Occupation and temperature-related mortality in Mexico*

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Abstract

We investigate how occupation influences temperature-related mortality in Mexico. Using decades of nationwide death and weather data, we find that temperature-related mortality risk varies sharply by occupation. Young adults in climate-exposed jobs experience significantly higher heat risk: a 15-24-year-old agricultural worker is over 10× more likely to die from heat than an age-group peer in professional/managerial employment. Cold temperatures also increase mortality, especially for older non-workers. Our results suggest that occupational safety and adaptation policies may protect vulnerable workers from death and that ongoing economic shifts away from exposed sectors may moderate future heat-related mortality.

Keywords: Temperature, Climate, Occupation, Health, Mortality, Mexico

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1 Introduction

Climate and weather influence labor markets and human health. Both ambient heat and cold are significant causes of mortality (Gasparrini et al., 2015; Zhao et al., 2021), with climate change projected to increase global mortality overall (Carleton et al., 2022). Heat also affects workers by reducing work hours (Graff Zivin and Neidell, 2014), decreasing productivity (Behrer et al., 2021; Somanathan et al., 2021), and raising the likelihood of workplace injuries and illnesses (Dillender, 2021; Park et al., 2021; Ireland et al., 2023). It is typically thought that climate impacts on mortality will be primarily concentrated among older individuals who are less likely to be in the labor force, suggesting that these two channels of climate change impacts fall on disjoint groups. However, at least one recent study in Mexico reveals that working-age adults are particularly vulnerable to heat-related mortality (Wilson et al., 2024), indicating that workers may face a dual threat from climate change—both to their health and productivity. At the same time, cold temperatures remain a major cause of death in Mexico (Cohen and Dechezleprêtre, 2022), underscoring that both ends of the temperature distribution pose health risks. This paper investigates how occupation influences temperature-related mortality. The goal is to determine whether the working population bears a disproportionate share of climate-related health impacts, in addition to the productivity challenges they are already understood to face.

Determining how much the temperature-mortality pattern is driven by occupation is important for characterizing the distributional impacts of climate change and informing policy. If occupations influence temperature exposure and related mortality, policies that aim to improve workplace safety—particularly those addressing occupational 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 extreme temperatures. These responses include providing cooling centers, informing the public about upcoming heat waves, and engaging in community health outreach (Jay et al., 2021; Sampson et al., 2013; Shrader et al., 2023). Likewise, understanding cold-related vulnerability can help design complementary interventions, such as improving heating, insulation, and healthcare access for the elderly and low-income households exposed to cold stress (Cohen and Dechezleprêtre, 2022; Sarmiento et al., 2024). Conversely, if occupation is not a significant factor, current responses may suffice but require better tailoring to the specific temperature sensitivity of different groups of individuals (e.g., young workers) (Wilson et al., 2024).

To determine how occupation influences temperature-related mortality, we leverage weather, mortality, and demographic microdata from Mexico, spanning over three decades. We focus on Mexico because it is a large middle-income country that features a diverse range of climates and occupations, providing high-quality vital statistics and labor force records. Notably, Mexican death certificates document the decedent's occupation, which allows 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 by occupation. Workers in the primary sector—those engaged in agriculture, fishing, livestock rearing, and hunting—experience notably higher mortality rates on both hot and cold days compared to other occupational categories, including individuals without paid employment. On a day with 32°C temperature (90°F) weather, the mortality rate for primary sector workers increases by approximately 0.3 deaths per 100,000 people compared to a day with 23°C temperature (73°F). This rate exceeds that of the next closest group—individuals without paid employment at the time of their death—by more than double. At the opposite end of the temperature distribution, primary sector workers are also the most vulnerable to cold, followed by non-workers.

We next examine the interaction between age and occupation. Economic conditions and existing research on the role of age on the temperature–health relationship prompt us to investigate how age and occupation together mediate the effect of temperature on mortality. Younger workers often occupy lower-wage and lower-amenity jobs. This situation restricts their ability to invest in resources that support adaptation to environmental shocks and may also limit their workplace flexibility to avoid environmental hazards. Consistent with this hypothesis, we find that the youngest and oldest workers in the primary sector face serious temperature-related mortality risks. Workers aged 15 to 24 in this sector experience a death rate approximately 2.4× higher compared to those aged 45 to 54. Moreover, a 15 to 24-year-old worker in the primary sector faces about a 10.5× greater risk from dying due to temperature exposure compared to a professional or managerial worker of the same age. Lastly, the results indicate that a 15 to 24-year-old worker in the primary sector carries a higher risk of mortality from heat than individuals over the age of 75. At the same time, older adults—particularly those outside the labor force as well as agricultural and manual laborers—face elevated mortality during cold spells.

Younger workers in the primary sector face higher mortality rates during warm and moderately hot temperatures, which frequently occur in Mexico. Among individuals aged 15 to

74, those under 25 who work in the primary sector account for 16% of heat-related deaths within our sample period. In comparison, they represent only 1.6% of the population and account for only 0.7% of *all* deaths. By contrast, cold-related deaths are disproportionately borne by older individuals, underscoring that both heat and cold matter for public health but affect different demographic and occupational groups.

We conduct several robustness checks to assess whether omitted variables, such as air pollution, humidity, or maximum temperatures, affect our results. We also apply a coarsened exact matching procedure to account for observable individual or regional differences that may confound our main result. Using increasingly detailed matching specifications, we demonstrate that differences in sensitivity across occupation groups can be partially explained by observable worker characteristics. However, because of persistent differences in exposure, primary sector workers remain at greater risk even after we account for all factors reported on death certificates and a comprehensive range of economic and regional variables, including local average income, poverty, climate, labor market conditions, and rurality.

The stark differences in vulnerability to ambient temperatures carry important implications for policies addressing temperature-related mortality and 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 Jay et al., 2021; Sampson et al., 2013, for examples of the use of this definition). These classifications have largely stemmed from studies conducted in high-income, cooler countries. In the hotter, middle-income setting we study, young people who are actively employed—but in relatively low-paying occupations—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 the city of 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 Appendix Section A for more details on the policy environment in Mexico).

Due to structural change, the pattern of occupation-specific vulnerabilities we observe may alter projected climate damages. Throughout the 20$^{\text{th}}$ century and continuing to the present, Mexico has rapidly transitioned from an agricultural economy to one largely based on services. This shift has also occurred broadly around the world. Our results suggest that this transition reduced the overall sensitivity of society to temperature-related mortality.

Continued sectoral transitions would further reduce sensitivity, which could be especially important in low-income countries with large agricultural labor forces. However, one area of uncertainty regarding climate impacts involves whether productivity losses in the agricultural sector could interact with non-homothetic preferences in agricultural commodities. Such interactions could reverse the positive trend, leading to an increase in the proportion of agricultural workers in countries experiencing the most severe climate shocks (Jayachandran, 2006; Liu et al., 2023; Nath, 2025). Considering the importance of mortality and agricultural productivity for projected climate damages (EPA, 2023), this type of dual shock could significantly worsen the effects of climate change (de Lima et al., 2021). Moreover, as societies age and retirement ages rise, the population share of older adults exposed to cold conditions is expected to increase, potentially amplifying cold-related mortality in the future (Achebak et al., 2019; Chen et al., 2024). This demographic shift implies that even in a warming world, cold exposure may remain a relevant health concern, particularly for aging workforces and low-income retirees living in poorly insulated dwellings.

The rest of the paper is organized as follows: Section 2 provides background on temperature-related mortality, reviews evidence about how occupational heat and cold exposure affect health and productivity, and discusses the context of this study. Particularly, we examine the relationship between temperature, mortality, and occupations in a middle-income country in relation to the existing literature. Section 3 describes the data on mortality, weather, and other relevant variables. Section 4 outlines the method and estimating equation used to determine the effect of temperature on mortality. Section 5 presents results on the temperature–mortality response functions by occupation and by age, as well as the total deaths attributed to temperature. Section 6 discusses the 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 (Carleton et al., 2022; Zhao et al., 2021). 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 (Aguilar-Gomez et al., 2025; Gould et al., 2024; Karlsson and Ziebarth, 2018; Sarmiento et al., 2025; White, 2017). In Mexico, previous research demonstrates that temperature significantly affects mortality. Cold conditions are especially deadly overall (Cohen and Dechezleprêtre, 2022), and hot and humid conditions are especially dangerous for younger individuals (Wilson et al., 2024; Burke et al., 2025).

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 (Leigh-Hunt et al., 2017; Soriano-Hernandez et al., 2022; Vassilieff et al., 1995; Zanobetti et al., 2013). Infants also face risks because of their underdeveloped thermoregulatory systems and limited personal control over adaptive margins (Falk and Dotan, 2008; Graff Zivin and Shrader, 2016). While young adults have a lower physiological 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 on how age and occupation interact and determine individuals' vulnerability 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 projections indicate an overall increase (Bressler et al., 2021; Carleton et al., 2022). The exact change depends on how society adapts to higher temperatures and how other factors interact 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.

