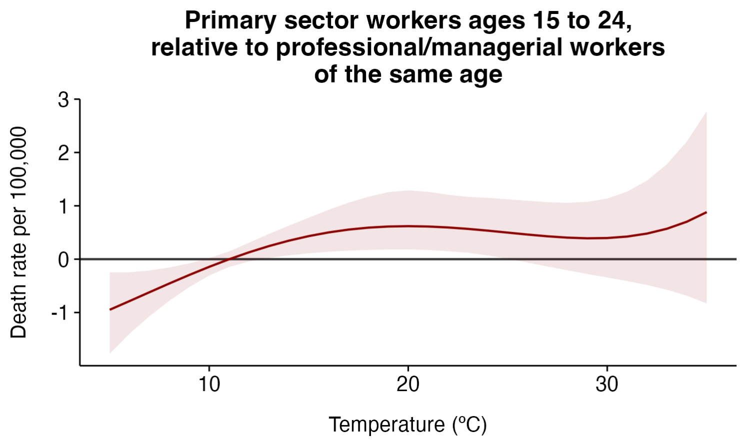


Notes: The figure shows hypothesis tests for the difference in death rate–temperature relationship for primary sector workers aged 15–24 versus 45–54. The tests are based on estimates generated using Equation (1). These estimates (shown in terms of relative risk) are provided in Figure 3. The shaded area is the 95% confidence interval based on state-level bootstrap.

[3]The results with all of the occupational categories, 10-year age groups, and absolute risk is shown in Figure A5.

A test of the significance of the difference in temperature-related mortality rate between 15–24 year old primary sector workers and 45–54 year old primary sector workers is shown in Figure 4. The figure shows that younger primary sector workers have significantly higher mortality rates than middle aged workers in the same sector at very cold temperatures and at warm or moderately hot temperatures. At very high temperatures, the mortality rates for these two groups converges, pointing to the overall danger posed by very hot temperatures regardless of age or occupation group.

Figure 5: Comparison of mortality-temperature exposure response for workers aged 15–24 in primary versus professional/managerial sectors



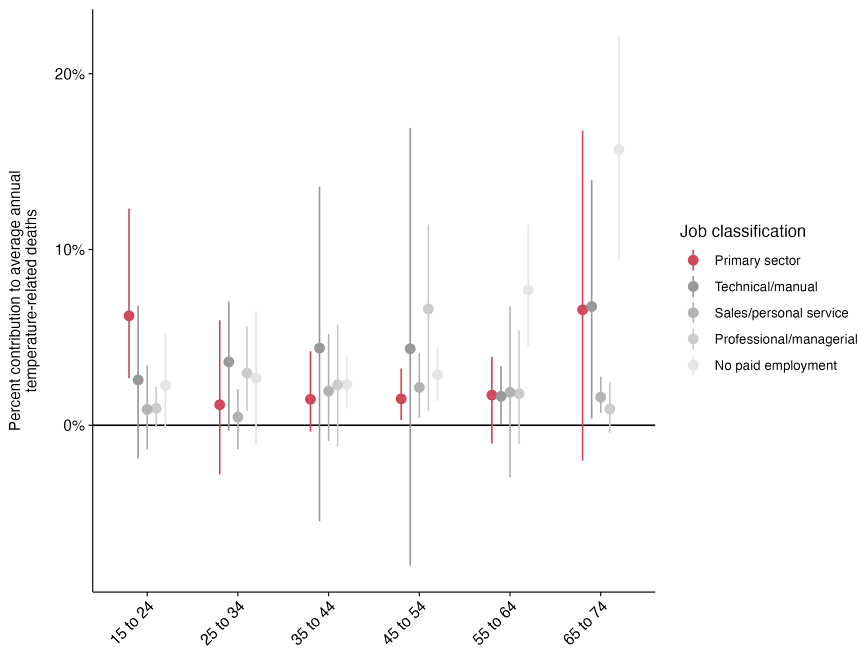
Notes: The figure shows hypothesis tests for the difference in death rate–temperature relationship for primary sector workers aged 15–24 versus professional/managerial workers of the same age. The tests are based on estimates generated using Equation (1). These estimates (shown in terms of relative risk) are provided in Figure 3. The shaded area is the 95% confidence interval based on state-level bootstrap.

A similar test, except this time for the difference between primary sector workers and professional/managerial workers in the same 15–24 age group is shown in Figure 5. Positive values in the figure indicate that young primary sector workers are more vulnerable to the given temperature relative to young professional/managerial workers. The figure indicates that primary sector workers experience significantly higher mortality rates across a wide range of moderate and warm temperatures. Young primary sector workers experience significantly lower mortality rates at cold temperatures, perhaps due to more flexibility during the times of year when these temperatures are likely to occur.

5.3 Total Deaths Attributable to Temperature

The previous results show the effect of temperature on the mortality rate per 100,000 people and the relative risk, which measures how mortality rates change relative to the unconditional mortality of specific occupations and demographic groups. These measures reveal the sensitivity of different groups to marginal temperature changes. However, the overall impact of temperature on mortality also depends on the time individuals spend in various temperatures. For instance, if individuals are sensitive to extremely hot or cold temperatures that occur infrequently, their overall mortality burden will be lower compared to if they were sensitive to more moderate and common temperatures. Additionally, the overall mortality for any demographic or occupational group will depend on the size of that group.

Figure 6: Annual temperature-related deaths within age and occupation groups



Notes: The estimates were generated by fitting versions of Equation (1) for each subgroup, calculating implied total annual mortality across Mexico for each sample year, averaging across years, then calculating the share of temperature-related deaths attributable to each age-by-occupation cell. Line ranges indicate bootstrapped 95% confidence intervals of econometric model uncertainty.

Figure 6 translates the mortality risk results by age and occupation from Section 5.2 into total deaths. This figure shows the percentage of annual temperature-related deaths attributed to each age-by-occupation group across five occupational categories, divided into 10-year age groups. The primary sector is shown in red, while the other sectors are depicted in shades of gray.[4]

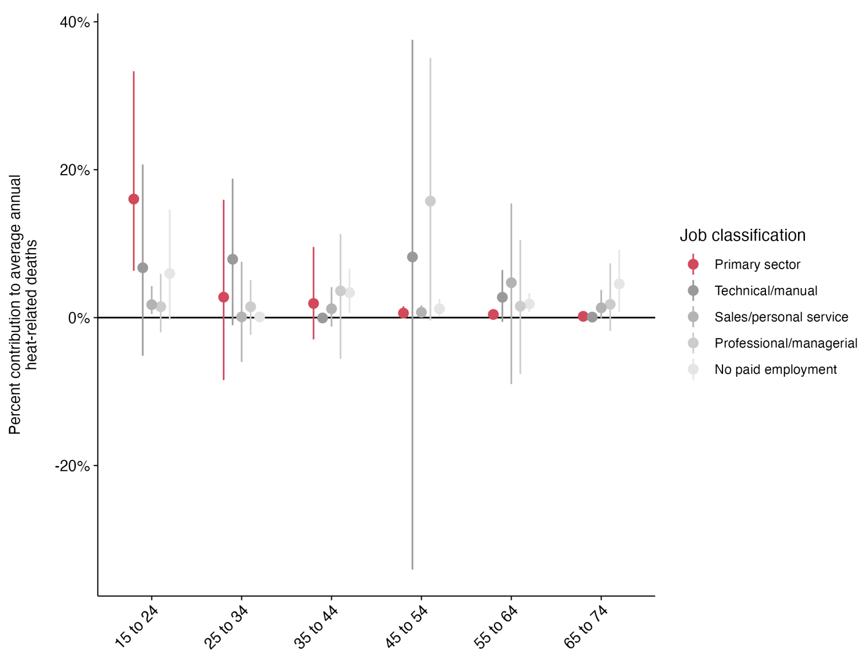
From the figure, total temperature-related mortality is especially high in four groups: 15–24 year old primary sector workers, 45–54 year old professional/managerial workers, people 45 and older who are not performing paid work, and people 65–74 in the primary or tech-

[4]Figure A9 shows the share of temperature-related deaths within each age group for three broader age groups (15–34, 35–54, and 55–74).

nical/manual sectors. The results for 45–54 year old professional/managerial workers is driven by their relative sensitivity to cold. Other groups that contribute nearly as much to temperature-related mortality are 25–44 year old technical/manual workers (though in these cases, the confidence intervals are large and include 0).

The large share of temperature-related deaths among primary sector workers who are 15–24 years old (more than 7%) is in contrast to the small share of overall deaths for this group (about 1.6%). Contrast this with temperature-related deaths for individuals 65–74 who are not in paid work. They constitute about 15% of temperature-related deaths and close to 30% of total deaths. Therefore, compared to overall deaths, temperature is substantially over-represented as a cause of death for younger, primary sector workers while it is under-represented as a cause of death among older workers even in the sector that experiences the highest mortality (not in paid work).

Figure 7: Annual **heat**-related deaths within age and occupation groups



Notes: The estimates were generated by fitting versions of Equation (1) for each subgroup, calculating implied total annual heat-related mortality across Mexico for each sample year, averaging across years, then calculating the share of such deaths attributable to each age-by-occupation cell. Line ranges indicate bootstrapped 95% confidence intervals of econometric model uncertainty.

