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Sam Cosaert, Adrián Nieto, Konstantinos Tatsiramos

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Temperature and the Timing of Work

Abstract

We leverage U.S. county-day temperature variation combined with daily time use data to examine the effect of temperature on the timing of work. We find that warmer (colder) temperatures increase (decrease) working time during the night and decrease (increase) working time in the morning. These effects are pronounced among workers with increased bargaining power, flexible work schedules, greater exposure to ambient temperature while at work, and fewer family-related constraints. Workers compensate for the shifts in the timing of work triggered by temperature fluctuations by adjusting their sleep time, without changing the timing of leisure and home production activities.

JEL-Codes: J220, Q540, I310.

Keywords: weather, time use, work schedule, labor supply, non-market activities, sleep.

Sam Cosaert
University of Antwerp / Belgium
Sam.Cosaert@uantwerpen.be

Adrián Nieto
Luxembourg Institute of Socio-Economic Research (LISER) / Luxembourg
Adrian.NeitoCastro@liser.lu

Konstantinos Tatsiramos
University of Luxembourg & Luxembourg Institute of Socio-Economic Research (LISER) / Luxembourg
konstantinos.tatsiramos@uni.lu

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1 Introduction

In recent decades, temperatures have increased, and extreme weather events have become more frequent (IPCC, 2023). Severe weather conditions, such as extreme heat or cold, can increase the disutility individuals experience during their working hours and have important implications for labor supply. A growing literature has studied the impact of temperature on the total time allocated to work (Graff Zivin and Neidell, 2014; Krüger and Neugart, 2018; Neidell et al., 2021; Somanathan et al., 2021) providing mixed evidence.[1] Temperature, however, may not only influence *how much* people work, but also when they work, that is, the *timing* of work *within the day*. To minimize physical discomfort, workers may re-allocate work to periods of the day when temperature conditions are less extreme.

Intra-day re-allocations of labor supply could moderate adjustments in the total labor supply, but also have important implications for economic production and earnings. For example, productivity often requires team collaboration (Hamilton et al., 2003) and synchronization between workers (Weiss, 1996). This is reflected in the typical 'bunching' of work hours in society, where work schedules tend to promote early work (Bonke, 2012). Moreover, specific sectors rely on shift work, where there is a compensation for individuals in the form of wage premiums (Kostiuk, 1990). Besides economic implications, changes in the timing of market work can trigger changes in the schedule of non-market activities, which could have significant implications for well-being. For example, individuals have intrinsic preferences regarding the times they prefer to work or not to work during the day (Mas and Pallais, 2017), have children who require supervision during fixed time periods (e.g., outside of school hours) and seek synchronized leisure time with their families (Cosaert et al., 2023). Additionally, the timing of work influences sleep schedules, potentially leading to significant health implications.

Despite the significance of the timing of work, our understanding of whether and how workers adjust their work schedules in response to changing temperature conditions is still

[1] We provide a detailed description of the findings of these studies later in this Section.

rather limited. Furthermore, the factors influencing these adjustments and the corresponding rescheduling of non-market activities remain unexplored. In this paper, we study labor timing choices across the temperature distribution. We circumvent the difficulty of measuring individuals' timing of work by combining daily time use data from the American Time Use Survey with information on weather conditions. Our sample comprises over 45,000 individual-time diary observations providing detailed information about the type of activities individuals engage in, along with the specific times of the day these activities occur. Our precise county-day data on temperature and weather conditions in the United States comes from the National Oceanic and Atmospheric Administration (NOAA).

We estimate a model which accounts for potential non-linearities in the relationship between temperature and the timing of work by including a set of dummies covering the full temperature distribution. The model controls for individual characteristics, other weather factors, and time-invariant unobservables at the county level. Moreover, we control for year-month, day-of-the-week, and holiday-day fixed effects. These controls account for time trends in work organization common across individuals over the period of analysis as well as potential differences in time allocation throughout the week.

We provide three sets of novel empirical findings. First, we show that while temperature conditions do not appear to change overall working hours, they substantially alter the timing of work. In particular, we find that lower temperatures lead to an increase in the time spent working in the morning, which is fully offset by a decrease in the time spent working during the night. Conversely, when temperatures are high, individuals reduce the time they work in the morning and early afternoon and increase their work during the night. These findings demonstrate that exposure to varying temperature conditions leads to an intra-day labor supply reallocation, causing individuals to work more during the parts of the day with favorable temperature conditions and less during times with adverse conditions.

Second, we shed light on the factors driving the effect of temperature on the timing of work. To achieve this, we categorize workers into different groups based on their bargaining power, workplace flexibility, family responsibilities, and risk to the ambient temperature exposure at work. We then examine how the effects of temperature vary across these subgroups. Our analysis shows that during periods of economic expansions, when workers have more outside job opportunities and higher bargaining power, individuals are more likely to adjust their work schedule in response to varying temperature conditions. Furthermore, our estimates are higher in magnitude for workers who work remotely on the observed day and thus have greater schedule flexibility. We also find that individuals working in industries with a higher risk of ambient temperature exposure, which makes them more vulnerable to weather, are more responsive to changes in temperature conditions. Lastly, we show that the presence of family constraints–such as having children at home–limit workers' ability to adapt their work schedule to different temperature conditions.

Our final set of evidence focuses on the adjustments in the allocation of non-work time along with the effects of temperature on the timing of work. We categorize non-work time into sleeping, leisure, and home production. Our findings reveal that low temperatures lead to a reduction of sleep time in the morning, while high temperatures result in reduced sleep time during the night. However, we do not find an effect of temperature on the time individuals allocate to leisure activities or home production throughout the different parts of the day. Therefore, the shifts in the timing of work due to changing temperature conditions are mainly compensated by adjustments in the timing of sleep.

Our study is related to two areas of research. The first concerns the implications of global warming for economic outcomes. Graff Zivin and Neidell (2014) find that exposure to different temperature conditions does not change overall hours of work, except for extremely high temperatures, which reduce labor supply. Neidell et al. (2021) show that the impact of temperature on hours of work is context specific, with very high temperatures reducing labor supply only during economic expansions. Somanathan et al. (2021) show that an increase in the number of hot days in India leads to higher absenteeism among workers. Krüger and Neugart (2018) find that women work less only when temperatures are low, while men's labor supply remains largely unaffected by changing temperature conditions. Beyond labor supply implications, there is evidence that extreme temperatures lead to lower productivity, economic growth, and output (Burke et al., 2015; Carleton and Hsiang, 2016; Chen and Yang, 2019; Dell et al., 2012; Dingel et al., 2019; Hsiang, 2010; Jain et al., 2020; LoPalo, 2023; Miller et al., 2021; Somanathan et al., 2021; Zhang et al., 2018). Moreover, extreme temperature conditions have been shown to have negative effects on wages and income per capita (Deryugina and Hsiang, 2014; Isen et al., 2017; Neidell et al., 2021), but a modest effect on agricultural profits (Deschênes and Greenstone, 2007).[2]

The second related area of research concerns the importance of the timing of market and non-market activities. We provide a brief overview of the literature on the timing of work at the start of Section 2, where we also provide a conceptual framework on how temperature can change intra-day labor supply reallocation decisions. Turning to non-work activities, prior studies have examined the importance that individuals place into the timing of non-market activities such as sleep. For example, Biddle and Hamermesh (1990) incorporate sleep into a consumption and time allocation model, challenging the assumption that sleep is a fixed parameter. Instead, they argue that sleep is an important choice variable that responds to different incentives, including wages. Using data from the American Time Use Survey, Ásgeirsdóttir and Ólafsson (2015) show that the demand for sleep is a decreasing function of wages. Lastly, Gibson and Shrader (2018) use the fact that individuals go to sleep earlier in winter as the identifying assumption in their analysis of the returns to sleep.

We contribute to both areas of the literature by providing insights and novel empirical evidence on the impact of temperature on the timing of work and its implications for the

[2]Prior literature has also shown that temperature has important effects on leisure and well-being. Fan et al. (2023) find that individuals reduce outdoors leisure time when temperatures are high. Other evidence shows that extreme temperatures adversely affect individuals' health (Burke et al., 2018; Deschênes, 2014; Graff Zivin and Shrader, 2016; Guirguis et al., 2018; Mullins and White, 2019; Noelke et al., 2016; White, 2017), cognitive ability (Graff Zivin et al., 2018, 2020), emotional state (Baylis, 2020; Baylis et al., 2018; Belloc et al., 2023), and increase mortality risk (Barreca et al., 2015, 2016; Barreca, 2012; Burgess et al., 2014, 2017; Deschênes and Greenstone, 2011; Deschênes and Moretti, 2009; Heutel et al., 2021). Temperature also has important effects on birth weight (Deschênes et al., 2009), fertility (Barreca et al., 2018; Barreca and Schaller, 2020; Eissler et al., 2019), commuting travel choices (Belloc et al., 2022), crime (Jacob et al., 2007), and migration (Deschênes and Moretti, 2009).

timing of non-market activities such as sleep. Our evidence can serve to understand how temperature impacts economic production, health, and well-being.

The rest of the article is organized as follows. In Section 2, we offer a theoretical motivation for our study. Section 3 describes the data and outlines our empirical strategy. Section 4 presents the main results on the impact of temperature on the timing of market work. Section 5 identifies the group of workers whose work schedules are more responsive to temperature. Section 6 explores the adjustments in the allocation of non-work time that compensate the changes in the timing of work to changing temperature conditions. Lastly, Section 7 provides our concluding remarks.

2 A Conceptual Framework

We present a conceptual framework in which temperature can affect the timing of work. We specify a decision-making model that explains work hours and timing choices, with exogenous variation in temperature. The aim of this section is to compare labor supply models with timing choices and to elaborate on the possible effects of temperature. Temperature effects can operate through two channels: the physical discomfort of work and the preferred timing of non-market activities.

Labor supply models with timing choices are scarce. Hamermesh (1999a) provides a formal discussion of the choice of timing, based on Winston (1982). His model divides the day in 24 discrete time intervals with time-specific utilities from work (and consumption). Daily utility is then the sum of all these time-specific utilities. In later work, Hamermesh (2002) drops the dependency of consumption on time, instead focusing on the time-specific utilities of non-work time of both partners in a couple. An individual's marginal utility of leisure at any given moment depends on whether or not the spouse has leisure at that time.

Even fewer models explicitly incorporate exogenous determinants of timing. Hamermesh (1999b) models the marginal disutility from work at time t as a function of the amount of crime at time t. Because individuals generally fear crime, they prefer to work and leave their home during daytime hours. Finally, Weiss (1996) presents a model in which daily variations in the physical environment affect the marginal disutility of work at any given moment.