Previous research provides reasons to suspect that occupational temperature exposure increases mortality. Heat exposure at work leads to shorter work hours (Graff Zivin and Neidell, 2014), decreased labor income (Behrer et al., 2021), reduced productivity (Foster et al., 2021; LoPalo, 2023; Somanathan et al., 2021), and a higher rate of occupational injuries (Bonauto et al., 2007; Dillender, 2021; Ireland et al., 2023; Park et al., 2021). These findings show that temperature affects workers on the job, suggesting that occupational temperature exposure could contribute to temperature-related mortality.

However, despite its importance, only a few studies examine the heterogeneity in the impact of temperature across labor groups. These studies predominantly cover high-income countries or specific sub-regions because bureaucratic burdens and limited public resources often hinder data collection and the measurement of mortality outcomes in low- and middle-income economies (Landrigan et al., 2018). For example, Gubernot et al. (2015) used the U.S. Census of Fatal Occupational Injuries database to show that workers in agriculture and construction face higher heat-related mortality risks compared to those in other sectors. However, their methodology likely undercounts heat-related deaths significantly, as heat-related causes are often misclassified in mortality records (Burke et al., 2025). Across 229 municipalities in South Korea, Park et al. (2019) finds that the elderly, outdoor workers, one-person households, and patients with chronic diseases are more sensitive to higher temperatures than other groups. In a small area within the Pune District of India, which includes around 135,000 people, Ingole et al. (2017) found that mortality risk from exposure to heat above 31°C was highest among manufacturing workers, followed by farmers, but these groups faced less mortality risk from winter temperatures compared to other occupations. In the city of Guangzhou, China, Yang et al. (2012) find that technical/manual workers face higher mortality risk within five days following both extreme heat and cold exposure compared to professional/managerial workers.

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 people in Mexico work outdoors or in hot/cold indoor environments, such as uncooled/unheated factories and offices. This includes approximately 15% of workers in agriculture and many others in outdoor urban jobs (Climate Resilience, 2024). During periods of extreme heat and cold, these workers face direct thermal stress. Crucially, most outdoor laborers belong to the informal sector and often lack formal employer oversight or social protection. This high level of informality parallels that of other large low- and middle-income economies, such as 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 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).

These extremes are rare globally, positioning Mexico as a crucial example of potential future heat-stressed climates. The country also faces frequent heat waves. In 2023, for instance, 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). At the same time, Mexico is not immune to extreme cold. Periodic incursions of Arctic or polar air masses have resulted in cold snaps in the southern United States and northern Mexico (e.g., the Texas freeze in February 2021). While research is ongoing, these cold spells may be increasing in frequency and intensity due to climate change (see Cohen et al., 2014, 2024). In short, Mexico offers a preview of the climate challenges many countries will confront, serving as a "natural laboratory" for studying the impact of heat and cold on worker health.

Policy environment and data availability: Mexico's situation allows researchers to assess outcomes within a comprehensive policy framework. The country has implemented heat and cold 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 boasts one of the best public databases on mortality, with each death is documented in a harmonized national database, granting researchers access to over 30 years of mortality data.

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 its 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 that protect workers during 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, the latest year for which data is available.

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 occupations include 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 sociodemographic characteristics 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 and apply 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, which reduces model efficiency but does not affect the consistency of our estimates (Cohen and Dechezleprêtre, 2022). This allows us to estimate annual population values for each municipality, occupation, and age group.[1]

[1] Across both mortality and population data, we account for 67 municipal boundary changes occurring between 1990 and 2024 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.

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 from 2005 to 2024 on the main occupations of respondents and match them to the five categories outlined above. The labor groups are consistent across death certificates and ENOE. We have access to various individual, household, and occupational characteristics, such as literacy, income support received, the workforce participation of household members, employment formality,[2] whether the respondent has a work contract, whether the respondent has a fixed work schedule, work shifts and location,[3] and the start date of their current job. We calculate an occupational flexibility index based on formality, contract status, and work schedules.[4]

Weather data: Weather data comes from the European Centre for Medium-range Weather Forecasting's ERA5-Land dataset (Muñoz-Sabater et al., 2021). The dataset includes hourly estimates of air temperature and precipitation at a 0.1 by 0.1-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 2023. We aggregated the hourly gridded data into population-weighted averages for each municipality using population rasters from the Global Human Settlement Layer (Schiavina et al., 2023). Figure A1 shows the distributions of temperature, weighted by person-days in each occupation category. Temperatures in Mexico center around 20°C, with a 5th percentile of 11°C and a 95th percentile of 27°C. Workers in the primary sector experience warmer temperatures than other sectors on average, but all occupations are well represented across the temperature distribution.

Humid heat poses significant risks for human health because people rely on sweating for thermoregulation, and humid air decreases sweating efficiency. Despite this mechanism, existing studies comparing the effects of humid and dry heat on mortality do not reveal a clear difference in outcomes (Baldwin et al., 2023). In Mexico, humid heat, as measured by

[2]ENOE includes a formality classification based on numerous workplace characteristics and benefits such as social security.

[3]We classify workers as outdoor workers if they report their workplace to be in the field, ambulatory, an informal shop, a vehicle, a semi-fixed place, or if their job takes place visiting clients or at a construction site. Additionally, we also classify workers as outside workers in the detailed occupational category of farm workers who do *not* work in their own home or the home of their boss.

[4]We calculate this 0–1 measure as the average of the share of workers who are informal, have no contract, and have no set hours at work. A higher score in this measure corresponds to more occupational flexibility. We normalize by dividing each job group by the flexibility index of the primary sector.

wet-bulb temperature, leads to approximately 10% more heat-related deaths than dry-bulb temperature (temperature measured without accounting for humidity), and the overall difference across the temperature distribution remains 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:

$$D_{aimy} = g_a(\mathbf{T}_{imy}) + q_a(\mathbf{R}_{imy}) + \delta_{aiy} + \theta_{aim} + \varepsilon_{aimy} \tag{1}$$

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 aged 15 to 74.

The main right-hand-side variables of interest are distributed lags of daily average temperatures, indicated by $\mathbf{T}$. 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 cumulative effect that grows over the course of a few weeks) (Deschenes and Moretti, 2009; White, 2017). We aggregate daily average temperatures over the month, my, allowing temperature exposure at any time during a month to affect mortality with an average effective lag period of half a typical month, which accounts for temporal displacement of mortality within the aggregation period.

Previous research shows that mortality rises on both hot and cold days, globally and in Mexico (Carleton et al., 2022; Cohen and Dechezleprêtre, 2022; Gasparrini et al., 2015;

Wilson et al., 2024; Burke et al., 2025). To correctly resolve the nonlinear effect of weather, we aggregate vectors representing nonlinear functions of weather metrics using 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 consist of control variables. We include daily total precipitation for the month of interest, $\mathbf{R}_{imy}$, in a manner similar to temperature, but we use a quadratic specification. We also include fixed effects to address both cross-sectional and time-series confounders: δ_{aiy} at the municipality-year level, which accounts for 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 accounts 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. This method accounts 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 potential confounders in the next section.

Finally, we apply regression weights based on monthly municipality-level populations of group a, which we linearly interpolate from population counts in the 1990, 2000, 2010, and 2020 Mexican Censuses. For the years 2020 through 2023, we assume the population remains constant. These weights improve spatial representativeness and address heteroskedasticity. We fit the models 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 receive coverage from 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, and 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 use the CEM weights to aggregate the data into the weighted number of deaths per municipality across occupations for workers who closely resemble primary sector workers.