Figure 7 further isolates deaths attributable to exposure to temperatures above each group's mortality minimizing temperature (MMT). We estimate MMT by determining the temperature at which each group's response function reaches a minimum, with the restriction that this temperature must fall between 10 and 30°C. As in Figure 6, the primary sector is shown in red, while the other sectors are depicted in shades of gray. Here, we see that heat-related mortality is dominated by younger age groups, especially individuals emplyed in the primary or technical/manual sectors. Partially this reflects the fact that older individuals experience minimum mortality risk at much higher temperatures, which is evident in Figure A2.

5.4 Mechanisms

The results show that the youngest primary sector workers experience high rates of temperature-related mortality, especially when compared with individuals just a couple decades older than them (Figure 6). It is not until one looks at workers who are 65 or older that primary sector heat-related mortality rises to such high levels. A natural question is about what mechanism could be driving the vulnerability of this group. A few candidate mechanisms are: that younger individuals engage in riskier activities; that these individuals have less ability to adapt either through lower income, less on-the-job flexibility, or some other reason; or that younger workers lack experience in how to protect themselves from temperature-related health risks.

The pattern of results suggests that whatever is affecting younger primary sector workers is strongly concentrated in that age group. This makes preference-based explanations less plausible. Experience could be an important explanation if the relevant experience is gained rapidly on the job. Using data from ENOE, we calculate the years that workers have spent in their current job (Table A3). Naturally, older primary sector workers have more experience. The average experience of primary sector workers aged 25–34, however, is just 3.9 years more than that of primary sector workers aged 15–24, despite their lower temperature-related mortality. Therefore, if experience plays an important role in reducing heat-related mortality, it has to be gained very rapidly during these years.

To investigate workplace flexibility, we also use ENOE data to estimate flexibility along four dimensions: labor formality, whether the worker has a contract, whether the worker is the primary earner in their household, and the variability of work hours. Among primary sector workers above 24 years old, older workers are more likely to have more occupational flexibility along several dimensions (Table A3). Older primary sector workers are more likely to not have a contract at work, have informal jobs, and have a higher standard deviation of hours worked as a percentage of their average weekly hours worked. On the other hand, older primary sector workers are less likely to be the sole breadwinner in their household. Overall, our occupational flexibility index—the composite of these flexibility measures—increases monotonically from younger (25–34) to older (65–74) primary sector workers. But importantly, young primary sector workers aged 15–24 also show greater occupational flexibility, likely due to the prevalence of part-time, informal jobs. Thus, as far as can be discerned from the ENOE data, the youngest primary sector workers are not subject to particularly inflexible work. Their high degree of informality, however, might leave them vulnerable to climate shocks due to a lack of worker protections.

6 Discussion: Implications for Climate Change Sensitivity and Adaptation

Climate-exposed work represents an important channel for climate health shocks. As the results here show, younger workers in climate-exposed sectors are at disproportionate risk of heat-related mortality. The results have multiple implications for projected climate change damage.

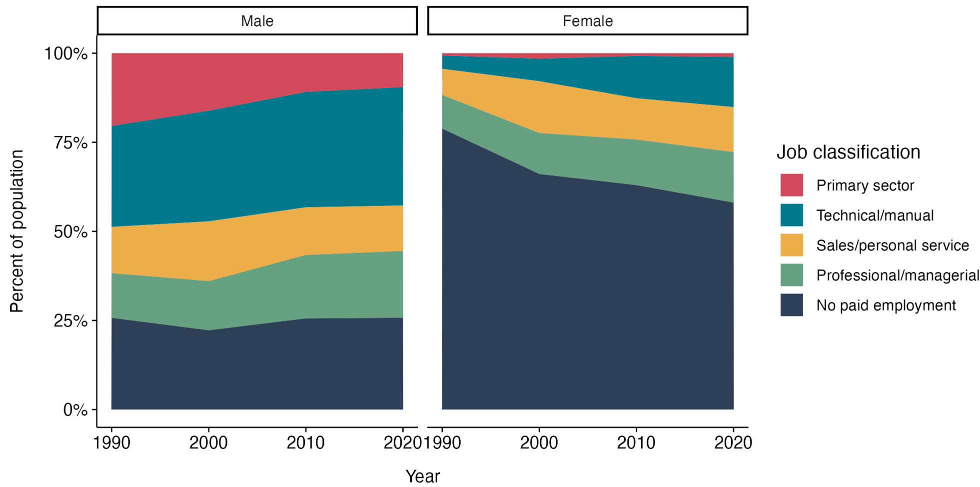
6.1 Structural Change

First, structural change and resulting sectoral reallocation have transitioned billions of workers from a climate-exposed agricultural sector to a service sector over the last century (see, for a review of the structural change literature Matsuyama, 2008). As Timmer et al. (2015) demonstrates, the agricultural labor share in Latin America fell from 47% in the 1960s to 14% in the 2010s. Declines of similar magnitude occurred in Africa and Asia. This reduction in agricultural labor share almost perfectly corresponds with a rise in the service sector labor share in Latin America, which increased from 32% to 64% during the same period. Census data over our sample period also shows a monotonic decline in the primary sector's share of the population, largely driven by men exiting the primary sector(Figure 8).

Given that we find that mortality from heat is concentrated among young, primary sector (largely agricultural) workers, the historical reduction in agricultural occupation shares has likely reduced the sensitivity of mortality to heat both in Mexico and—if similar patterns hold elsewhere—in other parts of the world. If future sectoral reallocation mirrors this historical trend, it could further reduce temperature-related mortality, potentially offsetting some of the mortality increase caused by warming temperatures due to climate change. Adaptation efforts influencing workers' occupational choices could accelerate or impede this process.

But climate change might reverse this historical pattern. One main mechanism driving the shift away from agricultural employment has been non-homothetic preferences (Świkecki, 2017). As economies grow, spending on agricultural outputs as a share of budget has fallen.

Figure 8: Occupation shares in Mexico



Notes: The figure shows occupation shares in five occupation classifications (including a group for those not in paid employment) for the entire Mexican population, based on data from decennial Censuses between 1990 and 2020. The left panel shows the data for males and the right panel shows the data for females.

However, this same preference-based mechanism could lead to increased employment in the agricultural sector in the future. Climate change severely affects agricultural productivity (Schlenker and Roberts, 2009; Lobell et al., 2011; Ortiz-Bobea et al., 2021). Since food is essential for survival and many countries strive to produce a significant share of their food domestically for various reasons, a reduction in productivity could paradoxically *increase* employment in the agricultural sector as lower productivity firms scramble to meet inelastic demand (Nath, 2025).[5]

Agriculture is not the only climate-exposed sector that could exhibit these dynamics. In the construction sector, productivity is highly dependent on the weather (Downey et al., 2023), with high rates of occupational injury relative to other occupations (Park et al., 2021), and the output from the sector is a necessary good (shelter) that could have highly inelastic demand if production falls sufficiently. More fine grained sectoral shifts could also increase occupational climate exposure. For example, there has been substantial growth in service sector delivery jobs in Mexico (and other countries around the world). These jobs are exposed to the climate, are predominantly filled by younger adults, and demand dynamics end up concentrating climate risks onto these workers (Papp, 2024).

[5]See Casey et al. (2019) for a similar argument but in the context of trends in fertility.

6.2 Adaptation Policy

Explicit adaptation policies can reduce temperature-related mortality based on the results above. Workers exposed to heat can adapt by taking frequent breaks, staying hydrated, and recognizing signs of heat-related illness. Public policy can further reinforce these adaptation actions. As discussed in Section 2, Mexico and other countries have implemented policies aimed at ensuring these protections for some workers.

The results also have implications for existing public policy responses to heat. Over the past few decades, policymakers have identified more effective ways to protect public health during high heat events. Especially after the high-mortality heat waves in Chicago in 1995 and in Europe in 2003, policies were implemented to improve early warning systems and enhance public health outreach. These efforts aim for help vulnerable populations—often identified as a elderly, in this literature, identified as elderly, poor, or chronically ill individuals) into cooling shelters or otherwise to protect them from heat (Sampson et al., 2013; Jay et al., 2021). Weather early warning systems have improved steadily over recent decades (Bauer et al., 2015), though there are still important inequities in forecast accuracy and access in low and middle-income countries relative to high-income countries (Linsenmeier and Shrader, 2023). Temperature forecast improvements have been found to substantially reduce mortality from heat (Shrader et al., 2023). The results here, however, complicate these adaptation efforts and heat action plans. The results show that younger workers are vulnerable to elevated mortality across a wide range of both warm and hot temperatures. Further complicating the needed messaging, at some temperatures we find that young primary sector workers are dying from "heat" (temperatures above their mortality-minimizing temperature) while others are dying from "cold" (temperatures below their mortality-minimizing temperature). Therefore, tailored information might be needed alongside temperature action plans that recognize the different vulnerabilities faced by different groups.

7 Conclusion

This study examines how a person's occupation influences their risk of death due to temperature and the implications of this relationship for policy responses and climate change. The motivation arises from evidence indicating that climate-related mortality impacts not only the elderly but also young, working-age adults vulnerable to heat (Wilson et al., 2024).

We focus on Mexico, a middle-income country with many people employed in weather-exposed jobs, to investigate the intersection of occupation and climate risk. This research question holds scientific and policy relevance: if certain jobs have higher mortality risks in hot weather, then the health impacts of climate change will be unevenly distributed across the workforce. Identifying at-risk groups is crucial for designing effective interventions and understanding the broader economic implications of a warming climate. Our findings show that occupation significantly influences temperature-related mortality. Workers in climate-exposed sectors face substantially higher death rates due to temperature fluctuations than their counterparts.