We contribute to this literature a labor supply model in continuous time that is empirically tractable. In our model, individuals choose the amount and the timing of their work on a given day with maximum temperature T. The decision variables of the model are s, the start time of work, and h, the total labor supply for that day. Per unit of work, the individual earns an income W but also incurs a disutility. This marginal disutility depends not only on individual-specific costs of effort ϵ_i but also on the specific time-of-the-day t when the individual works. Consistent with the ATUS survey, we let the day start at 4 A.M. in the morning (i.e., at $t = 4$) and we let it end at 4 A.M. the morning after (i.e., at $t = 28$).

$$U_i(s, h; T) = \int_s^{s+h} \left(W - \epsilon_i - \left(\frac{t - \alpha(T)}{16} \right)^2 - \beta(T) \left(1 - \left(\frac{t - 12}{16} \right)^2 \right) \right) dt \qquad (1)$$

Timing matters in our model for two reasons. First, the opportunity cost of time is not necessarily constant within the day. When the individual is working, they cannot look after the children, spend time with others, or sleep. The value of parental childcare is likely higher outside of school hours. The value of leisure is increasing in the number of friends or family that are available to meet up. The value of sleep depends on circadian rhythms. In Section 6, we will explicitly investigate the temporal patterns of all non-work activities. We denote the time of the day with the smallest opportunity cost of work by $\alpha(T)$. It is important to note that $\alpha(T)$ *can* depend on temperature. For instance, people may adjust the timing of their social activities to weather conditions. Furthermore, individuals may prefer to go to sleep earlier on very cold days, but later on very hot days. Figure 1 provides an illustration. On very cold days, staying up to work late has a high opportunity cost in terms of sleep; the optimal timing of work is around $t = 12$. On very hot days, waking up to work early has a high opportunity cost as individuals went to sleep later and are more tired; the optimal timing of work is around $t = 20$. The model penalizes work at a moment different from $\alpha(T)$

(i.e., $t \neq \alpha(T)$) with an additional cost term $\left(\frac{t-\alpha(T)}{16}\right)^2$.

Apart from the opportunity costs, timing matters for a second reason in our set-up. Work at distinct times of the day may be associated with different levels of physical discomfort. On very hot days, work around midday can generate particularly high levels of discomfort. We denote the extent to which temperature reaches high extremes by $\beta(T)$. Here $\beta(T)$ is situated between 0 and 1, with 1 indicating very high temperatures. The model penalizes work at $t = 12$ especially when $\beta(T)$ is large. Work at midday is associated with an additional cost term $\beta(T)$. Notice that the additional cost term $\beta(T)\left(1 - \left(\frac{t-12}{16}\right)^2\right)$ becomes smaller when t is further from 12.

The overall utility function (1) takes the form of a definite integral over all benefits and marginal disutilities from the start time of work s to the end time of work $s+h$. This function is concave in s and h if certain regularity conditions are satisfied.[3] Under these conditions, it is possible to solve the utility maximization problem analytically for s and h. Detailed calculations are in Appendix A. Not surprisingly, the work hours equation is increasing in W and decreasing in ϵ_i. It is independent of $\alpha(T)$ if $\beta(T) = 0$, because then $h^* = 2\sqrt{W - \epsilon_i}$. By contrast, the work timing equation is increasing in $\alpha(T)$ and this regardless of the level of $\beta(T)$. In the special case where $\alpha(T) = 12$ and $\beta(T) = 0$, we obtain that $s^* = 12 - \sqrt{W - \epsilon_i}$. Figure 2 presents a richer set of simulations where $W = 1$, $\epsilon_i = 0.9$, $\alpha(T)$ is increasing quickly between $T = 25$ and $T = 35$, and $\beta(T)$ is increasing in T beyond 25 Celsius degrees. Without physical discomfort, higher temperatures imply that the work starts later but the number of hours remains the same. With physical discomfort, higher temperatures also reduce the amount of work.

One important prediction of the model is that temperature effects via physical discomfort are likely to also change the total amount of work, while temperature effects via non-market activities are likely to only influence timing. We deliberately kept the framework simple to

[3]More specifically, the Hessian matrix of second-order derivatives is negative definite if $\beta(T) \leq 1$, $s \leq \frac{\alpha(T)-12\beta(T)}{1-\beta(T)}$, and $s + h \geq \frac{\alpha(T)-12\beta(T)}{1-\beta(T)}$.

fix ideas and to show the fundamental trade-offs. However, the framework can be easily amended to make it more general. First, we assumed that workers are flexible: they can freely choose the amount and the timing of their work. This is not necessarily the case. To capture limited flexibility, one can impose limits on variables h and s, for instance, $h = 8$ and $s = 9$ for a standard 9–to–5 work schedule. Utility function (1) can then be used to quantify the welfare loss due to the lack of flexibility. An alternative possibility is to implement time-specific wages $W(t)$ instead of W, so that worker flexibility comes at the cost of losing potential wage premia. Second, we assumed homogeneous parameters $\alpha(T)$ and $\beta(T)$. In practice, 'morning-type' individuals may have very different timing preferences than 'evening-type' individuals. To account for this, one can allow for individual heterogeneity in $\alpha_i(T)$. Furthermore, some industries may be more exposed to extreme temperatures and some individuals may be more susceptible to meteorological conditions. Individual- or sector-specific functions $\beta_i(T)$ could address this issue.

3 Data and Methodology

3.1 Data

3.1.1 Weather Data

We use weather data from the National Oceanic and Atmospheric Administration (NOAA). This dataset contains information on weather conditions including maximum, average, and minimum temperature, as well as rainfall and snowfall, among others, for each of the stations (over 9,000) spread across the United States. We construct a panel dataset on weather conditions at the county-day level by averaging the information provided by the stations within each county on a daily basis during the period spanning from 2004 and 2019. We focus on counties as they represent the smallest geographical unit for which we have individual residential information in the American Time Use survey. By using geographical coordinates (latitude-longitude) of each station, we accurately allocate the stations to their respective counties. Without imposing any sample restrictions, we obtain a dataset containing information on weather conditions for more than 14.5 million county-day observations.

3.1.2 American Time Use Survey Dataset

We utilize daily time use data for the United States obtained from the American Time Use survey, which is administered by the Bureau of Labor Statistics and managed by the U.S. Census Bureau. This large cross-sectional dataset is representative of the U.S. population providing detailed information into individual's activities, the exact times of the day at which these activities are performed, as well as the companions and locations associated with each activity on the diary date. With this information, we can construct precise measures of the time individuals allocate to activities such as work, leisure, home production, or sleep throughout different parts of the day. These measures are used as the dependent variables in our analysis. Additionally, the American Time Use survey contains information on the socio-demographic characteristics of the interviewed individuals, such as their gender, age, level of education, ethnicity, household income, as well as information on the socio-demographic characteristics of the members of the household. Furthermore, the dataset contains detailed geographical information on individuals' county of residence. Using this geographical data combined with the information on the date when the diary was completed, we establish a link between the ATUS and weather condition data.

As the focus of our analysis is on exploring the effect of temperature on the timing of work, we restrict our sample to individuals who work on the diary date. Without imposing any other restrictions, our analysis is based on a sample of approximately 45,000 observations. Table 1 presents sample summary statistics for our outcomes of interest and individual characteristics. As shown, our sample comprises roughly an equal number of men and women, with an average age of 43 years, and with the majority of individuals having some college education. Moreover, individuals allocate more than 7 hours to work on the diary date, with most of this time occurring in the morning (between 4:00 A.M. and 12:00 P.M.) and the afternoon (between 12:00 P.M. and 4:00 P.M.), although a significant portion of working time also extends in the evening and the night.[4]

3.2 Empirical Strategy

We study the impact of temperature on the timing of work by exploiting day-county variation in temperature conditions. We estimate the following specification:

$$y_i = \alpha + f(Tmax_{c(i),t(i)}) + \phi X_{i,t(i)} + \gamma Z_{c(i),t(i)} + \delta_{c(i)} + g(t(i)) + \varepsilon_i \tag{2}$$

where y_i is the outcome of interest for individual i. The term $f(Tmax_{c(i),t(i)})$ captures a set of dummies representing temperature intervals with a width of 3 Celsius degrees. Each indicator takes value 1 if the maximum temperature in the county of residence of individual i on the diary date falls within their respective interval, and 0 otherwise. We use the maximum temperature for our explanatory variables of interest because it captures the largest fraction of the day when individuals are active. This set of indicators covers the full temperature distribution, allowing us to explore potential non-linearities in the relationship between temperature and the timing of work. The term $X_{i,t(i)}$ includes a set of socio-demographic individual characteristics such as gender, a second-order polynomial of age, an indicator for being white, and a set of dummies for the level of education (i.e. less than high-school, high-school graduate, and some college education). The term $Z_{c(i),t(i)}$ includes a set of controls for other weather conditions at the county of residence of individuals on the diary date, such as rainfall, snowfall and the minimum temperature. The term $\delta_{c(i)}$ includes a set of indicators accounting for time-invariant characteristics at the county level that could potentially influence the relationship between temperature and the timing of work. The term $g(t(i))$, which is a function of the diary date, includes a set of year-month, day-of-the-week,

[4]In Appendix B, we provide more detailed evidence on how individuals allocate their time within the day. We show the average probability and amount of time spent working, on leisure, sleep and on home production in the different parts of the day.

and holiday day indicators. These indicators control for changes in the timing of work that are common for individuals across different year-months of the period of analysis, across different days of the week, and across holiday relative to non-holiday days. The error term ε_i varies at the individual level. Throughout the analysis, we cluster standard errors at the state-month level.

4 Labor Responses to Temperature Conditions

4.1 Labor Supply

Before studying the impact of temperature on the timing of work, we assess whether temperature impacts labor supply, which is an outcome already studied in the literature. We estimate the specification of equation 3 using the minutes that individuals spent working on the diary date as the outcome variable. Figure 3 shows that the estimates of the impact of temperature on total working time are not statistically significant. Moreover, most estimates are close to zero, except for extremely hot temperatures, where we observe a negative estimate. These findings are in line with the findings provided by prior research (Graff Zivin and Neidell, 2014; Neidell et al., 2021). Overall, the evidence presented in this section suggests that temperature does not significantly alter total working time.