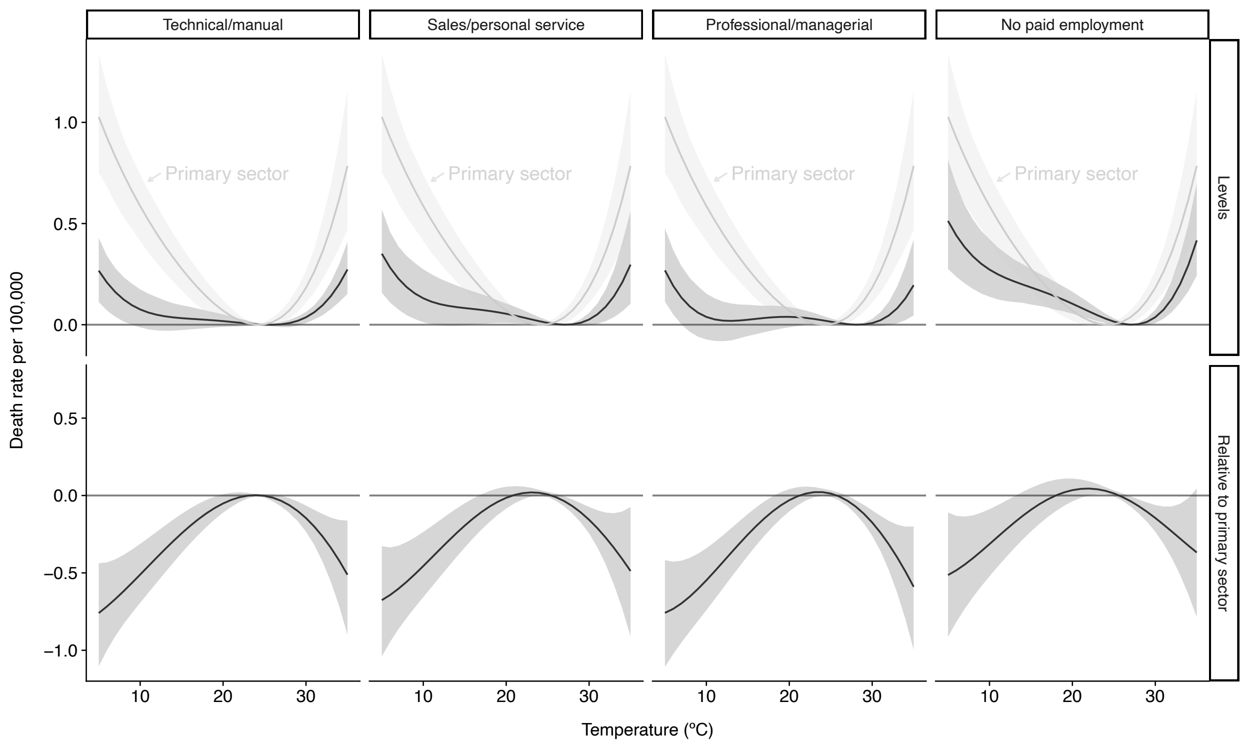
Selection on unobservables might still operate after matching. For example, workers who find it easier to work in relatively hot or cold conditions might select into occupations that are more exposed to those temperatures, and that worker type might not correlate with the observables in our CEM. This form of selection would mean that our estimates understate the true effect of temperature on mortality within occupations. For overestimates, the selection scenario would need to be less plausible: namely, workers who are relatively unsuited for a climate-exposed job would need to be more likely to take such a job. We further discuss the implications of worker selection into occupation in Section 5.3.

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. Both hot and cold temperatures increase mortality rates for all occupational groups. These findings align with previous studies that document a clear link between non-optimal temperatures and mortality.

Figure 1: Mortality-temperature exposure response by occupation



Notes: The top panels show estimates from fitting versions of Equation (1) separately for each of the given occupation groups using the baseline sample (darker color), with the estimate for primary sector workers shown for comparison (lighter color). 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 panels show the results of hypothesis tests of the difference in temperature–mortality response between primary sector workers and workers in other sectors.

Our results indicate that individuals in the primary sector are the most vulnerable to temperature. At all temperatures, 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 comprises individuals who were not engaged in paid work at the time of their death. Professional and managerial workers are the least vulnerable to temperature, although similar in magnitude to 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 mortality response to temperature. 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 that for workers 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 poses a unique and common risk for these workers compared to other groups. At the same time, the left tail of the temperature–mortality curve shows that cold temperatures also substantially increase mortality among primary sector workers. This pattern is consistent with multicountry evidence showing that cold exposure continues to account for the majority of temperature-related deaths even in warmer climates (Gasparrini et al., 2015; Burke et al., 2025). In the Mexican context, this implies that occupational exposure also magnifies cold risks, which is relevant especially as the population ages and retirement ages rise (Chen et al., 2024).

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 temperature-related mortality. Age is one of 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. We discuss and address other factors that may correlate with both occupation and temperature-related mortality in Section 5.3.

First, we run a version of our analysis using Poisson quasi-maximum likelihood. Figure A3 shows that our main results are robust under this specification. Next, we report an alternative specification that utilizes daily maximum temperatures in Figure A4. The results, consistent with Figure 1 reveal that primary sector workers experience the highest relative death rate across the range of daily maximum temperatures, except for the most extreme cold temperatures.

Physiologically, both heat and humidity affect the human body's ability to thermoregulate. Humans primarily cool themselves through sweating. High humidity reduces the effectiveness of sweating, which hinders thermoregulation in hot temperatures. The results presented above show the effect of temperature on mortality without considering humidity. Figure A5 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 finding aligns with previous literature indicating that the overall temperature-mortality relationship in Mexico remains consistent whether researchers consider wet-bulb temperature or use temperature measures that exclude humidity (Wilson et al., 2024). Further details on wet-bulb temperature and additional results can be found in Appendix Section E.

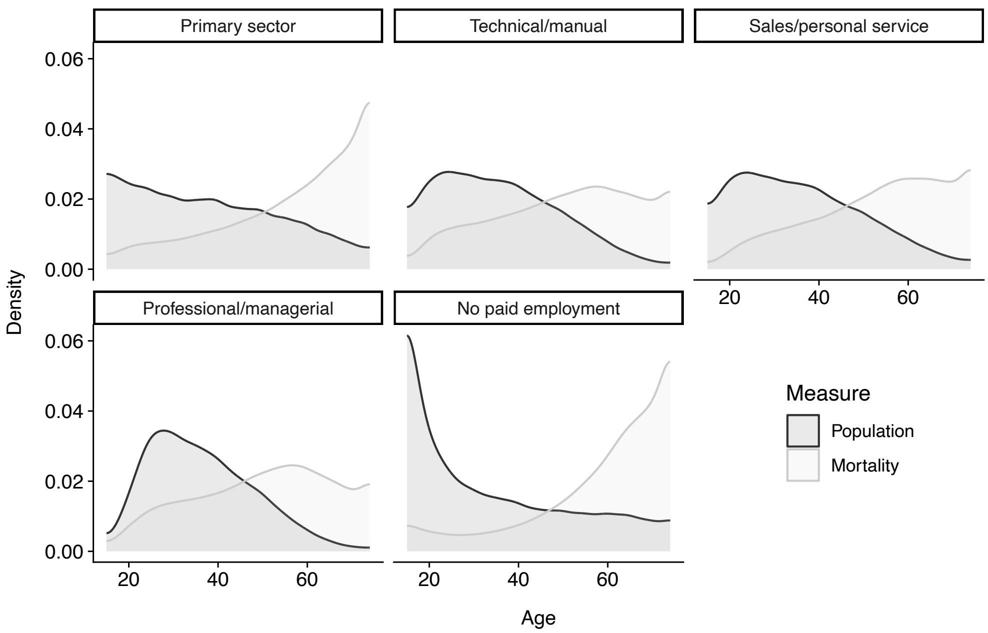
We also test whether pollution confounds our results. Figure A14 adds flexible controls for nine pollutants and shows that occupation-specific temperature-mortality responses remain unchanged.

Appendix 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, which requires that we develop a crosswalk to broader categories that remain consistent throughout the sample period. To assess sensitivity to this crosswalk, we instead map workers to three very broad classifications (manual workers, non-manual workers, and non-workers) that are less likely to be subject to arbitrary misclassification. Consistent with other results, we find that manual workers exhibit a much higher sensitivity to heat and cold.

5.2 Interaction of age and occupation

People's likelihood of working in different occupational groups changes throughout their lives, and mortality closely links 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. Compared to other occupations, primary sector workers are more evenly distributed across all age ranges. The density is highest among young workers, but there is still a sizable representation among middle-aged and older workers. In contrast, workers in other sectors exhibit distinct peaks in their age distribution, particularly in their 20s and 30s—reflecting Mexico's age distribution as a whole—before representation declines with age. A large share of very young or older individuals are not engaged in paid employment. 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, possibly reflecting their population share or their greater mortality risk.