In particular, the primary sector (agriculture and related outdoor work) exhibits the strongest mortality response to high temperatures. This effect is most pronounced among young adults. For instance, a 15—24 year-old in agriculture faces roughly 24× the heat-related mortality risk of a middle-aged agricultural worker and around 11× times the heat-related mortality risk of a young professional. Given the frequency of moderately hot days in Mexico, these elevated risks impose a disproportionate burden on young agricultural laborers, who experience significantly more heat-related deaths than their small population share would suggest. In contrast, cold weather impacts primarily affect those not in the labor force, particularly the elderly, highlighting a stark age–occupation divide in climate vulnerability.

In summary, heat poses a significant risk of death for young workers in manual occupations. The results carry important policy implications. They highlight an urgent need to incorporate occupational safety into heat adaptation strategies. Standard heat warning systems and public health programs typically focus on elderly populations, but our evidence indicates that young outdoor workers also belong to a high-vulnerability group. To protect these workers, targeted workplace measures are essential. For instance, labor regulations could mandate rest breaks, shade, and hydration during extreme heat conditions.

Ensuring protections for informal and agricultural workers in Mexico is crucial, as many at-risk laborers lack formal workplace standards. Early warning systems for extreme heat should alert employers and workers when to reduce physical exertion or adjust work hours during dangerously hot days. Policymakers must view heat exposure at work as a public health issue and implement regulations and awareness campaigns to mitigate risks for manual laborers. Climate change heightens the urgency for these interventions. As global temperatures rise, some trends suggest Mexico may experience more frequent and intense heat waves (Cavazos, 2024). Our findings suggest that without adaptation, heat-related mortality among working-age adults will increase. The health burden of climate change may increasingly affect younger, economically active populations along with the elderly.

This has broader economic implications: increased mortality and morbidity among workers can reduce labor productivity and earnings, exacerbating poverty in affected communities. If governments and industries prioritize heat protection in the workplace, they can mitigate the human toll of a hotter future. Understanding which occupations are most vulnerable allows for efficient targeting of adaptation efforts. Overall, our study emphasizes that the human cost of climate change depends not only on the extent of warming but also on how society manages workforce exposure.

The long-term evolution of the economy—structural transformation—will influence climate vulnerability. Historical trends show that Mexico has steadily shifted labor from agriculture to manufacturing and services over recent decades. This shift likely reduced the nation's overall sensitivity to heat, as fewer people work outdoors in fields today than a generation ago, limiting heat-related deaths. If this trajectory of sectoral reallocation continues, it could partially offset some of the increase in heat-related mortality that would otherwise occur with climate change. However, relying on structural transformation alone is risky. Climate change itself could disrupt progress. For example, if higher temperatures and droughts severely depress agricultural productivity, countries might paradoxically need more farm labor to meet food demand, potentially pulling workers back into harm's way. Similarly, even in a service-based economy, many jobs—such as construction or delivery services—remain weather-exposed and will continue to concentrate climate risk on certain groups.

These possibilities suggest that although economic development generally reduces population exposure to climate hazards, targeted policy interventions are necessary to protect workers in high-risk sectors. Future research should investigate whether occupation-based vulnerabilities exist in other contexts, especially in hotter low-income countries. Comparative studies across regions can clarify how context influences the occupation–temperature relationship. Another important direction is evaluating workplace adaptation strategies. For instance, studies could assess the health benefits of interventions like mandated rest breaks, cooling equipment, or adjusted work schedules to cooler hours. It's also worth exploring how workers and employers react to increasing heat—do individuals leave high-risk jobs, or do firms invest in protective technology? What barriers hinder such adjustments? Investigating these questions would enhance our understanding of how to protect at-risk workers as the climate warms. While we account for many factors, our analysis remains observational and cannot confirm causation. Unobserved differences between workers (e.g., baseline health or access to care) could partly explain the mortality gap across occupations despite our efforts.

Another caveat is that exposure is measured by ambient temperature at the municipality level, not at individual workplaces. This approach neglects micro-climate or behavioral differences, such as access to shade or hydration. Furthermore, we focus solely on mortality; heat-related illnesses and productivity losses are not captured, likely underestimating the full impact on worker well-being. Additionally, Mexico's context may differ from that of other countries, so caution is needed when generalizing these results. Nonetheless, the qualitative insight that young manual workers are especially vulnerable to heat is likely relevant to many low- and middle-income settings. Despite these limitations, this study enhances a understanding of how climate change intersects with economic structures and underscores the need for targeted adaptations to protect workers in a warming world.

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Online Appendix

Occupational Heat Exposure and Mortality

A Regulatory framework for the protection of Mexican workers to temperature changes

Protection for elevated and depressed thermal conditions: A cornerstone of Mexico's protections is the Official Mexican Standard on "Elevated or Depressed Thermal Conditions – Safety and Hygiene Conditions." Implemented in 2001, this standard sets maximum permissible exposure limits for high and low temperature environments at work (Secretaría de Economía, 2002) . It uses the Wet-Bulb Globe Temperature (WBGT) heat index and categorizes work intensity into three levels (light, moderate, heavy) to determine safe exposure durations. For instance, at 100% continuous exposure, the WBGT limit is 30°C for light work, 26.7°C for moderate work, and 25°C for heavy work. Higher temperatures are allowed only with work-rest cycles (e.g., 25% or 50% hourly rest). The standard also addresses cold stress, specifying when protective measures are necessary for low temperatures.

Employer Duties and Enforcement: Under this framework, employers must evaluate thermal conditions and implement controls to maintain workers' core body temperature between 36°C and 38°C. In practice, this involves providing cooling or warming measures as needed, adjusting work schedules, or limiting exposure time. According to NOM-015 and related safety regulations, employers must inform workers about heat risks, conduct risk assessments, and take preventive actions. Notably, if extreme temperatures result from climate conditions (e.g., outdoor summer heat) rather than industrial processes, employers must at a minimum inform workers of the risks, provide appropriate PPE (such as sun protection and ample water), and monitor workers' health.

Adaptation Measures and Climate Policy Integration: In recent years, Mexico has increasingly integrated heat protection into its climate adaptation and public health strategies. The National Climate Change Strategy (2007) and the General Law on Climate Change (2012) aimed and reduce the vulnerability of the the population and productive sectors to climate impacts (United Nations Development Programme (UNDP), 2025). At the national and state level, authorities now issue heatwave alerts and guidelines during extreme heat events, recognizing outdoor laborers as a vulnerable group. For example, during heat waves in 2023, the labor ministry in San Luis Potosí urged all employers to follow NOM-015 and implement extra precautions: ensuring rest breaks, maintaining water hydration stations at worksites, and regularly monitoring workers' body temperatures to keep them below 38°C.

B Additional Data Information

Table A1: Worker Classification

Occupation (INEGI)	Time Period
Primary Sector	
Workers in agriculture, livestock, hunting, and fishing activities	1998–2021
Technical/Manual	
Education workers	1998–2012
Workers in the processing industry	1998–2012
Fixed machinery operators	1998–2012
Assistants in the industrial and artisan production process	1998–2012
Drivers of mobile machinery and means of transport	1998–2012
Artisans	2013–2021
Industrial machinery operators, assemblers, and transport drivers	2013–2021
Workers in elementary and support activities	2013–2021
Sales/Personal Services	
Merchants, trade clerks, and sales agents	1998–2012
Vendors	1998–2012
Workers in personal services in establishments	1998–2012
Domestic Workers	1998–2012
Armed Forces, Protection and Surveillance Workers	1998–2012
Merchants, sales clerks, and sales agents	2013–2021
Workers in personal services and surveillance	2013–2021
Professional/Managerial	
Professionals	1998–2012
Technicians	1998–2012
Art, sports and entertainment workers	1998–2012
Officers and managers	1998–2012
Control personnel in the industrial production process	1998–2012
Middle-level administrative workers	1998–2012
Lower-level administrative workers	1998–2012
Officers, directors and heads	2013–2021
Professionals and technicians	2013–2021
Auxiliary workers in administrative activities	2013–2021

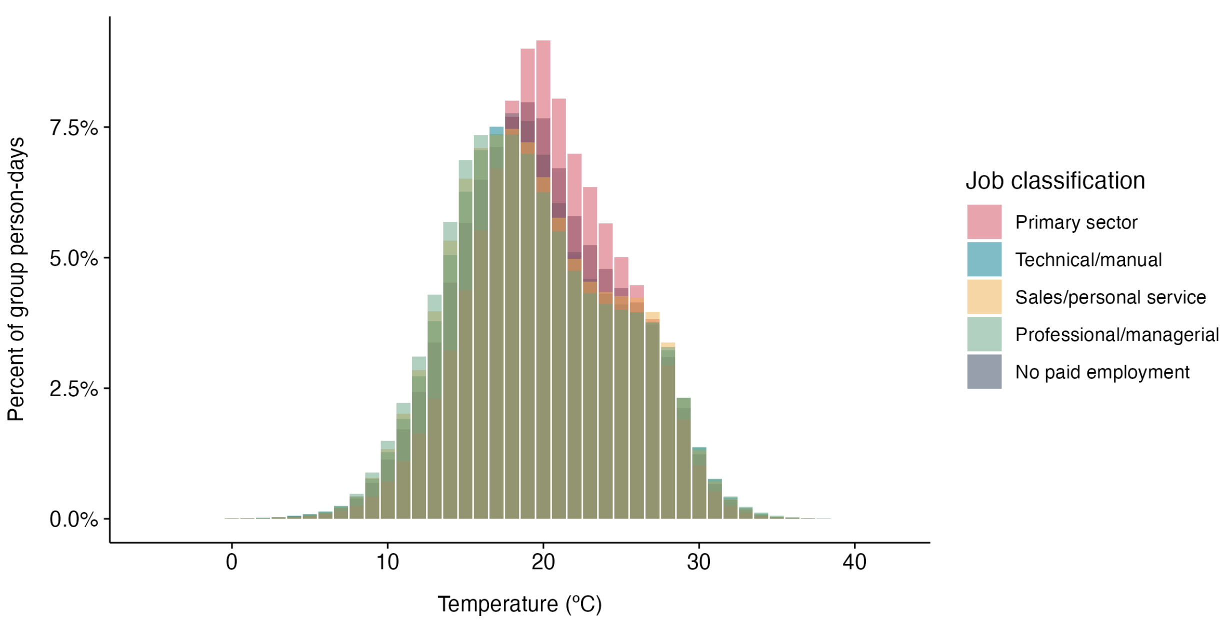
Notes: This table shows the concordance between the classification of occupations in Mexican death certificates and the categories used in this study. The Mexican National Institute of Geography and Statistics (INEGI) is responsible for determining the classification, with a notable break in 2013.