4.2 The Timing of Work

In this section, we explore whether exposure to varying temperature conditions impacts the timing of work. We estimate the specification of equation 2 using as the dependent variables the time that individuals allocate to work within the following intervals of the diary day: 4:00 A.M.–12:00 P.M., 12:00 P.M.–4:00 P.M., 4:00 P.M.–8:00 P.M., and 8:00 P.M.–4:00 A.M., respectively. As shown in panels A and D of Figure 4, we find that warm temperatures lead to reduced working time in the morning, which is offset by increased working time in the night. In contrast, cold temperatures result in more morning working time and less working time in the night. Examining the magnitude of these effects, we find that the impact of temperature on morning and night working time increases as temperatures becomes more extreme.

Moreover, we observe that the adjustments in the timing of work due to temperature are substantial. By comparing the estimates for extreme cold temperatures (below -4 Celsius degrees) and extreme hot temperatures (above 38 Celsius degrees) in terms of time spent working in the morning, we calculate that temperature can reduce this aspect of work time by more than 30 minutes. This decrease represents a 16.2 percent drop from the baseline level. The difference between the estimates for extreme cold and hot temperatures in night working time is of similar magnitude (approximately 25 minutes per day), but with an opposite sign, effectively compensating for the shift in morning working time. Panels B and C, however, indicate that temperature does not significantly alter the time individuals spend working in the afternoon (12:00 P.M.–4:00 P.M.) and evening (4:00 P.M.– 8:00 P.M.) except for a decrease in afternoon working time under extremely high temperatures. In summary, the evidence presented in this section illustrates that warm (cold) temperatures lead to a substantial shift in working time from morning (night) to night (morning).

We also investigate the role of the location of work for the impact of temperature on the timing of work. First, we estimate the specification of equation 2 separately using the time spent working from home and the time working from the workplace as the outcome variable. As shown in Figure C.1 of Appendix C, and similarly to Figure 3, most estimates are close to zero except for extremely hot temperatures where we observe a negative estimate for the time working at the workplace. Figure C.2 displays the estimates for the impact of temperature on working time from home and working time from the workplace in the different parts of the day. We find that exposure to extremely hot temperatures appears to reduce the time individuals spend working at the workplace both during the morning and afternoon hours, while increases the time allocated to remote work and workplace-based work during the night. Conversely, extreme cold temperatures lead to a reduction in the time spent working from home during both morning and night hours, and a decrease in workplace-based work during the night, while increase the duration of time working at the workplace in the morning.[5]

4.3 Robustness Tests

We proceed to assess the robustness of our baseline estimates through a series of sensitivity tests that address several empirical concerns. Firstly, changes in labor regulation, leading to changes in work organization, might influence our baseline estimates. While we already control for county and year-month fixed effects in our baseline analysis, effectively accounting for differences in labor conditions across U.S. counties and variation in labor organization in the country over different year-month periods, we further address this issue by including state-year dummies. We present the estimates in Figure E.1. Secondly, we consider the potential impact of seasonality in the relationship between temperature and the timing of work. Our baseline model already accounted for seasonal patterns in the timing of work by controlling for year-month dummies. We further address this issue by including state-month dummies, allowing seasonal changes in work organization to potentially differ across states. We present the estimates in Figure E.2. Thirdly, we examine the robustness of our baseline results when including our time-varying controls in the form of sets of dummies. While this sensitivity test complicates the functional form of the specification, it offers a more detailed control of individual characteristics. We present the estimates in Figure E.3. Fourthly, we re-estimate the baseline specification using the time spent working in more specific intervals of the day as dependent variables. We show these estimates in Figure E.4. Lastly, we explore the robustness of our baseline results by including our independent variables of interest in the form of dummies that cover a wider range of the temperature distribution. Although this new set of indicators reduces the granularity of the effects of temperature on work timing, it

[5] We have also examined the effect of temperature on social interactions at work by estimating the main specification using the time individuals spend with colleagues during the different parts of the day as the dependent variable. We report these estimates in Appendix D. As shown in Figure D.1, exposure to extremely hot temperatures appear to reduce the time individuals spend with colleagues both in the morning and afternoon hours.

simplifies the functional form of our specification. We present the estimates in Figure E.5. As shown in Figures E.1–E.5, our baseline estimates are robust to all these sensitivity tests.

4.4 Adaptive behavior

We proceed by examining the role of adaptive behavior, which concerns the potential influence of past temperature conditions on the effect of temperature on the timing of work. We first account for the possibility of past temperature conditions leading up to the diary date affecting individual behavior. We extend our baseline specification by including a set of dummies that take a value of 1 if the temperature one, two, and three days before the diary date falls within specific 3-degree Celsius intervals in the individual's county of residence. The results shown in Figures F.1–F.3 in Appendix F are very similar to the ones in our baseline analysis, suggesting that interday substitution has no influence on our baseline findings.

To test for adaptive behavior, we also investigate the effect of high temperatures on the timing of work during two distinct periods: April–June and July–September. This comparison allows us to explore whether the response of individuals' timing of work to high temperatures changes based on their prior exposure to such conditions in the previous months. Figure F.4 shows that warm temperatures lead to reduced afternoon work time only in April–June, but increasing night work time in both April–June and July–September. In Figure F.5, we replicate this analysis for the periods October–December and January–March, focusing on the impact of cold temperatures. Here, we observe that cold temperatures only increase morning work time during January–March. In summary, the estimates of Figures F.4 and F.5 suggest that the impact of warm and cold temperatures on the timing of work is not entirely driven by adaptation to temperature conditions.

Lastly, we test for adaptive behavior by estimating the temperature effect for individuals residing in counties where the average temperature during the period of analysis is above or below the sample average temperature. The rationale is that individuals in warm (cold) counties are more accustomed to warm (cold) temperatures and less to cold (warm) temperatures. Figures F.6–F.7 present these estimates, showing that warm temperatures increase night work time and decrease morning and afternoon work time for both individuals in warm and cold counties. Moreover, cold temperatures appear to increase morning work time and decrease night work time for individuals living in cold counties. While estimates for cold (warm) temperatures are less precise for individuals in warm (cold) counties due to limited number of observations, the results suggest that exposure to certain past temperature conditions does not drive the temperature effect estimates.

5 Factors Influencing the Impact of Temperature on the Timing of Work

In this section, we investigate whether the impact of temperature on the timing of work is influenced by an individual's bargaining power, flexibility, exposure to ambient temperature at work, and family constraints. In theory, workers with greater bargaining power and more flexibility might find it easier to set their preferred work arrangements, allowing them to work during periods of the day when they are less exposed to extreme weather conditions. Moreover, workers highly exposed to ambient temperature at their workplace may be more motivated to work during parts of the day with milder temperatures. Conversely, family constraints could limit individuals' ability to adjust their work schedules according to weather conditions. Although this heterogeneity analysis is informative about the specific worker groups driving the temperature effect, it is important to note that the subsample sizes for this analysis are sometimes small (see Appendix G for summary statistics for each of these subsamples), leading to reduced statistical power of our model and less precise estimates. To simplify the heterogeneity analysis, we estimate the baseline model restricting the number of explanatory variables for the different temperature intervals to five dummies.

5.1 Bargaining Power

We begin by investigating whether the impact of temperature on work timing varies based on workers' bargaining power. We estimate our baseline model using the timing of work outcomes as the dependent variables, and explore potential heterogeneity in our estimates during economic recessions and expansions. During expansion periods, workers tend to have more outside job opportunities, and this improved bargaining power may enable them to negotiate better working conditions with their employers. We present the results of this analysis in Table 2: during economic expansions, estimates are statistically significant and also higher in magnitude. Specifically, we find that during expansions extreme hot temperatures decrease (increase) the morning (night) working time, and extreme cold temperatures reduce night working time. Instead, the estimates during recessions are not statistically significant and of lower magnitude. Overall, our analysis highlights that the effect of temperature on work timing is most pronounced when workers have higher bargaining power allowing them to negotiate better working conditions.

5.2 Flexibility

We also test whether individuals with flexible job arrangements are more likely to adjust their work schedules to avoid periods of the day with extreme temperature conditions. To explore this aspect, we group individuals into those with flexible or rigid work arrangements based on whether or not they spend some time working from home on the diary date. We then re-estimate our baseline model while exploring heterogeneity for these two groups of workers. We present the results in Table 3. The estimates for extreme hot temperatures are negative (positive) for morning (night) working time, regardless of the flexibility of individuals' work arrangements. However, the magnitude and statistical significance of the estimates are considerably greater for individuals with greater flexibility at work. The estimates for extreme cold temperatures are less precise, yet they suggest that individuals with higher flexibility at work tend to reduce their labor supply independent of the time of the day.

Conversely, individuals with lower flexibility spend less time working at night but more time in the morning. Overall, the evidence presented in this section suggests that individuals with lower flexibility in their work arrangements have fewer opportunities to adapt their work schedules and are therefore more vulnerable to the impacts of extreme temperatures.

5.3 Exposure to the Ambient Temperature

We next examine whether the individuals' exposure to ambient temperature in their workplaces influences their adjustment to different temperature conditions. To achieve this, we estimate the baseline specification separately for workers in industries with high and low-risk exposure.[6] There are at least two reasons why the temperature effect on work timing may differ for these two groups of workers. On one hand, those in high-risk exposure industries are more likely to face the adverse impact of extreme temperature conditions, potentially motivating them to reduce their working time during periods of such conditions. On the other hand, those in low-risk exposure industries may be more flexible in choosing their work hours, finding it easier to adjust their work schedules to weather conditions. The results we present in Table 4 are consistent with our baseline estimates. We find that extreme hot (cold) temperatures decrease (increase) the morning working time and increase (decrease) night working time. However, the estimates for extreme temperatures are both more statistically significant and of larger magnitude for individuals employed in industries with higher exposure to ambient temperature conditions.

5.4 Family Constraints

Finally, we explore the role of family constraints in relation to the impact of temperature on the timing of work. To achieve this, we estimate the baseline specification separately for

[6] We follow the definition proposed by Graff Zivin and Neidell (2014) and classify as low-risk workers individuals working in the retail trade, information, financial, professional and business, educational, health, leisure and hospitality, and public sectors. Instead, we classify as high-risk workers individuals working in the agriculture, forestry, fishing, mining, construction, manufacturing, and transportation sectors.

individuals living with children and those without.[7] The underlying idea is that individuals with children may need to align their schedules with that of their children, thus facing more constraints when they want to avoid extreme temperature conditions. The results of this analysis, shown in Table 5, are in line with our baseline estimates indicating that individuals exposed to warm (cold) temperatures postpone (advance) their working schedules within the day. Moreover, we find that these estimates are both larger in magnitude and more statistically significant for individuals without children.[8] Overall, these estimates suggest that family constraints diminish workers' ability to adjust their work schedule to different temperature conditions.