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

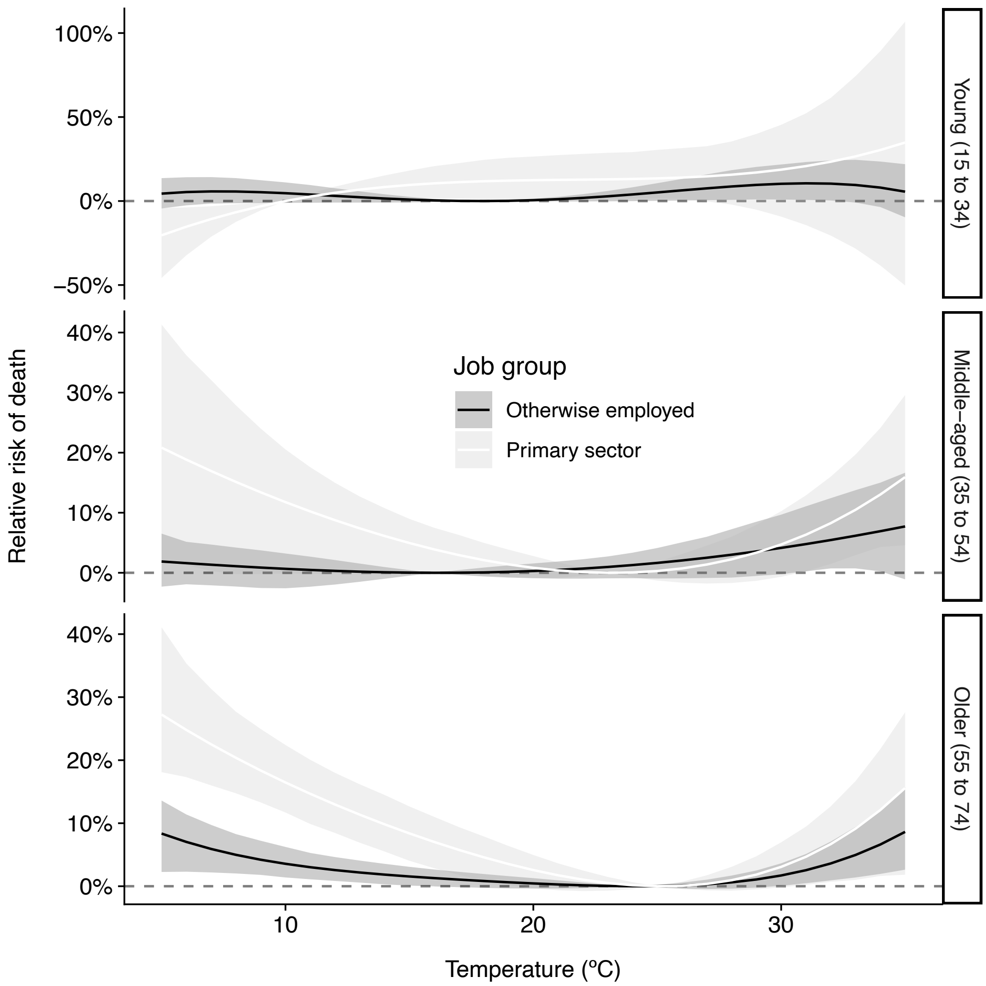


Notes: Each subpanel shows, for the given occupation class, the age distribution of the population and of all recorded deaths in Mexico.

Age is an important determinant of how sensitive one's health is to temperature. Figures A6 and A7 show the effects of dry and wet-bulb temperatures on mortality, stratified by 10-year age groups. The results reveal that different age groups exhibit 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, experience increased mortality at moderately hot and hot temperatures but are less vulnerable to cold. These findings align with those reported in Wilson et al. (2024).

Overall, these figures and results suggest that occupational outcomes displayed in Figure 1

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 indicated occupation groups. The top panel shows estimates for individuals between 15 and 34 years old, the middle panel shows estimates for individuals 35 to 54 years old, and the bottom panel shows estimates for individuals between 55 and 74. The dependent variable is relative risk of death (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 lighter gray line and shared area is the estimate for primary sector workers and the darker gray line and shaded area is for all other individuals.

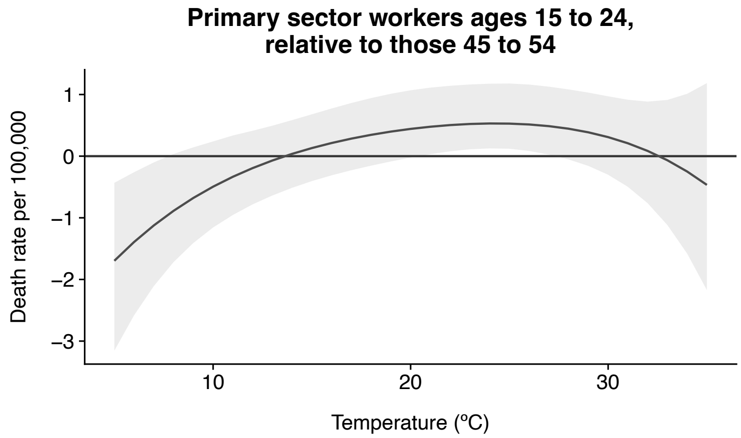
may stem, at least in part, from differences in the age distribution across occupations. To test this, Figure 3 analyzes whether the primary/non-primary sector difference remains within age groups by showing the relative risk of mortality as a function of temperature using the unconditional mortality rate within each age and occupation cell as the denominator for calculating the relative risk.[5] The figure shows that within each age group, primary sector workers show greater temperature-mortality sensitivity than workers in other sectors, except for young workers at cold temperatures. In other words, the occupational results depicted in Figure 1 remain qualitatively consistent across each age group. Younger individuals between 15 and 34 demonstrate much greater vulnerability to warm temperatures when they are primary sector workers. Older individuals also exhibit greater vulnerability to warm temperatures when working in the primary sector, although the difference is not as stark.

The elevated mortality rate for younger primary sector workers shown in Figure 3 masks the extent to which this group is disproportionately affected compared to older groups. The temperature range at which the youngest age group exhibits a significantly elevated mortality rate constitutes a substantial fraction of the total temperature distribution in Mexico (recall that the 5^{th} percentile of temperature is around 11°C; see Figure A1). Thus, younger primary sector workers face a higher risk of temperature-related mortality precisely on the days that are most common. This situation has implications for the total mortality attributable to temperature, which we will address when estimating total deaths from temperature in Section 5.4.

A test of the significance of the difference in temperature-related mortality rates between 15 to 24-year-old primary sector workers and 45 to 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 across the range of common temperatures in Mexico—roughly all days with an average temperature between 15 and 32°C. At the highest and lowest temperatures, which occur rarely (see Figure A1), the mortality rates for these two groups converge. For very cold temperatures, they are even statistically lower, highlighting the overall danger that very hot and cold temperatures pose regardless of age or occupation group.

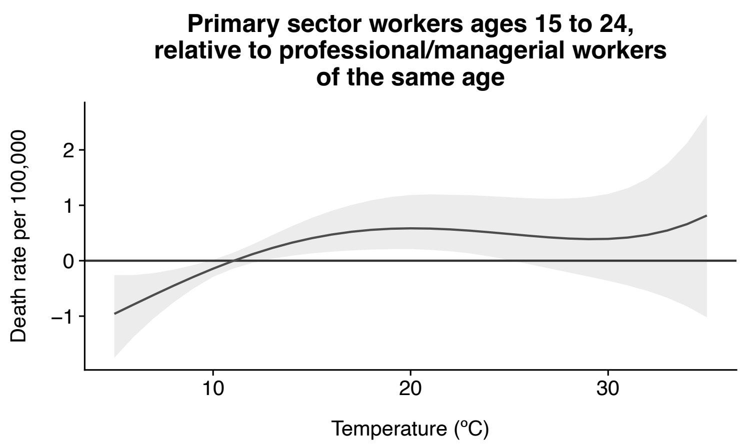
[5] The results with all of the occupational categories, 10-year age groups, and absolute risk are shown in Figure A8.

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.

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.

Figure 5 shows a test similar to that of Figure 4, but instead highlights the difference between primary sector workers and professional/managerial workers in the same 15–24 age group. Positive values in the figure indicate that young primary sector workers are more vulnerable to the given temperature compared to young professional/managerial workers. The figure demonstrates 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 their increased flexibility during the times of year when these temperatures are likely to occur.

5.3 Worker selection

Beyond age, various factors can influence both occupational choice and susceptibility to temperature-related mortality. In this section, we discuss these factors and analyze how workers' characteristics and non-work conditions vary across different occupations.

There are two main, opposing ways in which selection into occupation could affect our results. First, individuals who are more sensitive to heat may select into indoor jobs, while those who tolerate heat better may be more likely to work outdoors. Certain occupations that involve outdoor exposure and manual labor may also require physical fitness assessments. This selection might result in a downward bias in our estimates, as the observed mortality among outdoor workers would understate the true effect of heat if applied to a randomly assigned group. Conversely, individuals with poorer health, potentially due to factors like poverty and limited access to healthcare, may be overrepresented in jobs with greater exposure to environmental risks. In this scenario, our results could reflect an upward bias, since the elevated mortality risk observed among primary sector workers might indicate pre-existing vulnerabilities.