Table A2: Share of Mortality Records: Sociodemographic Characteristics by Labor Groups

	No Work	Work	Primary Sector	Technical Manual	Sales Personal Services	Professional Managerial
			Sex			
Male (%)	28.24	89.25	98.76	94.04	85.32	78.86
Female (%)	71.76	10.75	1.24	5.96	14.68	21.14
			Age			
[13, 20) (%)	1.97	1.22	1.03	1.60	0.82	1.44
[20, 40) (%)	5.26	16.22	8.30	19.62	15.75	21.20
[40, 60) (%)	15.09	29.93	16.90	34.28	31.71	36.84
[60, 120] (%)	77.69	52.63	73.77	44.50	51.72	40.52
			Education			
Unknown Education (%)	3.43	2.61	2.84	2.71	2.80	2.06
Professional (%)	5.02	14.26	0.42	4.63	6.17	45.82
High School (%)	15.25	23.31	5.59	25.84	32.71	29.10
No Education (%)	25.45	14.95	36.59	11.31	9.72	2.20
Primary School (%)	50.85	44.87	54.56	55.52	48.59	20.81

Notes: Each value represents the percentage share of mortality within the specified sociodemographic category and labor group. Data for sex, age, and education are derived from mortality records.

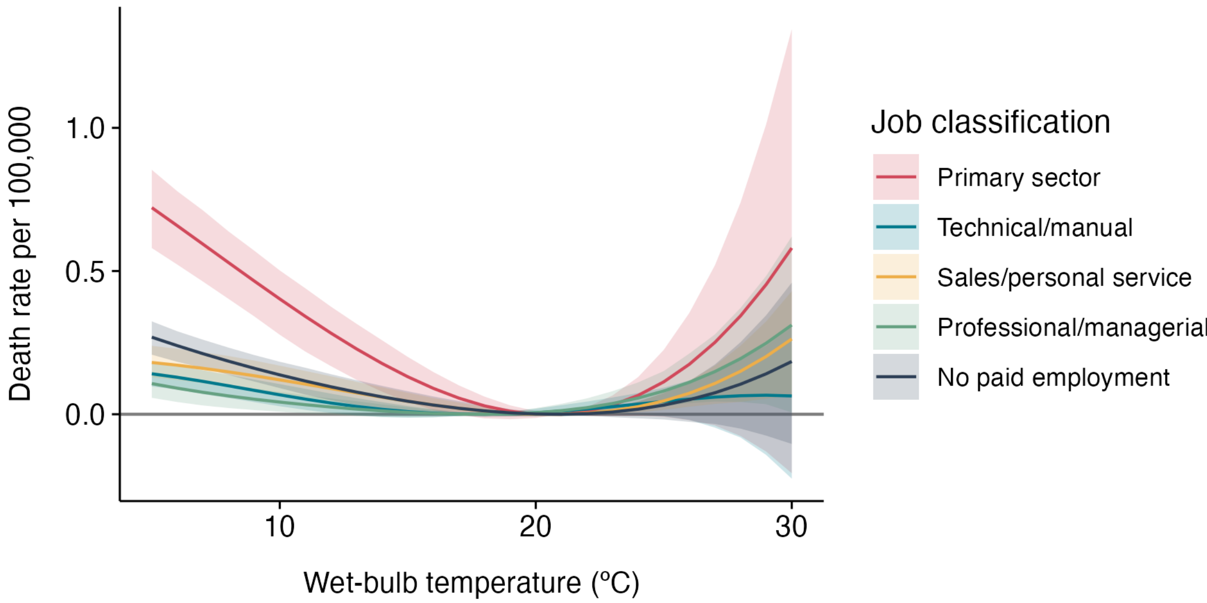
Figure A1: Distribution of temperature exposures by occupation group



Notes: Percent of person-days in each 1°C temperature bin across all municipalities and days, 1990–2023

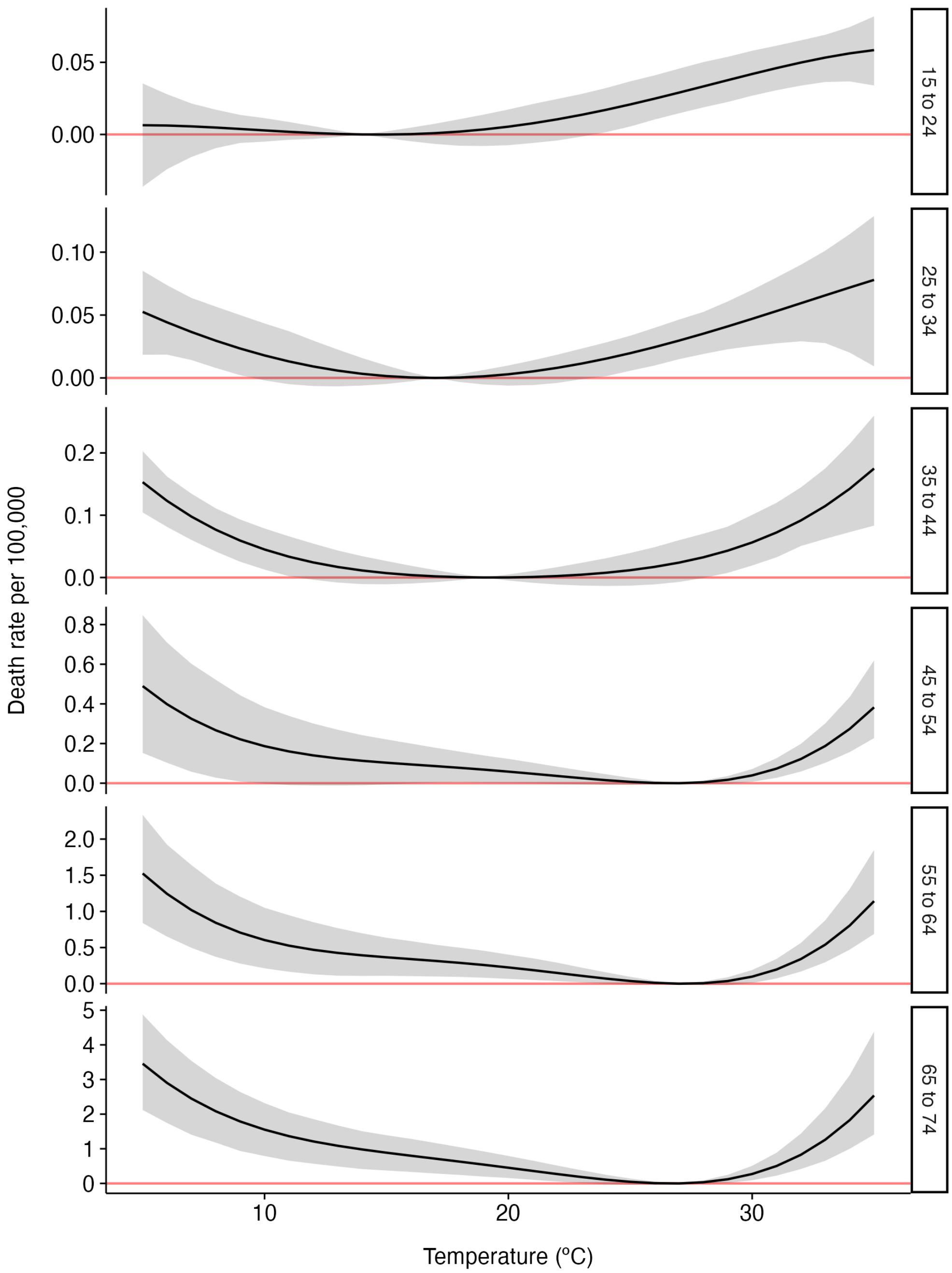
C Additional Results

Figure A2: Mortality–wet-bulb temperature relationship by occupation classification