6 Adjustments of Non-Working Time

The adjustments in the timing of work naturally also imply changes to individuals' non-working schedules. However, it is not immediately evident which specific types of non-working time individuals tend to reschedule alongside their working time. In this section, we examine the impact of temperature on the allocation of non-working time. We classify non-working time into three main categories: leisure, home production, and sleep. Moreover, following our baseline analysis, we explore the impact of temperature on each of these categories during different parts of the day: the morning (4:00 A.M.–12:00 P.M.), afternoon (12:00 P.M.–4:00 P.M.), evening (4:00 P.M.–8:00 P.M.), and night (8:00 P.M.–4:00 A.M.).[9]

[7]The American Time Use survey provides information on whether individuals live or not with a child. A child is defined as an individual younger than 18 years old.

[8]In Appendix H, we also show that the effect of temperature on the timing of work is decreasing in the number of children and is of smaller magnitude when the youngest child is under 10 years old.

[9]In Appendix I, we also examine the effect of temperature on total leisure, home production and sleep time during the diary day. As shown, the estimates on the effect of temperature on leisure and home production time are generally not statistically significant and we only find suggestive evidence that individuals dedicate some more time to leisure when temperatures are very high. We also find suggestive evidence that the relationship between temperature and sleep time is U-shaped.

6.1 The Timing of Leisure

We begin by exploring whether the adjustments in the timing of work to different temperature conditions are compensated by shifts in the timing of an individual's leisure activities during the diary date. As shown in Panels A–D of Figure 5, the estimates for the temperature effect on the timing of leisure are small in magnitude and statistical insignificant. This suggests that individuals do not significantly alter the timing of their recreational activities in response to different temperature conditions. This lack of adaptation in the timing of leisure may be due to the fact that most recreation activities are social in nature. Therefore, individuals may need to coordinate with their social network to modify the timing of their leisure plans, a process that may not always be feasible.

6.2 The Timing of Home Production

Another possibility is that individuals modify their timing of home production based on the temperature conditions. As shown in Figure 6, the estimates for the effects of temperature on the time individuals allocate to home production during the afternoon, evening and night are not statistically significant. Warm temperatures appear to somewhat increase the time individuals devote to home production in the morning (i.e., mirroring the drop of market work in the same period), but the effect is small overall. These results suggest that the adjustments in the timing of work along the temperature distribution, as previously outlined, are not influenced by intraday shifts in the timing of home production. Similar to the explanation provided for leisure, the lack of adjustment in the timing of individuals' home production might stem from the fact that a substantial part of home production activities involve other family members (i.e., children in the case of parental caregiving). Therefore, adjustment in the timing of home production may require coordination with others' schedules, which could be unattainable.

6.3 The Timing of Sleep

Lastly, we examine whether individuals adapt their sleep timing according to different temperature conditions. We estimate the baseline model using the time individuals spend sleeping in the morning, afternoon, evening, and night as outcome variables. As shown in Figure 7, cold temperatures reduce the time individuals allocate to sleep in the morning, which corresponds to the increase in working time observed during the same period under similar temperature conditions. Conversely, warm temperatures lead to a modest increase in sleep time during the afternoon and a substantial decrease during the night.[10] The decrease (increase) in sleep during the night (afternoon) corresponds to the rise (fall) in working time during the same parts of the day when temperatures are warm. In contrast to our findings for leisure and home production, which require coordination with others' schedules, individuals may have a greater flexibility to adjust their sleep in response to external conditions. It is therefore not surprising that the estimates we find regarding the effect of temperature on sleep timing are both highly statistically significant and large in magnitude. Overall, these findings suggest that the adjustments in the timing of work to different temperature conditions, outlined in Section 6, are mainly accommodated by shifts in individuals' sleep schedules. Furthermore, based on these results, we cannot rule out that the timing of work is influenced by intraday shifts in the timing of sleep.

7 Conclusions

This paper provides novel evidence on the effect of temperature on the timing of work. We employ daily time use data from over 45,000 time diaries from the American Time Use Survey, providing information on individuals' activities and the precise timing of activities within the day. We merge this information with data detailing exogenous temperature variation across

[10] In Appendix J, we explore whether the effect of temperature on the timing of work might also be influenced by adjustments in the time individuals spend commuting. As shown, the estimates of temperature are small and generally not statistically significant.

different days and counties in the United States and estimate a model that fully accounts for the non-linear relationship between temperature and the timing of work.

We provide three main sets of empirical findings. Firstly, we show that while different temperature conditions do not appear to affect overall labor supply, they do impact the timing of work. Specifically, we find that exposure to cold temperatures increases (decreases) work hours in the morning (night), while conversely, exposure to hot temperatures decreases (increases) morning (night) work hours. Therefore, our baseline estimates suggest that extreme temperatures bring an intra-day labor supply reallocation, with workers increasing (decreasing) working time during parts of the day with more favorable (adverse) temperature conditions.

Secondly, we investigate the factors influencing the effect of temperature on the timing of work, by categorizing workers into different groups and exploring how the effect of temperature varies across these groups. Our results indicate that the impact of temperature on the timing of work is more pronounced for workers employed during economic expansions (e.g., because they enjoy better outside job opportunities and greater bargaining power), for those working from home on the diary date (e.g., because they experience greater workplace flexibility), for those in industries with a high-exposure to ambient temperature, and for those with fewer family constraints (e.g., because they can more easily adjust their work schedules to different temperature conditions).

Our final set of findings highlights the adjustments in the allocation of non-working time that correspond with the shifts in the timing of work triggered by the varying temperature conditions. We find that temperature does not impact individuals' timing of leisure or home production. Instead, we find that workers adjust their sleep schedules in response to temperature fluctuations on the diary date. When temperatures are low, individuals sleep less in the morning, while warmer temperatures lead to reduced sleep during the night.

Overall, the empirical evidence provided in this paper shows considerable amounts of intra-day substitution of work in response to temperature shocks. We offer a theoretical framework to provide explanations for this intra-day substitution, which can be roughly classified in two categories. The first obvious explanation is that individuals reduce their exposure to extreme temperatures. This can explain the reduction of labor supply in the early afternoon, but not necessarily the decrease of labor supply in the morning, on very hot days. The second explanation is that temperature also changes the optimal timing of non-market activities. The timing of sleep, in particular, reacts strongly to temperature conditions. Individuals tend to start their day later on hot days, and this also postpones the start of their work.

We identified groups of workers for whom the timing of work is more constrained. These workers have less freedom to reduce their exposure to extreme circumstances at work, and less discretion to choose the start or end of their day. These individuals may end up working in the parts of the day when their productivity is lower, thereby reducing economic production. The suboptimal timing of sleep may further lead to a worsening of their health status and a reduction in well-being. The documented shifts in the timing of work (and sleep) support the view that preferences for work and non-work activities vary substantially within the day. Extreme weather conditions can magnify intra-day variation of reservation wages. This is expected to further increase the value that lies in flexible work schedules (Chen et al., 2019).

References

Ásgeirsdóttir, T. L. and S. P. Ólafsson (2015). An empirical analysis of the demand for sleep: Evidence from the american time use survey. *Economics & Human Biology 19*, 265–274.

Barreca, A., K. Clay, O. Deschênes, M. Greenstone, and J. S. Shapiro (2015). Convergence in adaptation to climate change: Evidence from high temperatures and mortality, 1900–2004. *American Economic Review 105*(5), 247–251.

Barreca, A., K. Clay, O. Deschênes, M. Greenstone, and J. S. Shapiro (2016). Adapting to climate change: The remarkable decline in the us temperature-mortality relationship over the twentieth century. *Journal of Political Economy 124*(1), 105–159.

Barreca, A., O. Deschênes, and M. Guldi (2018). Maybe next month? temperature shocks and dynamic adjustments in birth rates. *Demography 55*(4), 1269–1293.

Barreca, A. and J. Schaller (2020). The impact of high ambient temperatures on delivery timing and gestational lengths. *Nature Climate Change 10*(1), 77–82.

Barreca, A. I. (2012). Climate change, humidity, and mortality in the united states. *Journal of Environmental Economics and Management 63*(1), 19–34.

Baylis, P. (2020). Temperature and temperament: Evidence from twitter. *Journal of Public Economics 184*, 104161.

Baylis, P., N. Obradovich, Y. Kryvasheyeu, H. Chen, L. Coviello, E. Moro, M. Cebrian, and J. H. Fowler (2018). Weather impacts expressed sentiment. *PloS one 13*(4), e0195750.

Belloc, I., J. I. Gimenez-Nadal, and J. A. Molina (2022). Weather conditions and daily commuting. *IZA Discussion Paper*.

Belloc, I., J. I. Gimenez-Nadal, and J. A. Molina (2023). Extreme temperatures: Gender differences in well-being. *Discussion Paper*.

Biddle, J. E. and D. S. Hamermesh (1990). Sleep and the allocation of time. *Journal of Political Economy 98*(5, Part 1), 922–943.

Bonke, J. (2012). Do morning-type people earn more than evening-type people? how chronotypes influence income. *Annals of Economics and Statistics* (105/106), 55.

Burgess, R., O. Deschenes, D. Donaldson, and M. Greenstone (2014). The unequal effects of weather and climate change: Evidence from mortality in india. *Cambridge, United States: Massachusetts Institute of Technology, Department of Economics. Manuscript*.

Burgess, R., O. Deschênes, D. Donaldson, and M. Greenstone (2017). Weather, climate change and death in india. *University of Chicago*.

Burke, M., F. González, P. Baylis, S. Heft-Neal, C. Baysan, S. Basu, and S. Hsiang (2018). Higher temperatures increase suicide rates in the united states and mexico. *Nature climate change 8*(8), 723–729.

Burke, M., S. M. Hsiang, and E. Miguel (2015). Global non-linear effect of temperature on economic production. *Nature 527*(7577), 235–239.

Carleton, T. A. and S. M. Hsiang (2016). Social and economic impacts of climate. *Science 353*(6304), aad9837.

Chen, M. K., P. E. Rossi, J. A. Chevalier, and E. Oehlsen (2019). The value of flexible work: Evidence from uber drivers. *Journal of political economy 127*(6), 2735–2794.

Chen, X. and L. Yang (2019). Temperature and industrial output: Firm-level evidence from china. *Journal of Environmental Economics and Management 95*, 257–274.

Cosaert, S., A. Theloudis, and B. Verheyden (2023). Togetherness in the household. *American Economic Journal: Microeconomics 15*(1), 529–579.

Dell, M., B. F. Jones, and B. A. Olken (2012). Temperature shocks and economic growth: Evidence from the last half century. *American Economic Journal: Macroeconomics 4*(3), 66–95.