We begin by reviewing existing evidence related to these two hypotheses. Epidemiological studies comparing the health of primary sector workers to that of the general population yield mixed results. Some studies suggest a *"healthy worker effect"* for farmers; however, this finding mainly arises in high-income countries like the U.S. and Sweden and is more pronounced in earlier time periods. Importantly, these papers cannot disentangle the effects from selection into the primary sector from possible work-related lifestyle differences, such as high levels of physical activity.[6] In contrast, research from Australia finds that male farmers and farm managers have a higher incidence of several diseases, including prostate cancer and heart disease (Fragar et al., 2011). They also tend to be less likely to see a

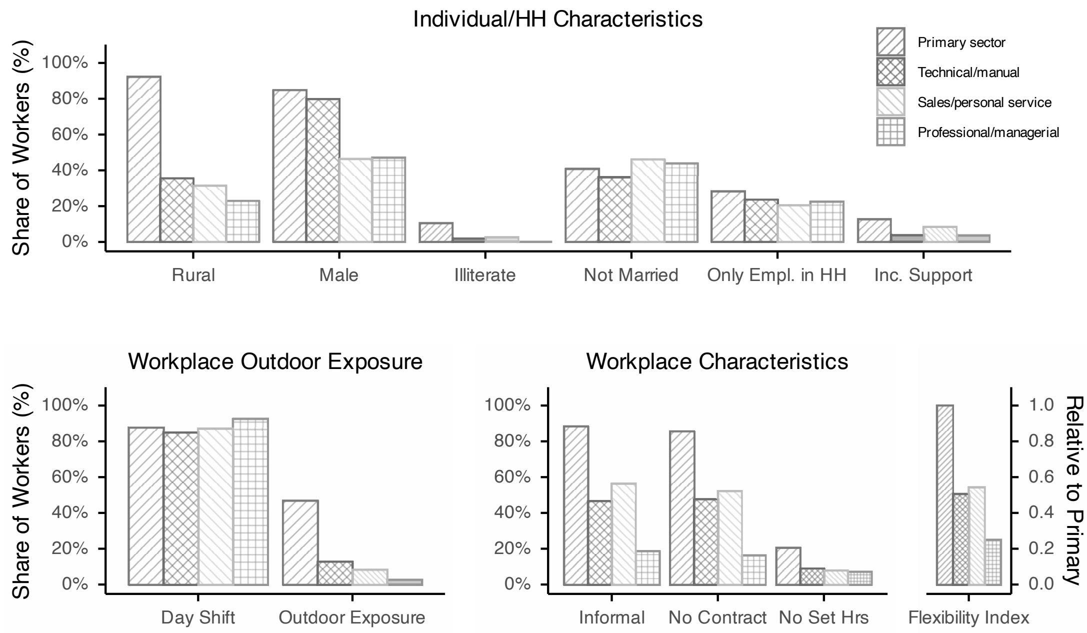
[6] A paper in the U.S. comparing male farmers to non-farmers living in the same rural county found lower all-cause mortality among farmers (Pomrehn et al., 1982), while others found lower total mortality and cancer rates for farmers than the general population (Blair et al., 2005; Waggoner et al., 2010). Farmers were less likely to smoke or consume alcohol and more likely to exercise (Pomrehn et al., 1982). Similarly, a study of Swedish farmers found that hospitalization rates were lower among farmers than among matched rural or urban workers, and mortality was lower compared to urban control workers (Stiernström et al., 2001).

general practitioner, often preferring to manage their health independently (Brew et al., 2016). Literature reviews and meta-analyses have also suggested worse mental health and higher suicide risk for farmers (Daghagh Yazd et al., 2019; Klingelschmidt et al., 2018). All of these patterns may be highly context-specific and influenced by other factors, such as urban–rural differences in access to healthcare and the gender composition of occupational groups. For example, in many countries, including Mexico, populations in rural areas have worse access to healthcare, while physiological differences (e.g., sweating and cardiovascular fitness) between men and women may suggest that women are at higher risk of heat-related illness.[7]

We next analyze the ENOE labor force survey data to examine worker and workplace characteristics. These data allow us to describe the average worker in each occupational group instead of focusing solely on average mortality rates. This analysis helps identify factors, beyond age, that may influence both occupational selection and vulnerability to heat-related mortality. Figure 6 presents key worker and occupational characteristics for the four main job groups.

[7] A systematic review of gender-specific heat tolerance in the armed forces found some evidence that women had a greater risk of heat illness from exertion (Alele et al., 2020).

Figure 6: Worker and occupational characteristics by job group



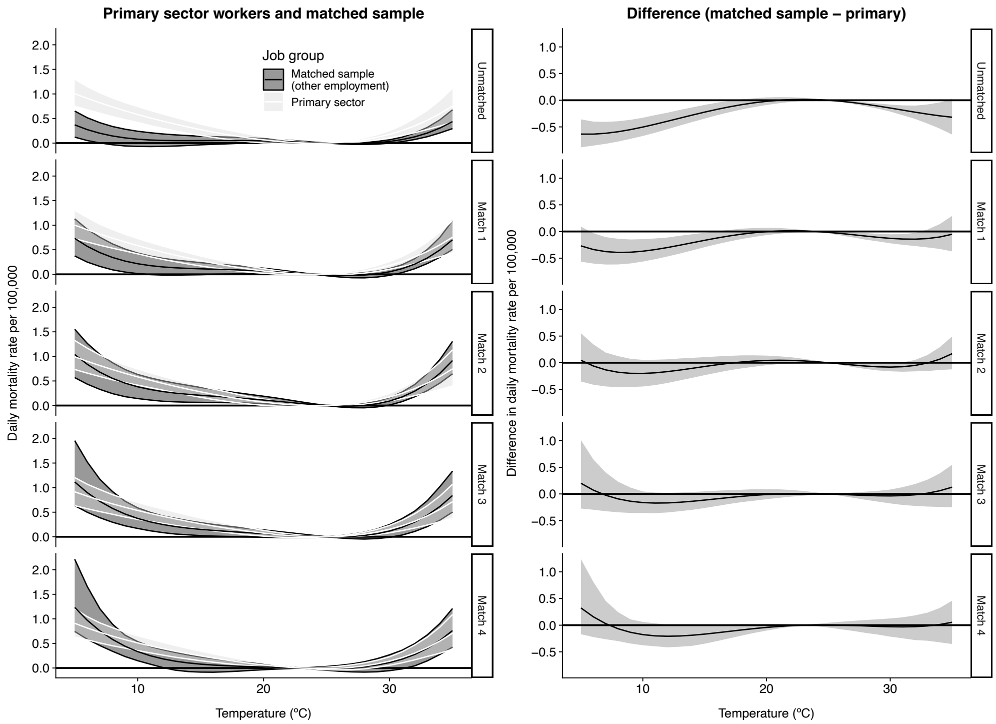
Job Group	Primary sector	Technical/manual	Sales/personal service	Professional/managerial
Median Age	33	34	35	36
Median Job Experience	4	3	3	5
Median Hourly Income (MXN)	27.83	37.78	32.91	66.83

Notes: The figure shows summary statistics on individual and workplace characteristics of the main job groups based on ENOE data (2005–2023). All values show means by job group. Flexibility index is a composite measure of: employment formality, employment contract, set or usual working hours and is normalized such that the primary sector value is equal to 1. Median hourly income is in 2024 Mexican Pesos.

Primary sector workers are significantly more likely to be rural (92.1% of workers compared to 22.9–35.5% in other groups) and male (84.8% versus 46.3–47.1% among professional and sales workers). They are also more likely to be illiterate and to rely heavily on government income support. If illiterate and rural workers have worse access to healthcare, and these factors increase the likelihood of selecting into primary sector work, this could lead to an upward bias in observed mortality effects. Conversely, a male-dominated workforce might suggest that individuals who can tolerate heat tend to choose physically demanding outdoor jobs, potentially skewing our estimates downward. Workplace characteristics also differ markedly among job groups. Primary sector workers are much more likely to work outdoors during daytime hours, increasing their direct exposure to environmental conditions. At the same time, they are more likely to engage in informal employment, lack a formal contract, and have no fixed schedule (Figure 6). Although these factors may indicate greater precarity and could be related to worse baseline health or healthcare access, the associated flexibility might also enable adaptive responses to extreme temperatures, such as adjusting work hours in cooler parts of the day.

We address potential confounding by conducting a coarsened exact matching exercise, detailed further in Appendix Section D. We progressively include more matching variables to control for possible confounders more rigorously by matching on: (1) age group; (2) previous variables plus sex, education, and marital status; (3) previous variables plus municipality-level average income, rural population share (as of 2020), the 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 variables plus municipality-level average household size, the share of people in the municipality speaking an indigenous language, and Köppen climate classification. As shown in Figure 7, the results are mixed. Adjusting for age ("Match 1") partially addresses differences in temperature sensitivity between primary sector workers and those in other sectors. At very cold and moderate temperatures, which are relatively common, effects decrease by up to half. However, very hot temperatures, which are rare but more harmful, the differences nearly vanish. When we match using the complete set of individual-level covariates ("Match 2"), we observe further reductions in differences, although sizable gaps remain for all but the most extreme warm temperatures. Matching on occupation-related municipality-level covariates ("Match 3") shows no differences for heat exposure; however, disparities persist for a broad range of cold temperatures. This pattern continues when we adjust for the full set of municipality-level covariates ("Match 4"), though the rigor of this specification means that about 30% of primary sector workers cannot be matched with similar workers from other sectors. Here, differences between the response functions of matched primary sector workers and their non-primary sector counterparts are not statistically different from zero over a wide range of temperatures. In other words, a meaningful fraction of sensitivity differences to warm temperatures between primary sector workers and those employed in other sectors can be explained by individual characteristics independent of occupation and age, as well as the sociodemographic characteristics of the worker's municipality of residence. However, primary sector workers remain more vulnerable to cold temperatures, indicating a persistent vulnerability that we cannot explain with covariates.