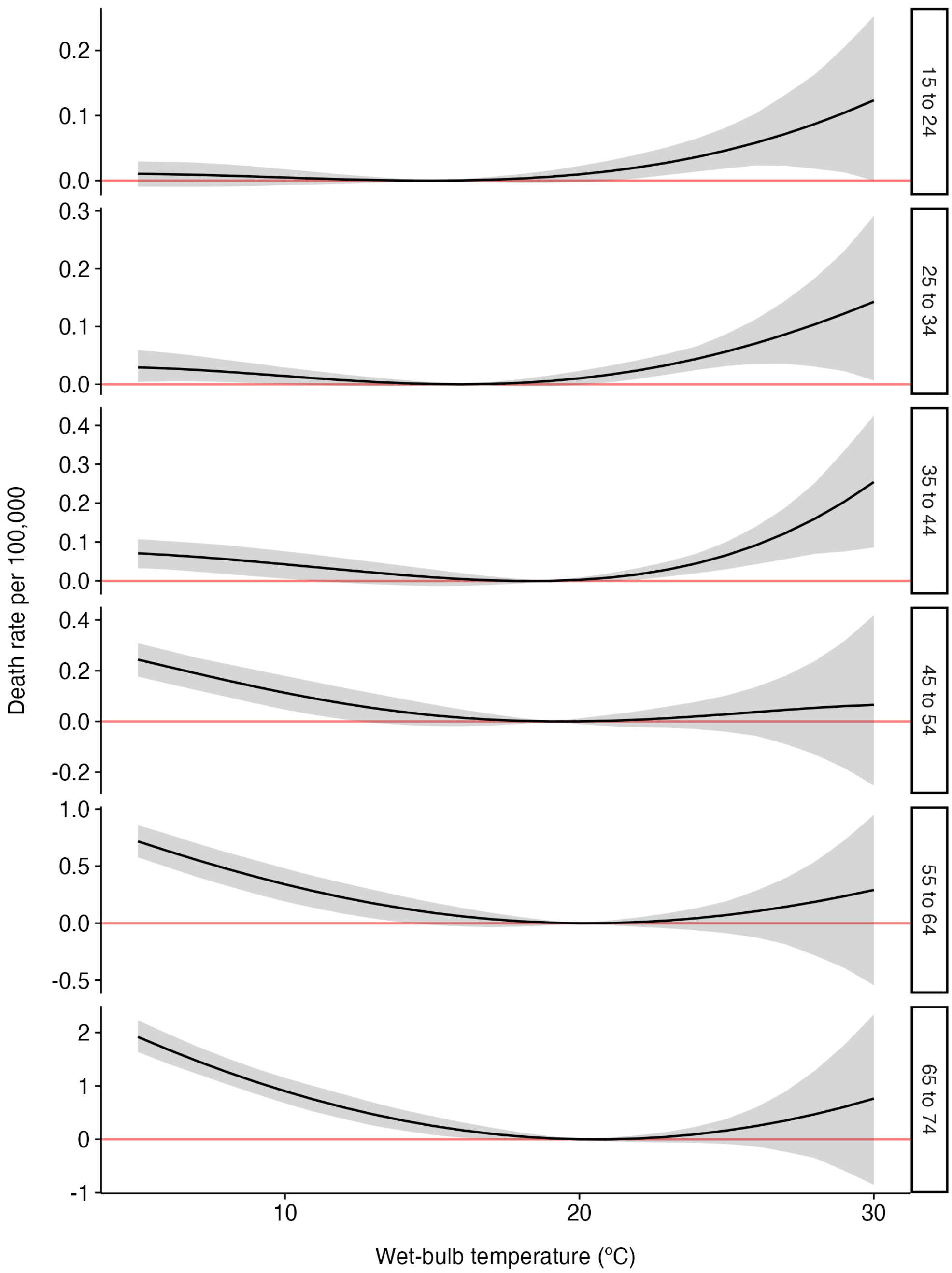
Notes: The figure shows estimates from fitting versions of Equation (1) separately for each of the given occupation groups using the baseline sample. The right-hand-side variable is wet-bulb temperature, in contrast to dry-bulb temperature results shown in Figure 1. The estimates are conditional on controls for precipitation as well as fixed effects for municipality by year and municipality by month. Shaded areas show 95% confidence intervals based on bootstrapped standard errors clustered at the state level.

Figure A3: Mortality–temperature relationship by age



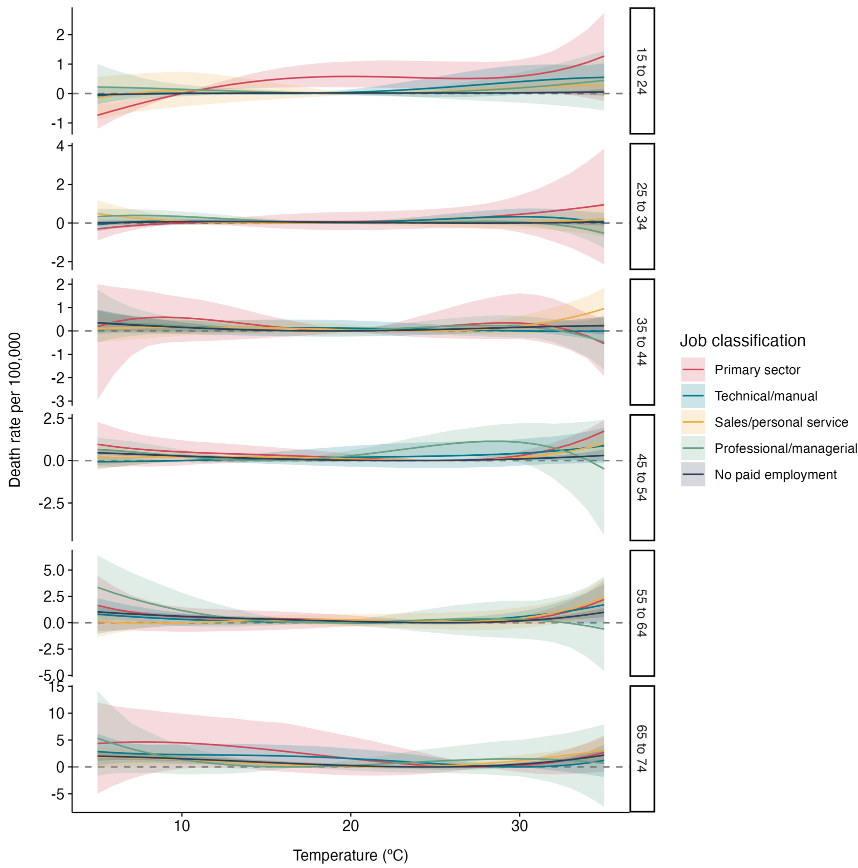
Notes: The figure shows estimates from fitting versions of Equation (1) separately for each of the given age groups using the baseline sample. The right-hand-side variable of interest is dry-bulb temperature (compare with Figure A4). The estimates are conditional on controls for precipitation as well as fixed effects for municipality by year and municipality by month. Shaded areas show 95% confidence intervals based on bootstrapped standard errors clustered at the state level.

Figure A4: Mortality–wet-bulb temperature relationship by age



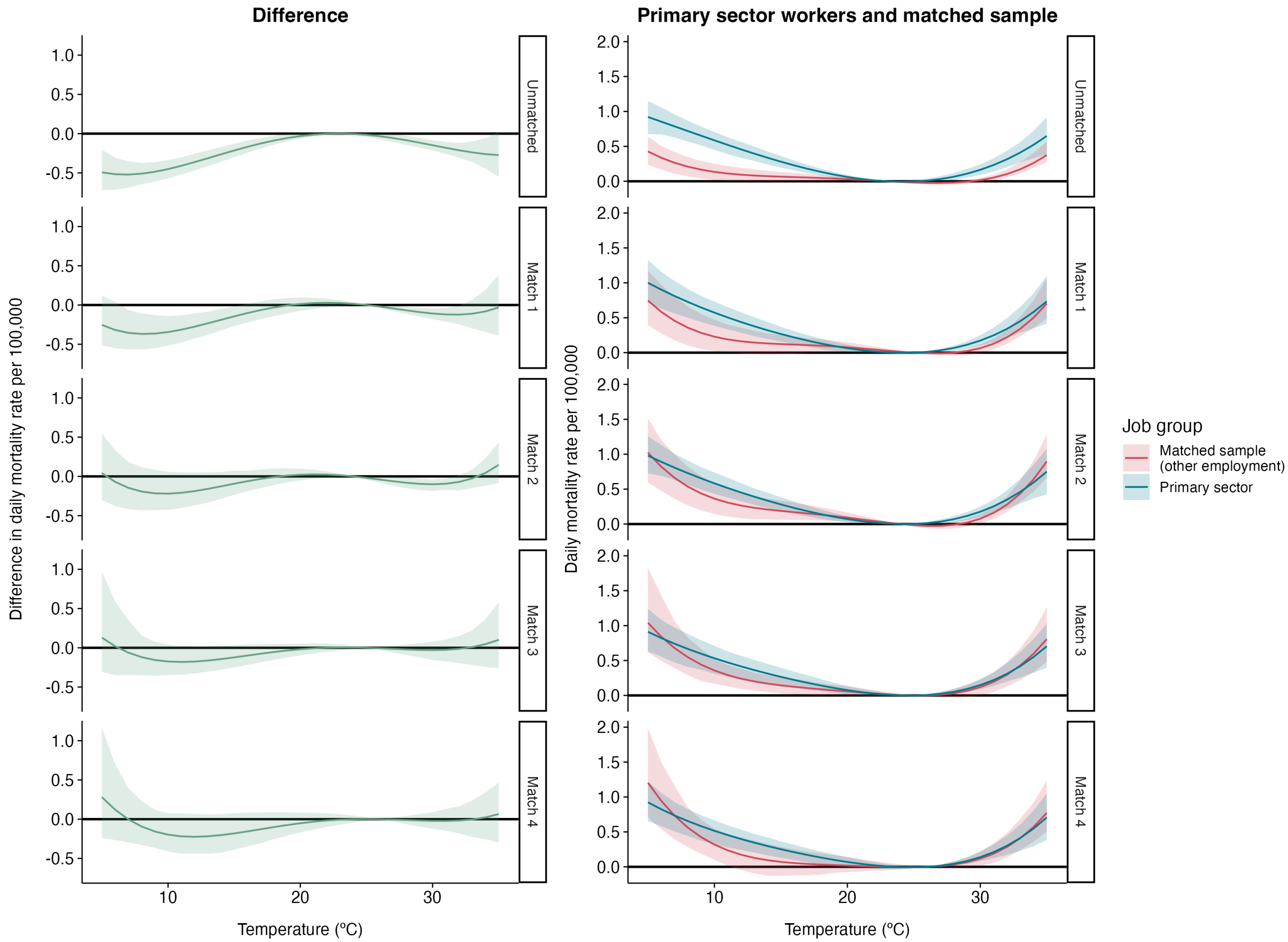
Notes: The figure shows estimates from fitting versions of Equation (1) separately for each of the given age groups using the baseline sample. The right-hand-side variable of interest is wet-bulb temperature (compare with Figure A3). The estimates are conditional on controls for precipitation as well as fixed effects for municipality by year and municipality by month. Shaded areas show 95% confidence intervals based on bootstrapped standard errors clustered at the state level.