Deryugina, T. and S. M. Hsiang (2014). Does the environment still matter? Daily temperature and income in the united states. *NBER working paper 20750*.

Deschênes, O. (2014). Temperature, human health, and adaptation: A review of the empirical literature. *Energy Economics 46*, 606–619.

Deschênes, O. and M. Greenstone (2007). The economic impacts of climate change: evidence from agricultural output and random fluctuations in weather. *American economic review 97*(1), 354–385.

Deschênes, O. and M. Greenstone (2011). Climate change, mortality, and adaptation: Evidence from annual fluctuations in weather in the us. *American Economic Journal: Applied Economics 3*(4), 152–185.

Deschênes, O., M. Greenstone, and J. Guryan (2009). Climate change and birth weight. *American Economic Review 99*(2), 211–217.

Deschênes, O. and E. Moretti (2009). Extreme weather events, mortality, and migration. *The Review of Economics and Statistics 91*(4), 659–681.

Dingel, J. I., K. C. Meng, and S. M. Hsiang (2019). Spatial correlation, trade, and inequality: Evidence from the global climate.

Eissler, S., B. C. Thiede, and J. Strube (2019). Climatic variability and changing reproductive goals in sub-saharan africa. *Global Environmental Change 57*, 101912.

Fan, Y., J. Wang, N. Obradovich, and S. Zheng (2023). Intraday adaptation to extreme temperatures in outdoor activity. *Scientific Reports 13*(1), 473.

Gibson, M. and J. Shrader (2018). Time use and labor productivity: The returns to sleep. *The Review of Economics and Statistics 100*(5), 783–798.

Graff Zivin, J., S. M. Hsiang, and M. Neidell (2018). Temperature and human capital in the short and long run. *Journal of the Association of Environmental and Resource Economists 5*(1), 77–105.

Graff Zivin, J. and M. Neidell (2014). Temperature and the allocation of time: Implications for climate change. *Journal of Labor Economics 32*(1), 1–26.

Graff Zivin, J. and J. Shrader (2016). Temperature extremes, health, and human capital. *The Future of Children*, 31–50.

Graff Zivin, J., Y. Song, Q. Tang, and P. Zhang (2020). Temperature and high-stakes cognitive performance: Evidence from the national college entrance examination in china. *Journal of Environmental Economics and Management 104*, 102365.

Guirguis, K., R. Basu, W. K. Al-Delaimy, T. Benmarhnia, R. E. S. Clemesha, I. Corcos, J. Guzman-Morales, B. Hailey, I. Small, A. Tardy, D. Vashishtha, J. Graff Zivin, and A. Gershunov (2018). Heat, disparities, and health outcomes in san diego county's diverse climate zones. *GeoHealth 2*(7), 212–223.

Hamermesh, D. S. (1999a). Crime and the timing of work. *Journal of Urban Economics 45*(2), 311–330.

Hamermesh, D. S. (1999b). The timing of work over time. *The Economic Journal 109*(452), 37–66.

Hamermesh, D. S. (2002, nov). Timing, togetherness and time windfalls. *Journal of Population Economics 15*(4), 601–623.

Hamilton, B. H., J. A. Nickerson, and H. Owan (2003). Team incentives and worker heterogeneity: An empirical analysis of the impact of teams on productivity and participation. *Journal of Political Economy 111*(3), 465–497.

Heutel, G., N. H. Miller, and D. Molitor (2021). Adaptation and the mortality effects of temperature across us climate regions. *The review of economics and statistics 103*(4), 740–753.

Hsiang, S. M. (2010). Temperatures and cyclones strongly associated with economic production in the caribbean and central america. *Proceedings of the National Academy of sciences 107*(35), 15367–15372.

IPCC (2023). Climate change 2023. *Synthesis Report*.

Isen, A., M. Rossin-Slater, and R. Walker (2017). Relationship between season of birth, temperature exposure, and later life wellbeing. *Proceedings of the National Academy of Sciences 114*(51), 13447–13452.

Jacob, B., L. Lefgren, and E. Moretti (2007). The dynamics of criminal behavior: Evidence from weather shocks. *Journal of Human resources 42*(3), 489–527.

Jain, A., R. O'Sullivan, and V. Taraz (2020). Temperature and economic activity: Evidence from india. *Journal of Environmental Economics and Policy 9*(4), 430–446.

Kostiuk, P. F. (1990). Compensating differentials for shift work. *Journal of Political Economy 98*(5), 1054–1075.

Krüger, J. J. and M. Neugart (2018). Weather and intertemporal labor supply: Results from german time-use data. *Labour 32*(1), 112–140.

LoPalo, M. (2023). Temperature, worker productivity, and adaptation: evidence from survey data production. *American Economic Journal: Applied Economics 15*(1), 192–229.

Mas, A. and A. Pallais (2017). Valuing alternative work arrangements. *American Economic Review 107*(12), 3722–3759.

Miller, S., K. Chua, J. Coggins, and H. Mohtadi (2021). Heat waves, climate change, and economic output. *Journal of the European Economic Association 19*(5), 2658–2694.

Mullins, J. T. and C. White (2019). Temperature and mental health: Evidence from the spectrum of mental health outcomes. *Journal of health economics 68*, 102240.

Neidell, M., J. Graff Zivin, M. Sheahan, J. Willwerth, C. Fant, M. Sarofim, and J. Martinich (2021). Temperature and work: Time allocated to work under varying climate and labor market conditions. *PloS one 16*(8), e0254224.

Noelke, C., M. McGovern, D. J. Corsi, M. P. Jimenez, A. Stern, I. S. Wing, and L. Berkman (2016). Increasing ambient temperature reduces emotional well-being. *Environmental research 151*, 124–129.

Somanathan, E., R. Somanathan, A. Sudarshan, and M. Tewari (2021). The impact of temperature on productivity and labor supply: Evidence from indian manufacturing. *Journal of Political Economy 129*(6), 1797–1827.

Weiss, Y. (1996). Synchronization of work schedules. *International Economic Review 37*(1), 157.

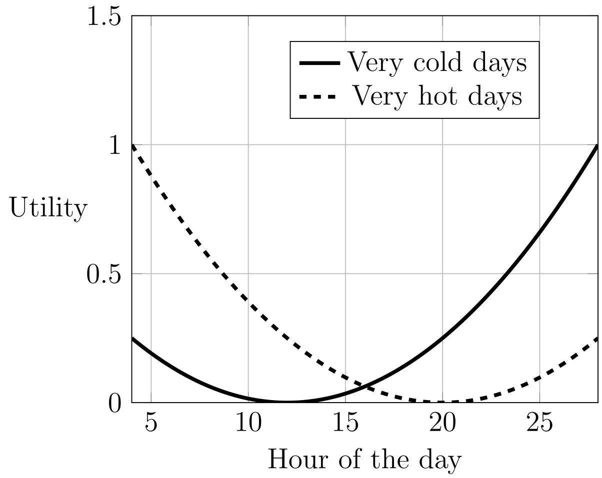
White, C. (2017). The dynamic relationship between temperature and morbidity. *Journal of the Association of Environmental and Resource Economists 4*(4), 1155–1198.

Winston, G. (1982). *The Timing of Economic Activities.* New York: Cambridge University Press.

Zhang, P., O. Deschênes, K. Meng, and J. Zhang (2018). Temperature effects on productivity and factor reallocation: Evidence from a half million chinese manufacturing plants. *Journal of Environmental Economics and Management 88*, 1–17.

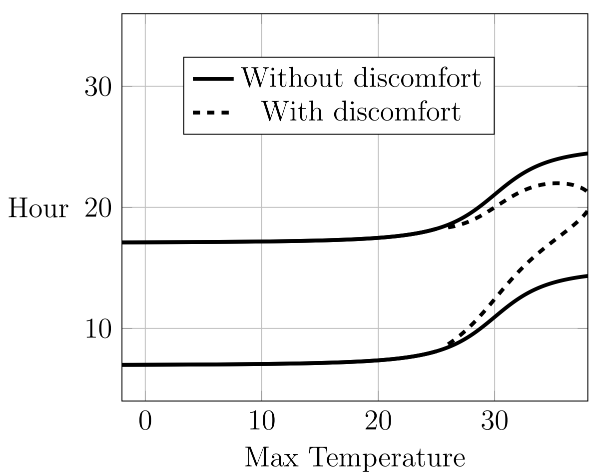
Figures

Figure 1: The marginal utility of sleep, by hour of the day



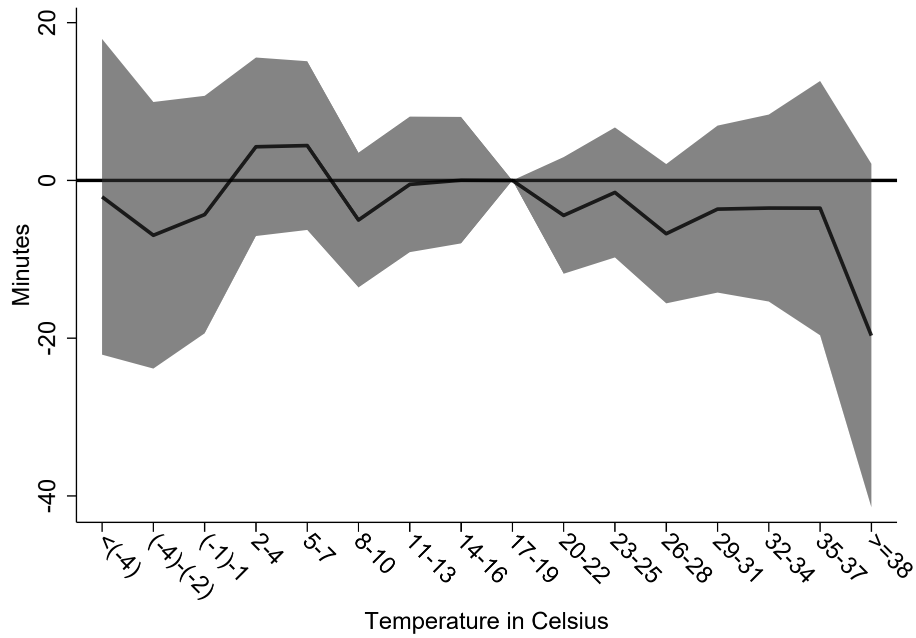
Notes: The figure illustrates a possible scenario in which the marginal utilities of sleep differ between hot and cold days. On hot days, the marginal utility of sleep is minimal at $\alpha = 20$ and there is a strong willingness to sleep in early parts of the day. On cold days, the marginal utility of sleep is minimal at $\alpha = 12$ and there is a strong willingness to sleep in later parts of the day.