Figure 7: Results from coarsened exact matching exercise



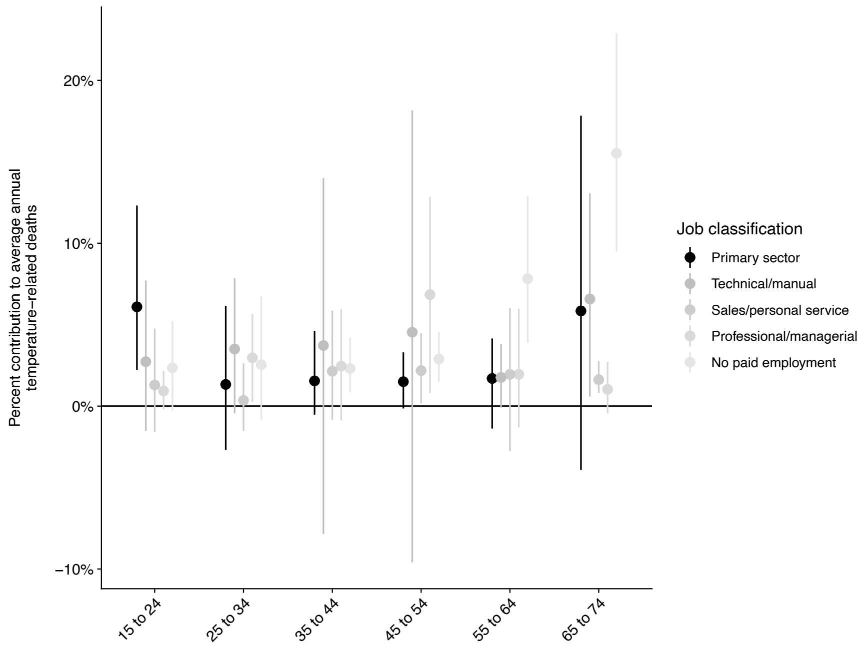
Notes: The figure shows estimates from fitting versions of Equation (1) for primary sector workers and workers employed in other sectors, with panels to the left showing these estimates in levels and panels to the right showing the differences between the estimate for those with other employment (or no employment) in a comparison sample and the primary sector estimate. The top panels show 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. For information on the associated distribution of exposures, see Figure A12.

Importantly, however, the risk of experiencing death due to temperature exposure is a function of both one's response function (the risk associated with a given temperature realization), but also the distribution of one's exposures (how frequently a given temperature is experienced). Within Mexico, different occupation groups have distinct temperature exposure profiles (Figure A1) as well as varying exposure to outdoor conditions when at work (Figure 6). Comparing differences in exposure in our matched and unmatched samples (Figure A12), we see that despite convergence in sensitivity to given temperature realizations, matched workers in our first and second matching specifications experience quite different distributions of temperatures. Some of these differences are addressed when we match on municipality-level covariates in matching specifications three and four, but important differences remain. Convolving the exposure distributions of matched workers with their corresponding response functions, we see that progressively more rigorous matching at first leads to a convergence and then a divergence in the total annual risk of death from temperature for matched primary sector and non-primary sector workers, which we take as suggestive evidence of persistent differences between overall worker risk despite rigorous adjustment for observable characteristics.

5.4 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 exposure, but the overall impact of temperature on mortality also depends on the frequency with which these exposures occur. For instance, if individuals are sensitive to extremely hot or cold temperatures that occur infrequently, they will experience a lower overall mortality burden compared to being sensitive to more moderate and common temperatures. Furthermore, the overall temperature-related mortality burden for any demographic or occupational group will depend on the size of that group.

Figure 8: Annual temperature-related deaths within age and occupation groups

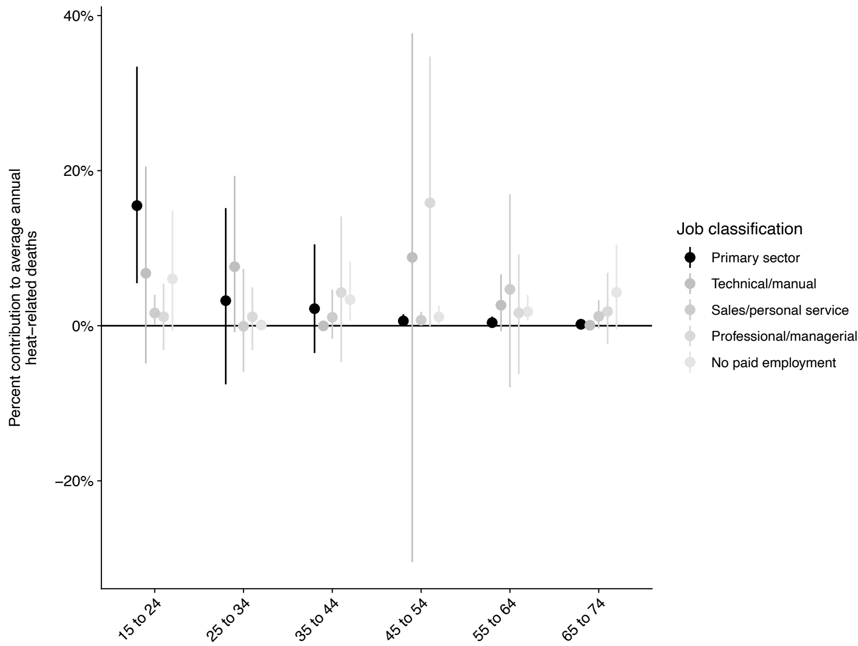


Notes: The estimates were generated by fitting versions of Equation (1) for each age–occupation subgroup (as in Figure A8), calculating implied total annual mortality across Mexico for each sample year, averaging across years, then calculating the share of temperature-related deaths attributable to each age-by-occupation cell. Values across all age-by-occupation cells add to 100%. Line ranges indicate bootstrapped 95% confidence intervals of econometric model uncertainty.

Figure 8 translates the mortality risk results by age and occupation from Section 5.2 into total deaths. This figure illustrates the percentage of annual working-age (age 15–74) temperature-related deaths attributed to each age-by-occupation group across five occupational categories, divided into 10-year age groups. The primary sector appears in black, while the other sectors are depicted in shades of gray.[8]

[8]Figure A16 shows the share of temperature-related deaths within each age group for three broader age groups (15–34, 35–54, and 55–74).

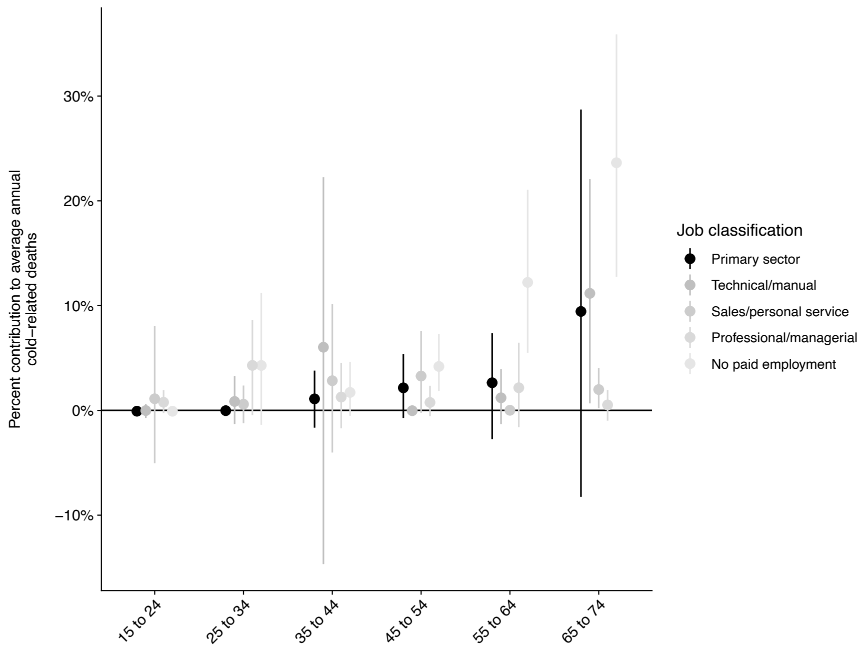
Figure 9: Annual **heat**-related deaths within age and occupation groups



Notes: The estimates were generated by fitting versions of Equation (1) for each age–occupation subgroup (as in Figure A8), 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. Values across all age-by-occupation cells add to 100%. Line ranges indicate bootstrapped 95% confidence intervals of econometric model uncertainty.

Figure 9 further isolates heat-related deaths—i.e., 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 (approximately the 2^{nd} and 98^{th} percentiles of Mexico's daily temperatures). As in Figure 8, the primary sector is shown in black, while the other sectors appear in shades of gray. As in Wilson et al. (2024), we observe that heat-related mortality disproportionately affects younger age groups, but here we find that these deaths are especially concentrated among individuals employed in the primary and technical/manual sectors: 19% of heat-related deaths occur among primary sector workers aged 15–34, yet less than 1% of deaths from all causes occur among this group (see table A5). This partly reflects the fact that older individuals experience minimum mortality risk at much higher temperatures, which is evident in Figure A5. Older individuals are comparatively far less vulnerable to heat compared to their background mortality rate: although 56% of overall deaths occur among 55 to 74-year-olds (see table A5), only 19% of heat-related deaths occur among this age group. This is in stark contrast to cold-related mortality as we discuss in the following paragraph.