Figure A5: Mortality–temperature exposure response functions by age and occupation



Notes: The figure shows estimates from fitting versions of Equation (1) separately for each of the given age-by-occupation groups using the baseline sample. Compare with Figure 3, which shows similar results for a simplified set of age groups. The estimates are conditional on controls for precipitation as well as fixed effects for municipality by year and municipality by month. Shaded areas show 95% confidence intervals based on bootstrapped standard errors clustered at the state level.

Figure A6: Results from coarsened exact matching exercise



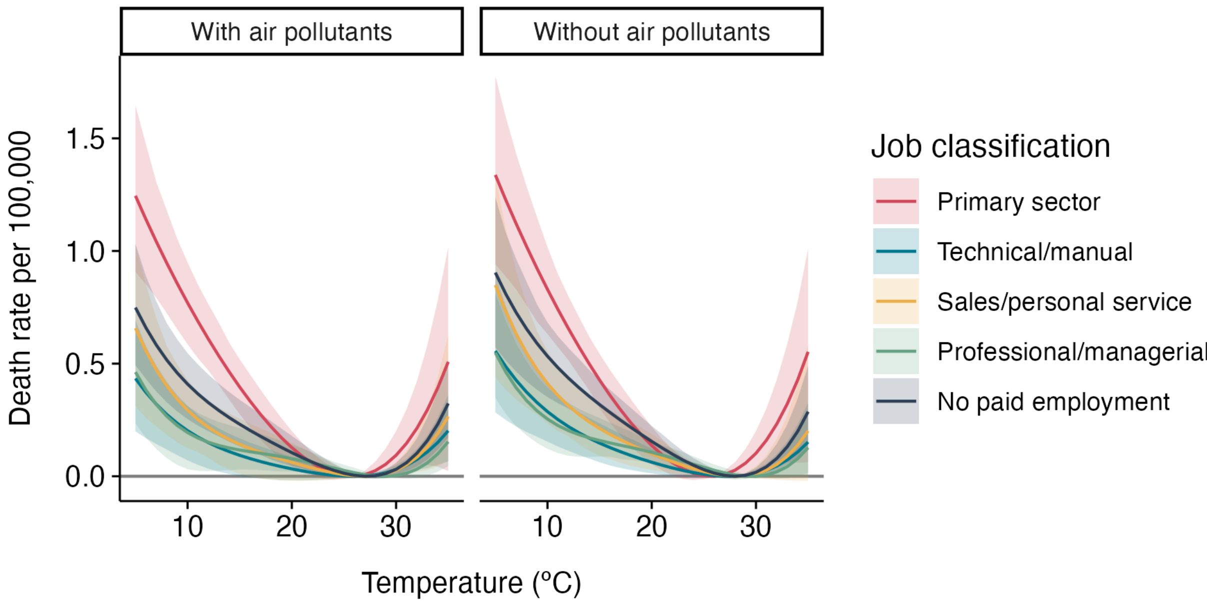
Notes: The figure shows estimates from fitting versions of Equation (1) for primary sector workers and workers employed in other sectors. The top panel shows this result for the unmatched sample. The next four panels show results from fitting this model for comparison groups constructed with coarsened exact matching. Match 1 shows this result when matching primary sector workers to other workers on age. Match 2 adds sex, education, and marital status. Match 3 adds municipality-level controls related to income. Match 4 adds additional municipality-level controls related to other sociodemographic characteristics and climate. The estimates are conditional on controls for precipitation as well as fixed effects for municipality by year and municipality by month. Shaded areas show 95% confidence intervals based on bootstrapped standard errors clustered at the state level.

Table A3: Occupational Flexibility Measures by Age Group and Occupation Type

Age Group	Primary Sector	Technical/Manual	Sales/Personal Services	Professional/Managerial
Contract (% Without Contract)				
15-24	83.6%	64.9%	59.8%	31.7%
25-34	76.3%	53.2%	38.9%	14.8%
35-44	77.9%	54.6%	37.1%	11.4%
45-54	78.0%	55.2%	37.6%	10.3%
55-64	82.2%	62.7%	44.1%	12.2%
65-74	91.5%	81.1%	63.6%	21.9%
75+	93.2%	82.3%	68.1%	26.5%
Formality (% Informal)				
15-24	86.0%	69.4%	67.3%	43.1%
25-34	80.9%	58.8%	51.0%	23.6%
35-44	81.3%	61.5%	52.2%	18.3%
45-54	81.0%	63.8%	54.1%	17.1%
55-64	83.0%	71.7%	60.4%	21.5%
65-74	85.2%	86.4%	70.8%	34.3%
75+	84.6%	89.8%	73.0%	37.4%
Sole Breadwinner (% Not Sole Breadwinner)				
15-24	83.1%	89.1%	91.0%	88.6%
25-34	55.5%	70.8%	78.1%	77.4%
35-44	61.0%	69.5%	74.8%	69.2%
45-54	67.9%	74.3%	77.9%	69.9%
55-64	64.4%	70.5%	74.9%	67.5%
65-74	55.9%	62.7%	67.8%	58.0%
75+	48.5%	58.8%	63.3%	56.4%
Std.Dev. of Hours Worked during Weekdays (% of Weekly Hours)				
15-24	3.08%	3.25%	3.80%	2.71%
25-34	2.85%	3.18%	3.42%	1.99%
35-44	2.91%	3.63%	3.28%	1.89%
45-54	2.78%	3.99%	3.21%	1.89%
55-64	2.80%	4.86%	3.30%	2.30%
65-74	2.96%	6.34%	3.37%	3.42%
75+	3.32%	6.49%	2.84%	3.92%
Flexibility Index (0-1, Higher: More Flexible)				
15-24	63.8%	55.1%	53.9%	40.2%
25-34	53.9%	44.4%	39.3%	28.6%
35-44	54.5%	44.8%	37.0%	24.2%
45-54	55.6%	46.6%	38.0%	23.5%
55-64	56.9%	49.6%	40.3%	24.0%
65-74	60.4%	57.9%	48.7%	27.6%
75+	60.0%	57.9%	51.1%	30.2%
Average Weekly Hours Worked				
15-24	39.3	40.6	40.8	38.6
25-34	41.3	43.7	45.6	40.3
35-44	41.1	42.7	46.0	39.6
45-54	40.8	41.3	45.8	38.7
55-64	39.3	38.3	44.5	37.3
65-74	36.3	32.6	42.6	33.9
75+	32.4	29.1	43.0	31.8
Job Experience (Years)				
15-24	3.3	2.4	2.0	1.8
25-34	7.2	4.7	4.0	4.4
35-44	12.9	7.6	6.7	9.5
45-54	19.4	11.0	9.4	15.5
55-64	26.5	14.3	11.7	19.6
65-74	34.8	17.8	14.3	23.6
75+	43.9	21.0	18.5	26.9