Figure 2: Simulations of start and end times of work, by temperature



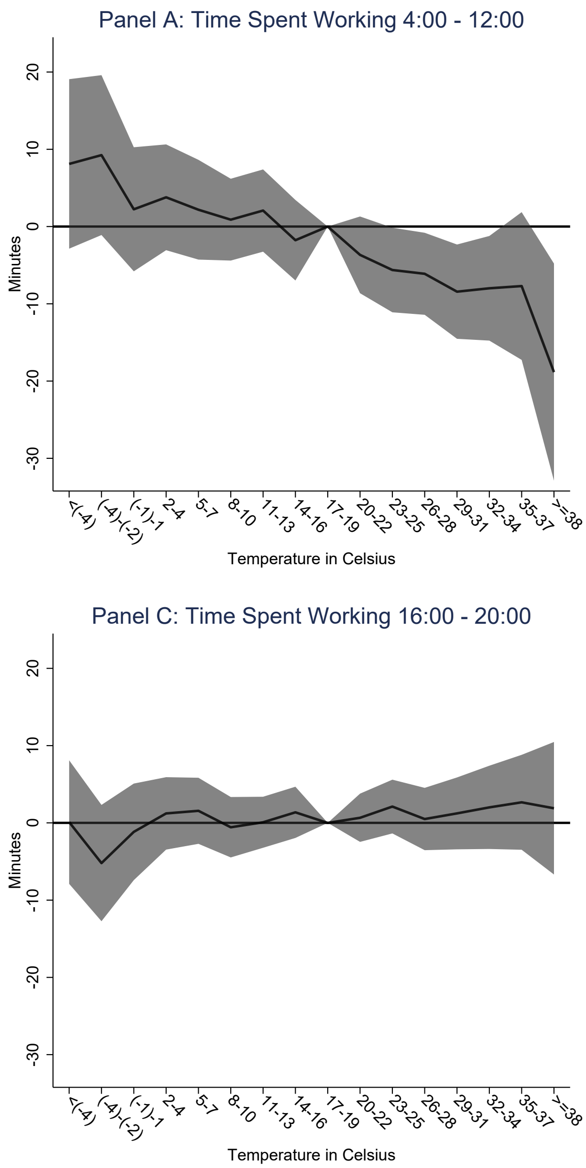
Notes: The figure shows the simulated daily start and end times of market work (lower bound s and upper bound $s + h$) in function of temperature. For this simulation, we set $W = 1$, $\epsilon_i = 0.9$ and we specify the temperature relation as follows: $\alpha(T) = 16 + 4\frac{T/5-6}{\sqrt{1+(T/5-6)^2}}$. We consider a scenario without physical discomfort ($\beta(T) = 0$) and one with physical discomfort ($\beta(T) = \frac{T-25}{100}$ if $T \geq 25$ and 0 otherwise).

Figure 3: Working Time



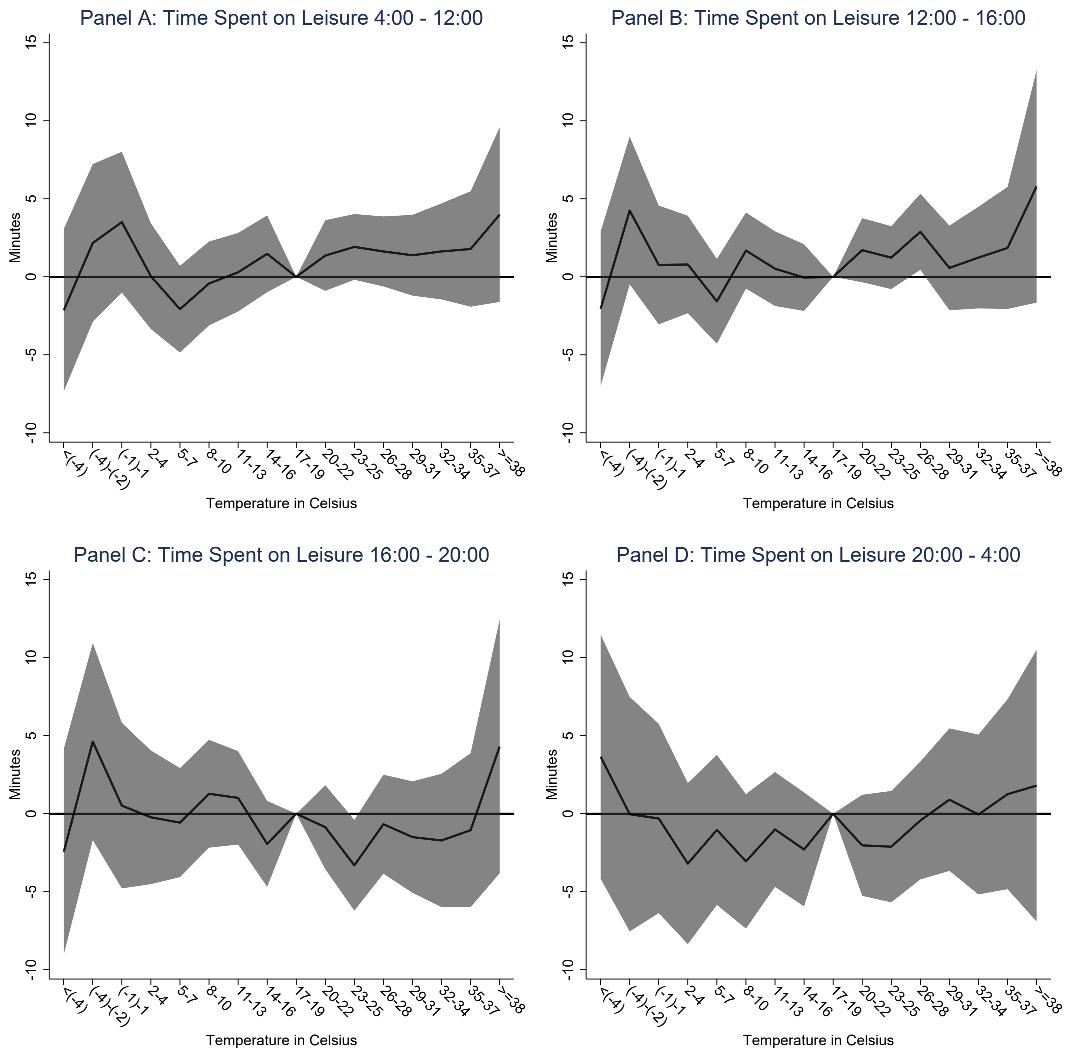
Notes: The figure presents the estimates of a set of indicators of whether temperature in a county-day falls within specific 3-degree Celsius intervals. The set of dummies covers the full temperature distribution and we use as the benchmark the interval between 17 and 19 Celsius degrees. We use as the dependent variable the time (in minutes per day) that individuals spend working on the diary date. The sample consists of individuals who work on the diary date.

Figure 4: Working Time by Part of the Day



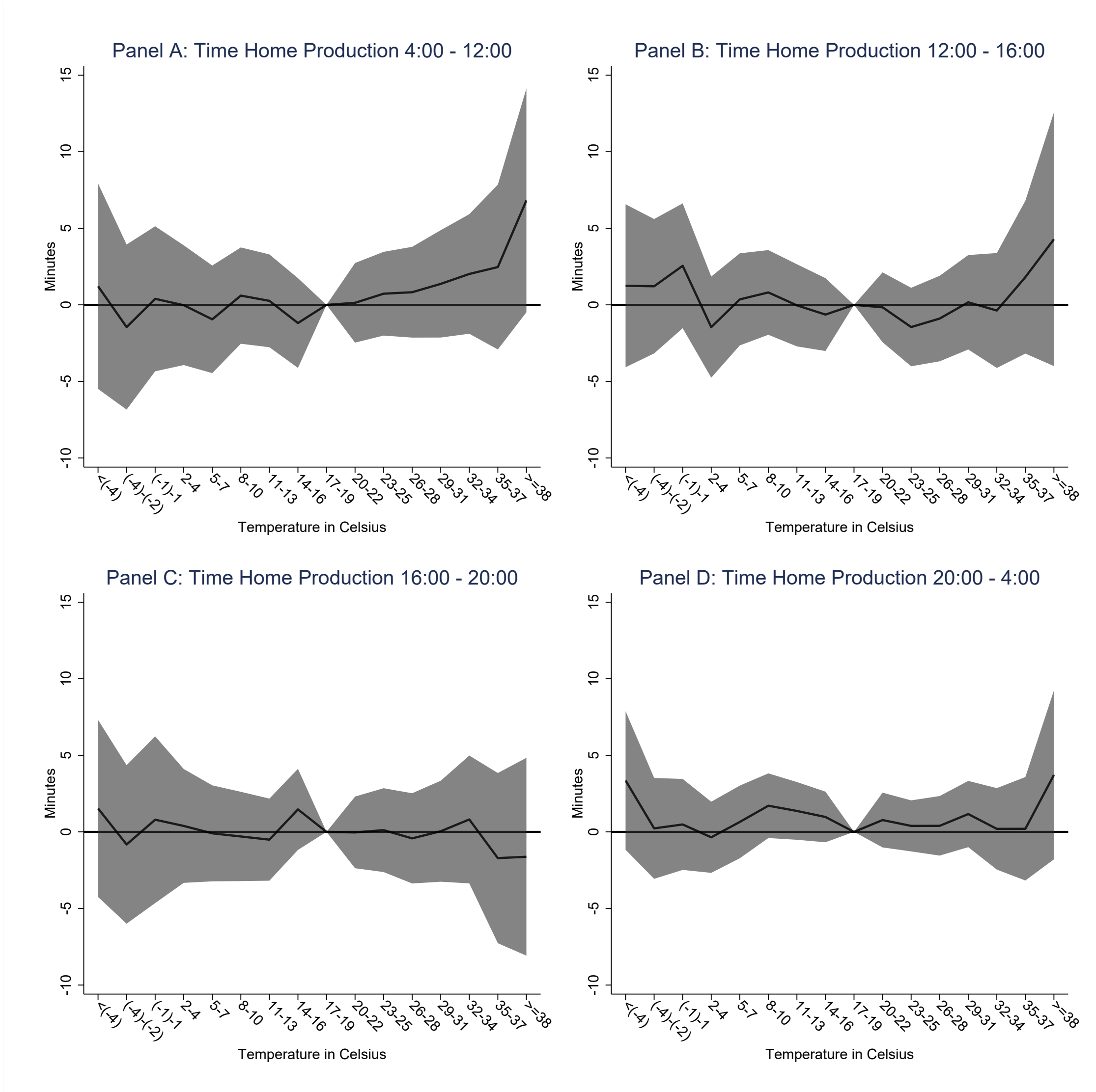
Notes: The figure presents the estimates of a set of indicators of whether temperature in a county-day falls within specific 3-degree Celsius intervals. The set of dummies covers the full temperature distribution and we use as the benchmark the interval between 17 and 19 Celsius degrees. We use as the dependent variables the time (in minutes per day) that individuals spend working in the following intervals of the diary day: 4:00 A.M.–12:00 P.M., 12:00 P.M.–4:00 P.M., 4:00 P.M.–8:00 P.M., and 8:00 P.M.–4:00 A.M.. The sample consists of individuals who work on the diary date.