Figure 10: Annual **cold**-related deaths within age and occupation groups



Notes: The estimates were generated by fitting versions of Equation (1) for each age–occupation subgroup (as in Figure A8), calculating implied total annual cold-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. Values across all age-by-occupation cells add to 100%. Line ranges indicate bootstrapped 95% confidence intervals of econometric model uncertainty.

Figure 10 shows the share of cold-related deaths by age and occupational categories. In sharp contrast to heat-related deaths, cold-related deaths concentrate more in older age groups and among non-workers. Individuals with no paid employment represent the largest occupational category. Furthermore, nearly half of cold-related deaths occur among the 65–74 age group. In sharp contrast to heat-related mortality, very little cold-related mortality occurs among primary sector workers aged 15–34.

Figure A2 presents the absolute number of working-age cold- and heat-related deaths, disaggregated by age group and job classification. Cold-related mortality concentrates among older individuals, averaging 6,013 annual deaths for those aged 55–64 and 7,594 for those aged 65–74. Correspondingly, individuals without paid employment account for the largest share of cold-related deaths (around two-thirds). In contrast, heat-related mortality is more prevalent among younger individuals: on average, 734 deaths occur annually among those aged 15–24 and 563 among those aged 25–34. Furthermore, heat-related deaths are disproportionately concentrated among primary sector workers. Although they only represent a small share of deaths from all causes, primary sector workers experience the highest heat-related mortality aside from those not in paid employment, averaging an estimated 312 deaths per year throughout our sample period—27% of heat-related deaths, as compared to only 14% of deaths from all causes. Finally, while the total annual number of temperature-related deaths is similar when we estimate age-group and occupation-group heterogeneity, the estimated split of this total across heat and cold differs. We attribute this to the ability of the age-focused approach to better capture differences in the minimum mortality temperature, which is particularly sensitive to age (Wilson et al., 2024).

5.5 Mechanisms

Our results show that the youngest primary sector workers represent a large portion of both overall temperature-related deaths (Figure 8) and heat-related deaths (Figure 9), despite constituting only a small fraction of overall deaths from all causes. This observation raises a natural question: what mechanism could drive the vulnerability of this group? A few candidate mechanisms include: younger individuals engaging in riskier activities; these individuals may have less ability to adapt due to lower income or less on-the-job flexibility; or younger workers might lack experience in protecting themselves from temperature-related health risks. While the elevated mortality of young agricultural workers during hot conditions diverges from the broader literature—which typically identifies older adults and individuals with pre-existing conditions as the groups most at risk from heat exposure (e.g., Gasparrini et al., 2015)—our results for cold-related mortality align more closely with prior evidence showing higher vulnerability among the elderly. For this reason, we focus this discussion on elucidating the mechanisms that may explain the unexpectedly high heat sensitivity of young primary sector workers, where behavioral, occupational, and physiological factors likely interact in distinctive ways.

The pattern of results suggests that factors affecting younger primary sector workers strongly concentrate in that age group. This concentration makes preference-based explanations less plausible. Experience can serve as an important explanation if workers quickly acquire the relevant experience on the job. Using data from ENOE, we calculate the years workers have spent in their current job (Table A4). Naturally, older primary sector workers have more experience. However, the average experience of primary sector workers aged 25–34 is just 2.7 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, workers must gain it very rapidly during these years.

We also use ENOE data to examine additional individual, household, and workplace characteristics that may contribute to the heightened vulnerability of young primary sector workers. We repeat the calculations shown in Figure 6, disaggregating them by age group within each job category. Table A3 shows that young primary sector workers are particularly likely to live in rural areas, even compared to primary sector workers overall, and they are also the most likely to work outdoors. However, primary sector workers aged 25–34 are nearly as rural, and they are only 3.9 percentage points less likely to work outside. Limited healthcare access among rural workers and greater direct exposure to extreme temperatures from outdoor work may contribute to the heightened vulnerability of young primary sector workers, but they are unlikely to be the only mechanisms.

To investigate workplace flexibility, we use ENOE data to estimate flexibility along three dimensions: labor formality, the presence of a contract, and the variability of worker schedules. Among primary sector workers over 24 years old, older workers are more likely to enjoy greater occupational flexibility across several dimensions (Table A4). Older primary sector workers are more likely to not have a contract, hold informal jobs, and not have set hours at work. Overall, our occupational flexibility index—the composite of these flexibility measures—remains fairly similar for age groups ranging 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. However, their high degree of informality may expose them to climate shocks due to a lack of worker protections.

Municipality characteristics may lend some insight into what mediates differences in the overall temperature–mortality sensitivity of working people. Following this insight, we separately estimate the temperature–mortality relationship by occupation group for municipalities with above- and below-median rurality, labor market formality, and income. As shown in Figure A9, we observe that workers in nearly all occupation classes are more sensitive to heat in municipalities that are more rural, lower-income, and that have less formal labor markets, while for a number of occupation groups the opposite is true for cold sensitivity. While suggestive, it is difficult to attach a clear interpretation to differences associated with municipality-level observable characteristics.

We also investigate the degree to which differences in sensitivity may be associated with differences in the degree of workplace exposure to ambient environmental conditions or the character of one's role within an occupation. To do this, we perform two comparisons.

First, we compare routine ("low-skill") workers and knowledge ("high-skill") workers within the technical/manual occupation class, which among occupation classes contains workers with the broadest range of specialized training. As shown in Figure A10, routine workers exhibit significantly more sensitivity to environmental conditions than other workers in the technical/manual occupation class. Second, we compare routine ("low-skill") workers that we believe, based on their detailed occupation class, are likely to experience high or low exposure to environmental conditions in their role. As shown in Figure A11, routine workers with high workplace exposure are considerably more sensitive to ambient environmental conditions, with risk minimized at a lower temperature (around 23°C, versus 27°C for low exposure routine workers).

6 Implications for climate change sensitivity and adaptation

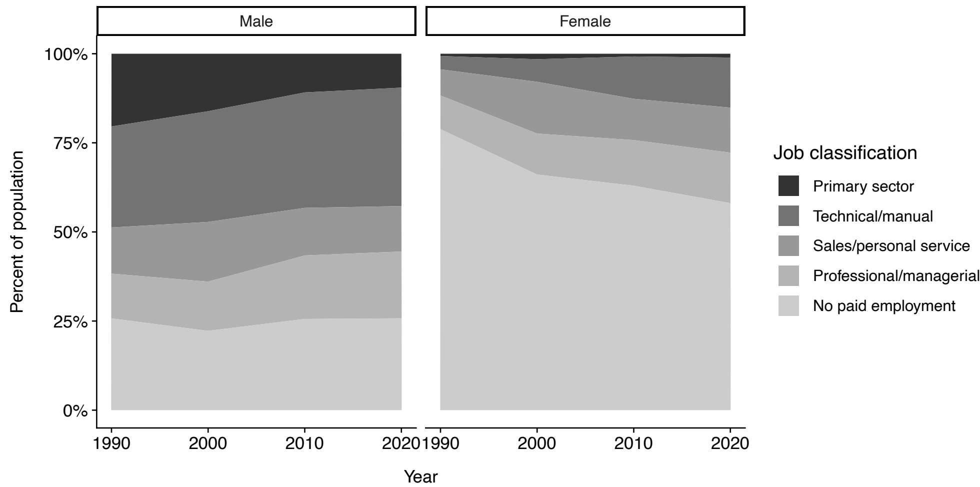
Climate-exposed work represents an important channel for climate health shocks. As the results show, younger workers in climate-exposed sectors face disproportionate risks of heat-related mortality. These findings have multiple implications for projected climate damages.

6.1 Structural change

First, structural change and resulting sectoral reallocation have transitioned billions of workers from the climate-exposed agricultural sector to the service sector over the last century (see Matsuyama (2008) for a review of the structural change literature). As Timmer et al. (2015) demonstrates, the agricultural labor share in Latin America dropped 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 led to 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 11).

Because temperature-related mortality mainly affects young and old workers in the primary sector (largely agricultural), the historical reduction in the shares of agricultural occupations has likely played a significant role in decreasing societal sensitivity to temperature in both Mexico and, if similar patterns persist, in other world regions. 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

Figure 11: 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.

climate change. Adaptation efforts that influence workers' occupational choices could either accelerate or impede this process.