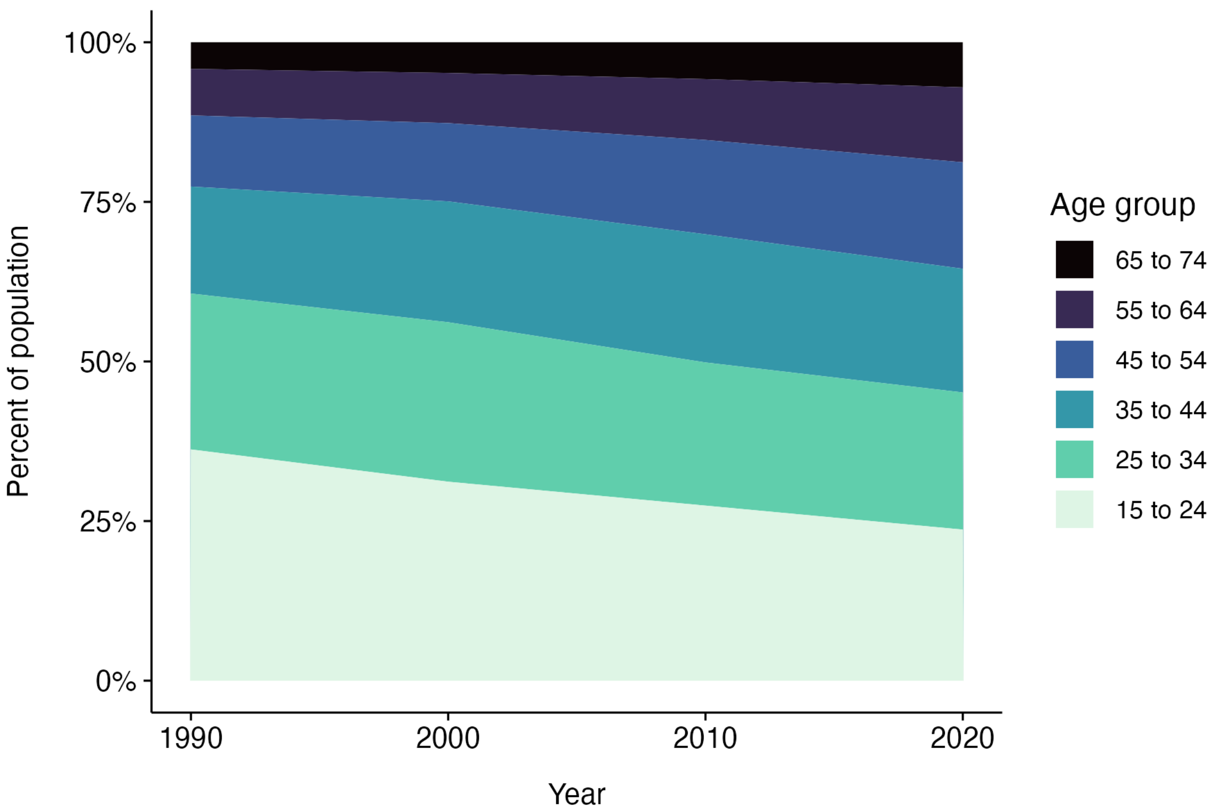
Notes: All values represent means by age group and occupation type. Flexibility index is a composite measure of employment formality, sole breadwinner status, employment contract, and hours standard deviation. Calculated using data from 2013-2023.

Figure A7: Mortality–temperature relationship by job classification, model estimated with and without nine air pollutants (data spanning 2003–2023)



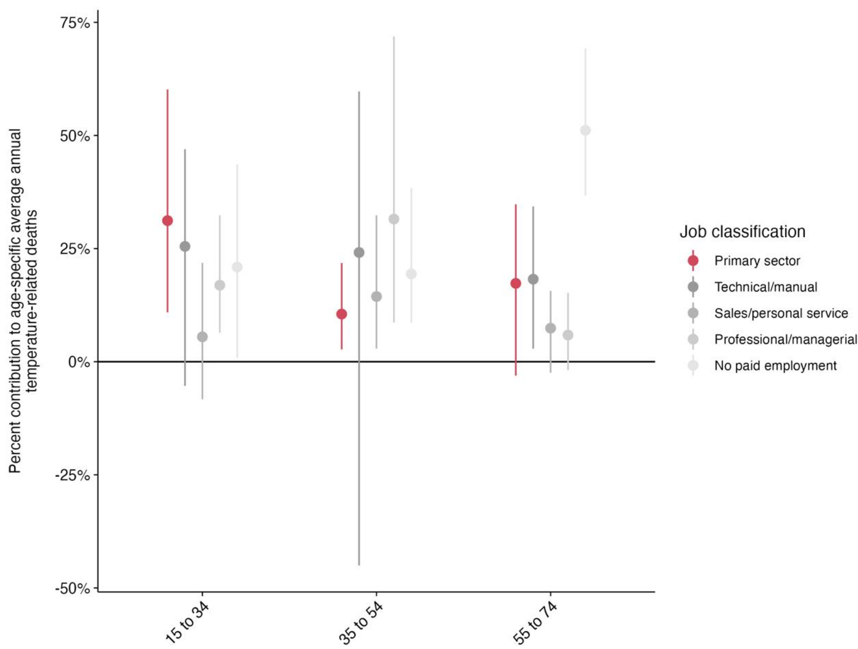
Notes: The figure shows estimates from fitting versions of Equation (1) separately for each of the given occupation groups using the sample from 2003 (when air pollution data is available) to 2023. For both panels, the estimates are conditional on controls for precipitation as well as fixed effects for municipality by year and municipality by month. The right panel further conditions on flexible functions for 9 air pollutants. Shaded areas show 95% confidence intervals based on bootstrapped standard errors clustered at the state level.

Figure A8: Distribution of Mexican residents by age



Notes: The figure shows the percentage of the population that falls into 10-year age groups between 1990 and 2020 based on census data.

Figure A9: Annual temperature-related deaths within age and occupation groups



Notes: The estimates were generated by fitting versions of Equation (1) for each subgroup, calculating implied total annual mortality across Mexico for each sample year, averaging across years, then calculating the share of temperature-related deaths for each occupation among all temperature-related deaths within a given age group. Line ranges indicate bootstrapped 95% confidence intervals of econometric model uncertainty.

D Coarsened Exact Matching

We attempt to address potential confounding through a coarsened exact matching exercise. In this exercise, we define "treated" individuals as those employed in the primary sector, matching them on observable dimensions to those employed in all other sectors. We then re-estimate our Equation 1 on these two subgroups and visualize and calculate differences.

We do this by matching primary sector workers ages 15 to 74 to all other workers within each Census, taking care to match on variables that are available both in the Census microdata and in mortality records. We assume that resulting weights—which differ by decennial Census—apply to proximate mortality observations; in other words, we assume that weights resolved for 1990 Census matches apply to mortality observations from 1990 to 1995, that those resolved for the 2000 Census apply to mortality observations from 1996 to 2005, and so on. To interpolate the population between Census, we apply matched weights to nearby Census (e.g., we apply Census 2000 weights to Census 1990, 2000, and 2010), then linearly interpolate the population of the matched sample, but keep only population values for matched mortality records. By aggregating mortality and Census population data in a similar fashion, we can construct a complete panel of monthly mortality rates for primary sector workers and a constructed matched sample of all other workers that match primary sector workers over time.

We apply four progressively more total matching specifications to control for possible confounders. In our first specification (1), we match only on age group. Out second specification matches on (1) plus sex, education, and marital status. Specification (3) combines (2) plus municipality-level average income, rural population share (as of 2020), share using wood or coal as fuel, and the NASA gridded deprivation index (Center For International Earth Science Information Network-CIESIN-Columbia University, 2022). Specification (4) combines (3) plus municipality-level average household size, share speaking an indigenous language, and Köppen climate classification.

Differences shown in Figure A6 reflect results from a bootstrap at the state-level of Equation 1 applied to treatment and matched samples.

E Sensitivity Analysis on Occupational Classifications

In the primary analysis, we classify occupations in two main ways. This classification process involves mapping different occupational classifications, which change over the sample period (See Section 3), into a consistent set of occupational categories. Here we test sensitivity to the classifications used in the main text by classifying death records into one of only three groups: non-workers, manual workers, and non-manual workers. This is a simplified classification scheme relative to the five sectors used in the main body, and it will bring together workers from different parts of those five sectors so long as their occupational category indicates that they do manual work (important in the Mexico context, for instance, given the large number of small-scale manual manufacturing workers).

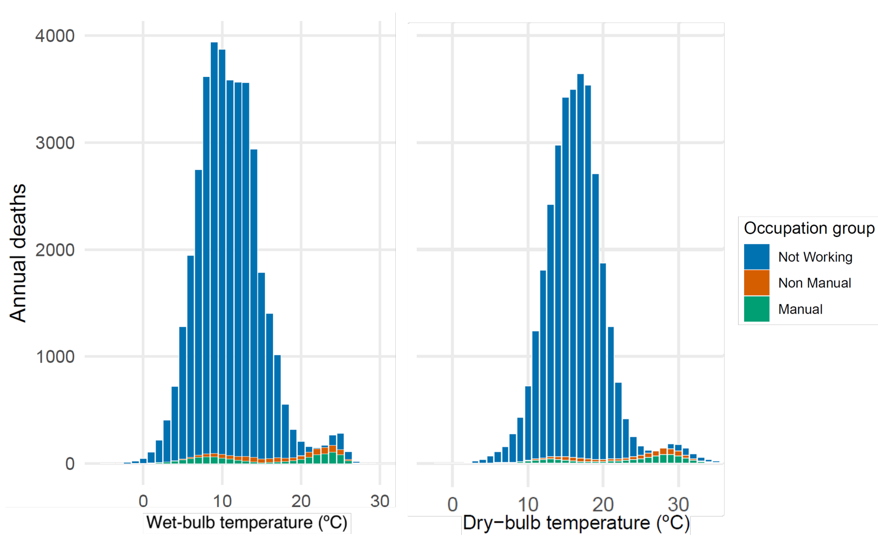
Figure A10 shows the effect of exposure to a single day at the indicated wet-bulb temperature on mortality risk for these three different occupational groups. For instance, the manual worker exposure-response function implies that when a manual worker experiences one day with an average wet-bulb temperature of 28°C, their risk of mortality increases by 20% relative to if they had experienced one day with an average wet-bulb temperature of 13°C. The bottom part of the figure below each exposure-response function is a histogram that shows the distribution of wet-bulb temperatures as experienced by people in Mexico over the sample period (gray bars) as well as the distribution of wet-bulb temperatures that they are expected to experience at the end of the century (red bars). This communicates how often people are exposed to wet-bulb temperatures at different levels. For instance, 8% of the days as experienced by people in Mexico over the sample period had a wet bulb temperature of 13°C, while temperatures rarely exceeded 26°C. Taken together, this figure communicates both how deadly a marginal day at a certain wet-bulb temperature is for each occupational group (exposure response functions in the top part of the figure), along with the frequency with which those days occur now and how often they are expected to occur in the future (histograms in the bottom part of the figure). As the figure shows, non-workers face the highest mortality risk from cold while manual workers face the highest mortality risk from heat.