Figure 5: Leisure Time by Part of the Day



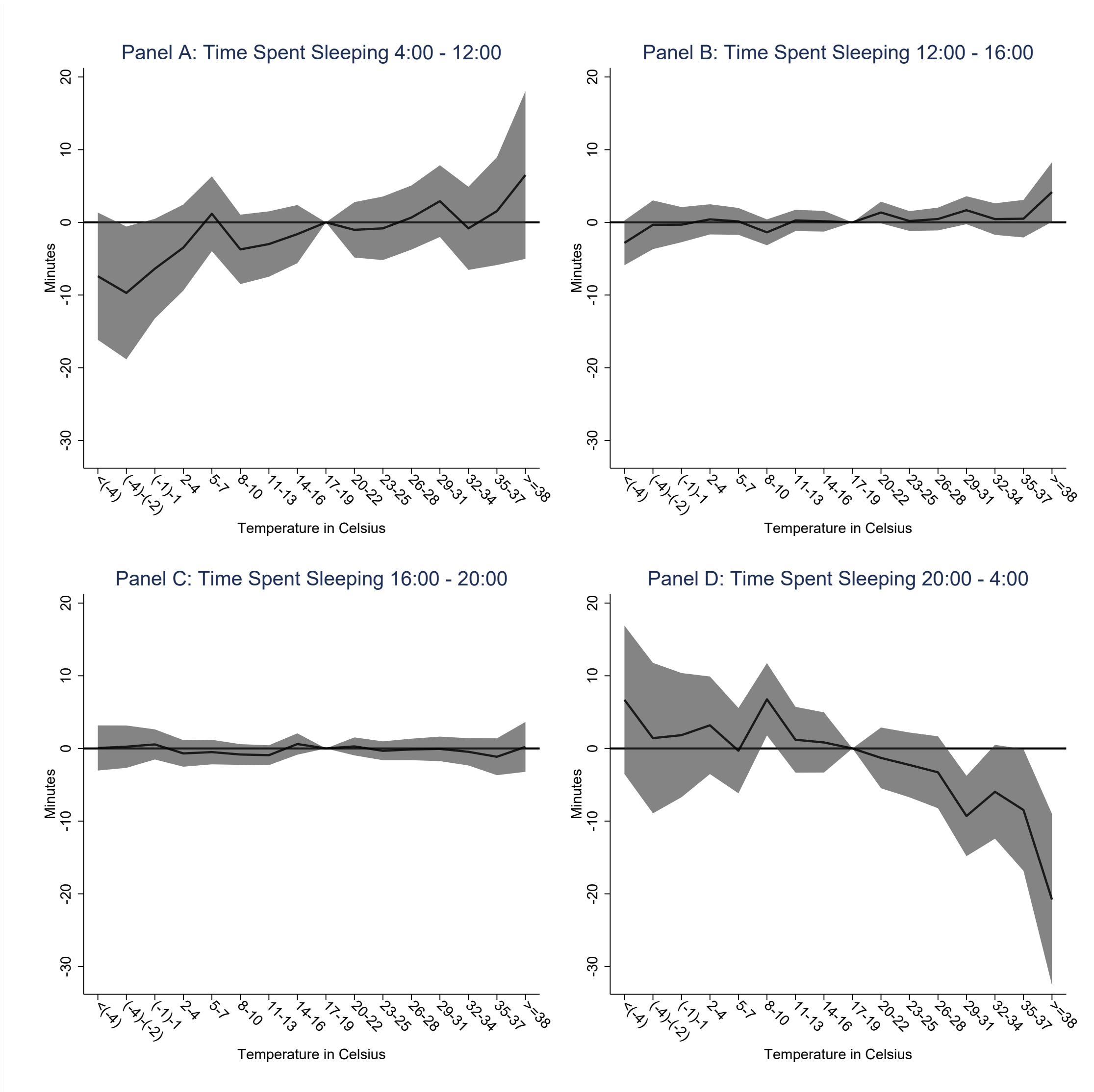
Notes: The figure presents the estimates of a set of indicators of whether temperature in a county-day falls within specific 3-degree Celsius intervals. The set of dummies covers the full temperature distribution and we use as the benchmark the interval between 17 and 19 Celsius degrees. We use as the dependent variables the time (in minutes per day) that individuals spend on leisure in the following intervals of the diary day: 4:00 A.M.–12:00 P.M., 12:00 P.M.–4:00 P.M., 4:00 P.M.–8:00 P.M., and 8:00 P.M.–4:00 A.M.. The sample consists of individuals who work on the diary date.

Figure 6: Home Production Time by Part of the Day



Notes: The figure presents the estimates of a set of indicators of whether temperature in a county-day falls within specific 3-degree Celsius intervals. The set of dummies covers the full temperature distribution and we use as the benchmark the interval between 17 and 19 Celsius degrees. We use as the dependent variables the time (in minutes per day) that individuals spend on home production in the following intervals of the diary day: 4:00 A.M.–12:00 P.M., 12:00 P.M.–4:00 P.M., 4:00 P.M.–8:00 P.M., and 8:00 P.M.–4:00 A.M.. The sample consists of individuals who work on the diary date.

Figure 7: Sleeping Time by Part of the Day



Notes: The figure presents the estimates of a set of indicators of whether temperature in a county-day falls within specific 3-degree Celsius intervals. The set of dummies covers the full temperature distribution and we use as the benchmark the interval between 17 and 19 Celsius degrees. We use as the dependent variables the time (in minutes per day) that individuals spend sleeping in the following intervals of the diary day: 4:00 A.M.–12:00 P.M., 12:00 P.M.–4:00 P.M., 4:00 P.M.–8:00 P.M., and 8:00 P.M.–4:00 A.M.. The sample consists of individuals who work on the diary date.

Tables

Table 1: Descriptive Statistics

	Full Sample
Female	0.49
	(0.50)
Age	42.99
	(13.12)
White	0.80
	(0.40)
Education Level: Less than High-school	0.08
	(0.27)
Education Level: High-school	0.20
	(0.40)
Education Level: Some College	0.72
	(0.45)
Precipitation (tenths of mm)	28.51
	(74.97)
Snowfall (mm)	1.55
	(11.69)
Time Spent Working	428.96
	(200.96)
Time Spent Working 4:00 – 12:00	185.20
	(122.63)
Time Spent Working 12:00 – 16:00	142.43
	(86.75)
Time Spent Working 16:00 – 20:00	67.32
	(76.00)
Time Spent Working 20:00 – 4:00	34.01
	(84.75)
N	45,755

Notes: Column 1 shows summary statistics of some socio-demographic characteristics and time use variables for the full sample. We report the mean of these variables, and their standard deviations in parentheses.

Table 2: Heterogeneity by Economic Activity

	Expansion				Recession			
	Time Working (mins) 4:00–12:00	Time Working (mins) 12:00–16:00	Time Working (mins) 16:00–20:00	Time Working (mins) 20:00–4:00	Time Working (mins) 4:00–12:00	Time Working (mins) 12:00–16:00	Time Working (mins) 16:00–20:00	Time Working (mins) 20:00–4:00
Temp < 0	4.950	-1.524	-3.695	-6.584**	1.021	-8.147	-5.802	-3.166
	(4.403)	(2.932)	(3.328)	(3.327)	(7.605)	(4.999)	(5.331)	(5.266)
Temp >= 0 & < 10	1.339	-1.341	0.286	0.477	3.660	-0.627	-3.886	-1.279
	(2.232)	(1.639)	(1.597)	(1.615)	(4.423)	(3.065)	(3.050)	(3.246)
Temp >= 20 & < 30	-5.111**	-1.507	1.409	2.443	-1.074	-0.827	0.950	-1.649
	(2.035)	(1.438)	(1.502)	(1.586)	(3.404)	(2.743)	(2.727)	(2.730)
Temp > 30	-6.837**	-2.134	3.670*	6.940***	-2.549	3.766	6.845	-0.344
	(3.043)	(2.386)	(2.228)	(2.416)	(6.044)	(4.670)	(4.514)	(4.433)
Time-varying cov	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Weather cov	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
County dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year-month dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	34559	34559	34559	34559	10368	10368	10368	10368

* p<0.10, ** p<0.05, *** p<0.01

Notes: Standard errors in parentheses. The table presents the estimates of a set of indicators of whether temperature in a county-day falls within specific temperature intervals. The set of dummies covers the full temperature distribution and we use as the benchmark the interval between 10 and 20 Celsius degrees. We use as the dependent variables the time (in minutes per day) that individuals spend working in the following intervals of the diary day: 4:00 A.M.–12:00 P.M., 12:00 P.M.–4:00 P.M., 4:00 P.M.–8:00 P.M., and 8:00 P.M.–4:00 A.M.. The subsamples consist of individuals who work on the diary date during a period of economic expansion and recession, respectively.