But climate change itself might instead reverse this historical trend. 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 household budgets has fallen. However, this same preference-based mechanism could lead to increased employment in the agricultural sector in the future. Climate change severely affects agricultural productivity (Hultgren et al., 2025; Ortiz-Bobea et al., 2021; Lobell et al., 2011; Schlenker and Roberts, 2009). 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 (Jayachandran, 2006; Nath, 2025).[9]

Agriculture is not the only climate-exposed sector that could exhibit these dynamics. In the construction sector, productivity highly depends on the weather (Downey et al., 2023) with high rates of occupational injury compared to other occupations (Park et al., 2021). The output from this sector is a necessary good (shelter) that could experience highly inelastic demand if production falls significantly. Furthermore, more detailed sectoral shifts could increase occupational climate exposure. For example, substantial growth in service sector

[9] Liu et al. (2023) find that increasing temperatures hinder sectoral reallocation out of agriculture in India. See Casey et al. (2019) for a similar argument but in the context of trends in fertility.

delivery jobs has occurred, both in Mexico and in many other countries around the world. These jobs are exposed to climate risks, predominantly filled by younger adults, and demand dynamics ultimately concentrate these climate risks on these workers (Papp, 2024).

More broadly, the historical norm of retiring before old age has served as an implicit (or possibly explicit, as in Albanese et al. (2025)) adaptation to the age-related risks of workplace cold and heat exposure. In many countries, however, retirement ages are projected to rise and the workforce is projected to grow older on average. As a result, society may become more vulnerable to temperature extremes, offsetting benefits from climate adaptation investments or a reduction in the frequency and intensity of cold spells (U.S. Environmental Protection Agency, 2023). Proactive adaptation could mitigate this trend, especially policies that focus on outdoor workers including improved workplace safety standards or more flexible work scheduling during extreme weather.

6.2 Adaptation

Adaptation can reduce temperature-related mortality. Workers exposed to heat may be able to effectively adapt by taking frequent breaks, staying hydrated, and recognizing the signs of heat-related illness, while those exposed to cold may be able to effectively adapt through investments in insulation, heating infrastructure, or physical protection like thick covers or jackets. Explicit adaptation policies can complement and reinforce behavioral adaptations Burke et al. (2025), though overall progress has been uneven Burke et al. (2024). As discussed in Section 2, Mexico and other countries have implemented policies to ensure these protections for workers.

Our 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, authorities implemented policies to improve early warning systems and enhance public health outreach. These efforts aim to help vulnerable populations—often identified as elderly, poor, or chronically ill individuals—access cooling shelters or otherwise protect themselves from heat (Jay et al., 2021; Sampson et al., 2013). While early warning systems have steadily improved over recent decades (Bauer et al., 2015), important inequities still exist in forecast accuracy and access in low and middle-income countries compared to high-income countries (Linsenmeier and Shrader, 2023). Temperature forecast improvements have been found to substantially reduce mortality from heat (Shrader et al., 2023), though results from studying the response of the construction industry to rainfall suggest that forecast lead times may need to be very large to protect worker health (Downey et al., 2023). Overall, our results complicate these adaptation efforts and the design of heat action plans. As shown in Figures 1 and 3, we find that primary sector workers—especially younger primary sector workers—start experiencing elevated mortality at temperatures well below those typically associated with heat waves and below the temperatures at which other demographic groups begin experiencing elevated mortality. Therefore, tailored information may be needed alongside temperature action plans that recognize the different vulnerabilities faced by different groups.

Adaptation to cold extremes also warrants attention, especially since cold weather in Mexico disproportionately affects the elderly outside the workforce. Recent evidence from Mexico's northern regions shows that strengthening household adaptive capacity can markedly reduce cold-related mortality. In particular, a large minimum-wage increase in 2019 enabled many low-income households to purchase electric heaters and increase heating use, which significantly improved cold resilience (Sarmiento et al., 2024). At least some of this effect may be explained through improvements to indoor air quality, which were suggested to be the relevant channel for such interventions in New Zealand (Howden-Chapman et al., 2008) and China (Xue, 2017). Some may also be due to income channels because individuals heat their houses more when heating is cheaper and use money saved on heating for other health-protective investments, protecting health (Deryugina et al., 2020; Hahn and Metcalfe, 2021; Doremus et al., 2022; Neidell et al., 2021; Angelini et al., 2019; Künn and Palacios, 2024; Tonn et al., 2023; Fyfe et al., 2020). Other work has emphasized the importance of the provision of healthcare more broadly (Chen et al., 2025). For example, the rollout of subsidized health insurance for low-income households in Colombia reduced the effect of moderate cold on mortality by at least half (Helo Sarmiento, 2023). Likewise, hospital desegregation in the U.S. South during the during the 1960s and 1970s, which improved access to acute care for Black populations, nearly eliminated the effect of cold temperatures on infant mortality, though the more general expansion of community health centers across the U.S. did little to moderate the effect of cold on mortality (Mullins and White, 2020). Finally, as with heat, accurate weather forecasts have been shown to protect health during particularly cold days (Shrader et al., 2023). These insights underscore the need to complement heat interventions with possible cold-weather adaptation strategies—such as fuel assistance for poor households, health services, and home insulation programs—to protect vulnerable groups year-round.

6.3 Comparison to existing estimates

It is difficult to compare the magnitude of our findings with previous literature because few studies have examined heterogeneity in the impact of temperature across labor groups. Nevertheless, in the United States, crop farm workers are estimated to face a 20–35× higher rate of heat-related death on the job compared to an average worker (Dahl and Licker, 2021; El Khayat et al., 2022), lending credence to our finding that young adults in primary sector jobs face a 10× higher risk than their age-group peers. Similarly, Cohen and Dechezleprêtre (2022) find that across the entire population of Mexico, a day at 32°C or above leads to around 0.2 additional deaths per 100,000, comparable to our estimate of 0.3 per 100,000 among primary sector workers. By contrast, Khatana et al. (2022) find extreme heat increases deaths in the U.S. by only 0.07 per 100,000, possibly reflective of greater levels of heat adaptation. In concrete terms, only a few dozen Americans are officially recorded as dying from occupational heat exposure each year, but farm laborers (who often are young, male, and Latino) make up a disproportionate share of those deaths (National Center for Farmworker Health, 2015).

Our results are in part at odds with some existing research about the age dependence of the temperature–mortality relationship. On the one hand, related work emphasizes that elderly populations face the highest mortality risk on very hot days (Carleton et al., 2022)—in the U.S., for example, very hot days are associated with roughly 0.23 additional deaths per 100,000 among seniors (≥65 years old), but only 0.04 per 100,000 among adults under 65 (Khatana et al., 2022). Multiple studies across temperate climates similarly show that senior citizens comprise the majority of heat-related mortality victims due to their frailty and the prevalence of chronic illnesses (e.g., Kenny et al., 2010). On the other hand, our estimates reveal that young outdoor workers can surpass the elderly in heat vulnerability, with 15 to 24-year-old Mexican agricultural workers facing a higher risk of dying on a hot day than a typical Mexican individual over 75 years old. It is unclear whether this distinction is unique to Mexico, where people under 35 accounted for roughly 75% of heat-related deaths, a disproportionate share (Wilson et al., 2024). It also likely highlights the important joint role of occupational exposure and demographic characteristics in shaping sensitivity to weather.

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. 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 or cold weather, the health impacts of climate change will distribute unevenly across the workforce. Identifying at-risk groups is crucial for targeting effective interventions and understanding the broader economic implications of a warming climate. Our findings show that occupation influences temperature-related mortality. Workers in higher exposure jobs face greater risk on cold and hot days than their counterparts in less exposed jobs.

In particular, the primary sector (agriculture and related outdoor work) exhibits the strongest mortality response to heat and cold. For heat, this effect impacts young adults the most. 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× 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. By contrast, cold weather primarily affects 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 are also a high-vulnerability group. Targeted workplace measures—such as mandated rest breaks, shade, and hydration during extreme conditions—are likely to help, though few have been systematically studied or implemented.

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 and cold should alert employers and workers when to reduce physical exertion or adjust work hours during dangerous temperatures. Policymakers must view temperature 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, Mexico will likely experience more frequent and intense heat waves (Cavazos, 2024). Our findings suggest that without additional adaptation, heat-related mortality among working-age adults will increase. At the same time, cold-related mortality may fall as the number of cold days falls, though climate change has also been linked to anomalous winter weather in North America (Cohen et al., 2024). Thus, 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. However, 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. Importantly, 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 temperature, as fewer people work outdoors in fields today than a generation ago, which limits temperature-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 while 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 involves evaluating workplace adaptation strategies. For instance, studies could assess the health benefits of interventions like mandated rest breaks, cooling or heating equipment, or shifting work schedules to temperate hours. Similarly, researchers could explore if employees leave high-risk jobs or if firms invest in protective technology in response to climate risks. 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, such as baseline health or access to care, might partly explain the mortality gap across occupations despite our efforts.

Another caveat is that we measure exposure using 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; we do not capture heat-related illnesses or productivity losses, which likely underestimates the full impact on worker well-being. Additionally, Mexico's context may differ from that of other countries, so we must exercise caution when generalizing these results. Nonetheless, the qualitative insight that young manual workers are especially vulnerable to heat while their older counterparts are more vulnerable to cold is likely relevant to many low- and middle-income settings. Despite these limitations, this study enhances our 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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