Figure A11 is the same as Figure A10 except that it uses dry bulb temperature as the main treatment variable. The figure shows that the occupation-specific results are also robust whether we use wet-bulb or dry-bulb temperature as the metric of exposure (also see further results below). We also find that the exposure-response function over wet-bulb temperature is estimated a bit more precisely than the exposure-response function over dry-bulb temperature.

As the exposure-response functions in figures A10 and A11 show, the hottest temperatures—e.g., 30°C wet-bulb temperature and 40°C dry-bulb temperature—are the most damaging temperatures in terms of their impact on heat-related deaths. However, as the bottom temperature-distribution histograms in those figures show, heat waves that reach those temperatures occur very rarely. This leads to the question: what is the overall temperature-related mortality burden associated with exposure to temperatures over the course of the whole year, from the coldest days to the hottest days?

This question is addressed in figure A12. The overall temperature-related mortality burden is a function of both (1) the damage caused by exposure to a certain temperature (i.e., figures A10 and A11 top panels) as well as (2) how often people are exposed to those temperatures (i.e., figures A10 and A11 bottom panels). Figure A12 combines these two factors to show the temperature-related mortality burden associated with exposure to each degree of temperature. The left hump of this figure represents cold-related deaths. The right hump of this figure represents heat-related deaths. The peak of the right hump—which represents the temperature exposure that causes the most heat-related deaths in the sample period—is at 25°C wet-bulb temperature and 29°C dry-bulb temperature. Whereas the peak of the left hump of the figure—the temperature exposure that causes the most cold-related deaths in the sample period—is at 9°C wet-bulb temperature and 17°C dry-bulb temperature.

Figure A12: Historical temperature-related deaths in Mexico



The panels show average annual temperature-related deaths resulting from exposure to days with the average temperatures shown on the x-axis during the historical period across occupation in Mexico. The left panel shows deaths resulting from exposure to wet-bulb temperature. The right panel shows deaths resulting from exposure to dry-bulb temperature.

Consistent with past literature on temperature-related mortality in Mexico (Cohen and Dechezleprêtre, 2022; Jáuregui-Díaz et al., 2020), we find that cold is historically associated with many more deaths than heat across the whole population. However, this masks substantial heterogeneity on the differential impacts of heat and cold on different demographic groups within the population. We break out premature deaths from both cold and heat in table A4 below.

Table A4: Annual Historical Cold-Related and Heat-Related Deaths in Mexico by Manual vs Non-Manual Occupation

	Cold-Related Deaths		Heat Related Deaths	
	Wet-Bulb Temperature	Dry-Bulb Temperature	Wet-Bulb Temperature	Dry-Bulb Temperature
Manual Workers	477 (1%)	341 (1%)	684 (47%)	766 (55%)
[2.5th-97.5th Percentile]	[193, 760]	[-13, 695]	[122, 1,256]	[153, 1,380]
Non-Manual Workers	267 (1%)	240 (1%)	408 (28%)	301 (22%)
[2.5th-97.5th Percentile]	[-403, 937]	[-79, 560]	[-11, 827]	[87, 515]
Not Working	36,849 (98%)	30,926 (98%)	359 (25%)	318 (23%)
[2.5th-97.5th Percentile]	[29,994, 43,703]	[22,291, 39,561]	[-342, 1,060]	[-474, 1,110]

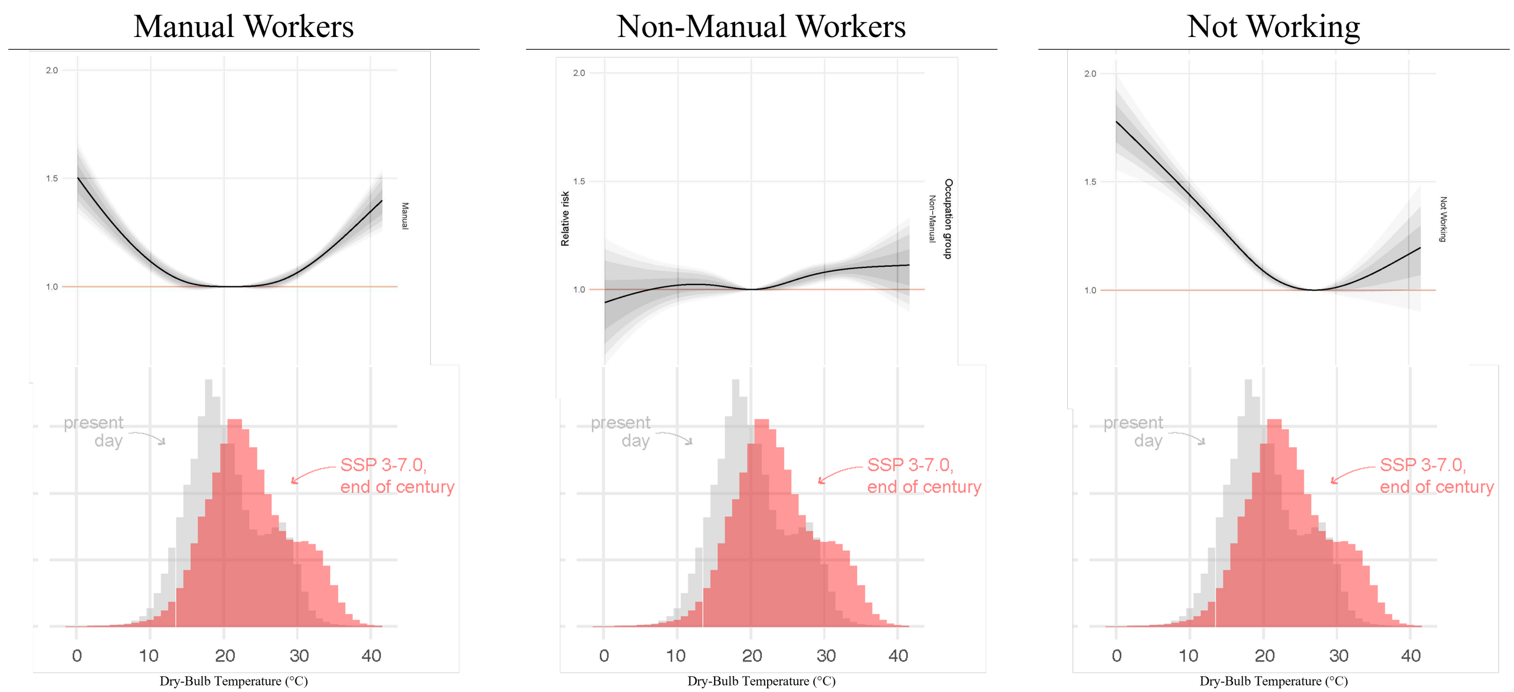
Table shows the average number of yearly cold and heat-related deaths broken down by occupation, using both wet-bulb and dry-bulb temperature as the metric of temperature exposure. The parentheses indicate the percentage of the total heat or cold deaths that are occurring in that occupational category. E.g., for heat-related deaths using wet-bulb temperature as the metric of temperature exposure, 47% of heat-related deaths are occurring among manual workers, 28% are occurring among non-manual workers, and 25% are occurring among non-workers.

For both wet-bulb temperature and dry-bulb temperature, cold-related mortality is overwhelmingly and disproportionally concentrated among non-workers, with 98% of cold-related deaths occurring among non-workers, who make up 85% of overall deaths in the population. Heat-related mortality, however, is quite a different story. Heat-related deaths are especially and disproportionally concentrated among manual workers: 47% of deaths occur among manual workers, who comprise just 9% of deaths in the overall population. While only 25% of deaths are among non-workers. When dry-bulb temperature is used as the exposure metric, manual workers make up 55% of heat-related deaths while non-workers make up just 23% of heat-related deaths. Non-manual workers are also disproportionally impacted by heat-related mortality, although not to the extent of manual workers. Non-manual workers comprise 28% of heat-related deaths when using wet-bulb temperature as the measure of exposure and 22% of heat-related deaths when using dry-bulb temperature despite comprising just 6% of the deaths in the overall population.

Figure A10: Relationships between mortality risk and exposure to wet-bulb temperature by occupation in Mexico

The top panels show the change in relative mortality risk (y-axis) caused by exposure to one day of the indicated average daily wet-bulb temperatures (x-axis) by occupation divided into manual, non manual, and not working. The bottom panels show the distribution of daily average wet-bulb temperatures in Mexico throughout the sample period as well as the ensemble mean of projected temperature distribution at the end of the century (2083–2099) under the SSP 3-7.0 emission scenario. Note that the bottom histograms represent the distribution of temperatures across the whole Mexican population, so each of the three histograms are exactly the same. Shaded bands around the functions in the top panels indicate 95, 90, 80, and 50% confidence intervals.

Figure A11: Relationships between mortality risk and exposure to dry-bulb temperature by occupation in Mexico



The top panels show the change in relative mortality risk (y-axis) caused by exposure to one day of the indicated average daily dry-bulb temperatures (x-axis) by occupation divided into manual, non manual, and not working. The bottom panels show the distribution of daily average dry-bulb temperatures in Mexico throughout the sample period as well as the ensemble mean of projected temperature distribution at the end of the century (2083–2099) under the SSP 3-7.0 emission scenario. Shaded bands around the functions in the top panels indicate 95, 90, 80, and 50% confidence intervals.