Table 3: Heterogeneity by Flexibility of the Job

	Does Not Work from Home				Works from Home			
	Time Working (mins) 4:00–12:00	Time Working (mins) 12:00–16:00	Time Working (mins) 16:00–20:00	Time Working (mins) 20:00–4:00	Time Working (mins) 4:00–12:00	Time Working (mins) 12:00–16:00	Time Working (mins) 16:00–20:00	Time Working (mins) 20:00–4:00
Temp < 0	8.992**	-1.760	-4.463	-5.810	-9.995	-6.905	-2.038	-4.123
	(4.140)	(3.090)	(3.363)	(3.711)	(6.481)	(4.789)	(4.160)	(4.040)
Temp >= 0 & < 10	2.511	-0.856	-0.384	1.765	-1.850	-2.288	0.156	-2.747
	(2.241)	(1.717)	(1.714)	(1.739)	(3.704)	(2.599)	(2.144)	(2.332)
Temp >= 20 & < 30	-2.568	-0.016	1.737	0.854	-7.398**	-4.695*	-0.395	2.961
	(2.090)	(1.494)	(1.571)	(1.724)	(3.149)	(2.500)	(2.011)	(1.884)
Temp > 30	-4.699	-0.927	4.360*	4.413	-9.953**	-1.731	2.942	6.471**
	(3.096)	(2.422)	(2.459)	(2.776)	(4.922)	(3.835)	(3.367)	(3.170)
Time-varying cov	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Weather cov	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
County dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year-month dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	32436	32436	32436	32436	12452	12452	12452	12452

* p<0.10, ** p<0.05, *** p<0.01

Notes: Standard errors in parentheses. The table presents the estimates of a set of indicators of whether temperature in a county-day falls within specific temperature intervals. The set of dummies covers the full temperature distribution and we use as the benchmark the interval between 10 and 20 Celsius degrees. We use as the dependent variables the time (in minutes per day) that individuals spend working in the following intervals of the diary day: 4:00 A.M.–12:00 P.M., 12:00 P.M.–4:00 P.M., 4:00 P.M.–8:00 P.M., and 8:00 P.M.–4:00 A.M.. The subsamples consist of individuals who work from home and who work but not from home on the diary date, respectively.

Table 4: Heterogeneity by Exposure to the Ambient Temperature

	High-risk Exposure to the Ambient Temperature				Low-risk Exposure to the Ambient Temperature			
	Time Working (mins) 4:00–12:00	Time Working (mins) 12:00–16:00	Time Working (mins) 16:00–20:00	Time Working (mins) 20:00–4:00	Time Working (mins) 4:00–12:00	Time Working (mins) 12:00–16:00	Time Working (mins) 16:00–20:00	Time Working (mins) 20:00–4:00
Temp < 0	5.555	0.941	-6.350	-5.629	0.803	-5.502**	-3.172	-5.773**
	(8.032)	(5.425)	(5.987)	(7.878)	(3.955)	(2.769)	(2.837)	(2.919)
Temp >= 0 & < 10	2.432	0.032	-5.364*	-0.385	1.192	-1.711	0.692	0.308
	(4.882)	(3.274)	(2.967)	(4.143)	(2.288)	(1.583)	(1.626)	(1.533)
Temp >= 20 & < 30	-9.121**	-0.241	4.187	3.702	-2.936	-1.186	0.506	0.768
	(3.934)	(2.578)	(2.608)	(3.345)	(1.859)	(1.461)	(1.439)	(1.597)
Temp > 30	-15.338**	-4.125	8.597**	5.740	-2.802	0.486	2.710	5.171**
	(6.089)	(4.279)	(4.240)	(5.364)	(2.937)	(2.383)	(2.287)	(2.351)
Time-varying cov	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Weather cov	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
County dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year-month dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	9489	9489	9489	9489	35151	35151	35151	35151

* p<0.10, ** p<0.05, *** p<0.01

Notes: Standard errors in parentheses. The table presents the estimates of a set of indicators of whether temperature in a county-day falls within specific temperature intervals. The set of dummies covers the full temperature distribution and we use as the benchmark the interval between 10 and 20 Celsius degrees. We use as the dependent variables the time (in minutes per day) that individuals spend working in the following intervals of the diary day: 4:00 A.M.–12:00 P.M., 12:00 P.M.–4:00 P.M., 4:00 P.M.–8:00 P.M., and 8:00 P.M.–4:00 A.M.. The subsamples consist of individuals who work on the diary date, and who work in high and low-risk exposure industries to the ambient temperature, respectively.

Table 5: Heterogeneity by Presence of Children

	No Child in the Household				Presence of Children in the Household			
	Time Working (mins) 4:00–12:00	Time Working (mins) 12:00–16:00	Time Working (mins) 16:00–20:00	Time Working (mins) 20:00–4:00	Time Working (mins) 4:00–12:00	Time Working (mins) 12:00–16:00	Time Working (mins) 16:00–20:00	Time Working (mins) 20:00–4:00
Temp < 0	2.637	-4.914	-4.843	-7.847*	3.761	-3.278	-3.685	-3.590
	(5.651)	(3.954)	(4.097)	(4.181)	(4.950)	(3.470)	(3.511)	(3.690)
Temp >= 0 & < 10	1.889	-1.925	-0.430	0.952	1.209	-1.223	-1.178	-0.187
	(2.827)	(2.046)	(2.164)	(2.081)	(2.503)	(1.990)	(1.873)	(2.193)
Temp >= 20 & < 30	-5.478**	-2.099	0.325	3.776*	-2.493	-0.573	1.654	-0.666
	(2.680)	(1.850)	(1.946)	(2.113)	(2.675)	(1.886)	(1.777)	(1.893)
Temp > 30	-7.448*	-2.001	1.992	8.218**	-3.944	0.171	6.010**	2.077
	(3.875)	(3.030)	(3.003)	(3.270)	(3.928)	(2.991)	(2.787)	(2.973)
Time-varying cov	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Weather cov	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
County dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year-month dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	22,152	22,152	22,152	22,152	22,749	22,749	22,749	22,749

* $p<0.10$, ** $p<0.05$, *** $p<0.01$

Notes: Standard errors in parentheses. The table presents the estimates of a set of indicators of whether temperature in a county-day falls within specific temperature intervals. The set of dummies covers the full temperature distribution and we use as the benchmark the interval between 10 and 20 Celsius degrees. We use as the dependent variables the time (in minutes per day) that individuals spend working in the following intervals of the diary day: 4:00 A.M.–12:00 P.M., 12:00 P.M.–4:00 P.M., 4:00 P.M.–8:00 P.M., and 8:00 P.M.–4:00 A.M.. The subsamples consist of individuals who work on the diary date, and who do not live and live with a child at home, respectively.

Appendix of Temperature and the Timing of Work

Sam Cosaert[*], Adrián Nieto[†], Konstantinos Tatsiramos[‡]

September 26, 2023

[*]University of Antwerp, Belgium

[†]Luxembourg Institute of Socio-Economic Research (LISER), Luxembourg

[‡]University of Luxembourg and Luxembourg Institute of Socio-Economic Research (LISER), Luxembourg

A Theoretical Appendix

We calculate the integral to express utility as a function of the two decision variables s and h. Utility function (1) is equivalent to

$$\begin{aligned} U(s,h) &= h/768((3\beta-3)s^2+((3\beta-3)h-72\beta+6\alpha)s \\ &\quad +(\beta-1)h^2+(3\alpha-36\beta)h-3\alpha^2-336\beta+768(W-\epsilon_i)) \end{aligned}$$

We compute the first- and second-order conditions corresponding to the optimal amount (h) and timing (s) of work.

$$\begin{aligned} dU/dh &= ((\beta-1)h^2+(2(\beta-1)s-24\beta+2\alpha)h+(\beta-1)s^2+2(\alpha-12\beta)s \\ &\quad -\alpha^2-112\beta+256(W-\epsilon_i))/256 \\ dU/ds &= ((2\beta-2)s+(\beta-1)h+2\alpha-24\beta)h/256 \end{aligned}$$

$$\begin{aligned} d^2U/dh^2 &= ((\beta-1)h+(\beta-1)s+\alpha-12\beta)/128 \\ d^2U/dhds &= ((\beta-1)h+(\beta-1)s+\alpha-12\beta)/128 = d^2U/dh^2 \\ d^2U/ds^2 &= (\beta-1)h/128 \end{aligned}$$

We use the first-order condition associated with s to write the number of hours as a function of the start time,

$$\begin{aligned} dU/ds &= 0 \Leftrightarrow \\ (2\beta-2)s+(\beta-1)h+2\alpha-24\beta &= 0 \Leftrightarrow \\ 2\left(\frac{\alpha-12\beta}{1-\beta}-s\right) &= h \end{aligned}$$

and we combine this with the first-order condition associated with h to solve for start time,

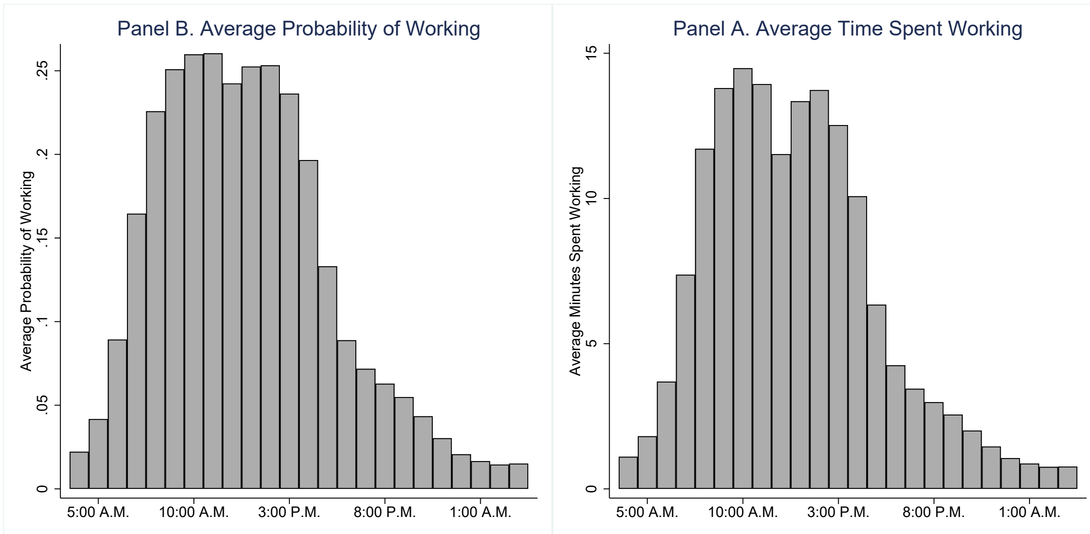
$$
\begin{aligned}
dU/dh &= 0 \Leftrightarrow \\
(\beta-1)s^2 + 2(\alpha-12\beta)s - \alpha^2 - 112\beta + 256(W-\epsilon_i) &= 0.
\end{aligned}
$$

This results in work hours and timing equations as a function of wages, cost of effort, temporal profiles of opportunity costs, and extremeness of weather conditions (with $h = 2\left(\frac{\alpha-12\beta}{1-\beta} - s\right)$):

$$
\begin{aligned}
s^* &= \frac{\alpha-12\beta}{1-\beta} - \frac{\sqrt{(1-\beta)256(W-\epsilon_i) + \beta(\alpha^2-24\alpha-112+256\beta)}}{1-\beta} \\
h^* &= \frac{2\sqrt{(1-\beta)256(W-\epsilon_i) + \beta(\alpha^2-24\alpha-112+256\beta)}}{1-\beta}
\end{aligned}
$$

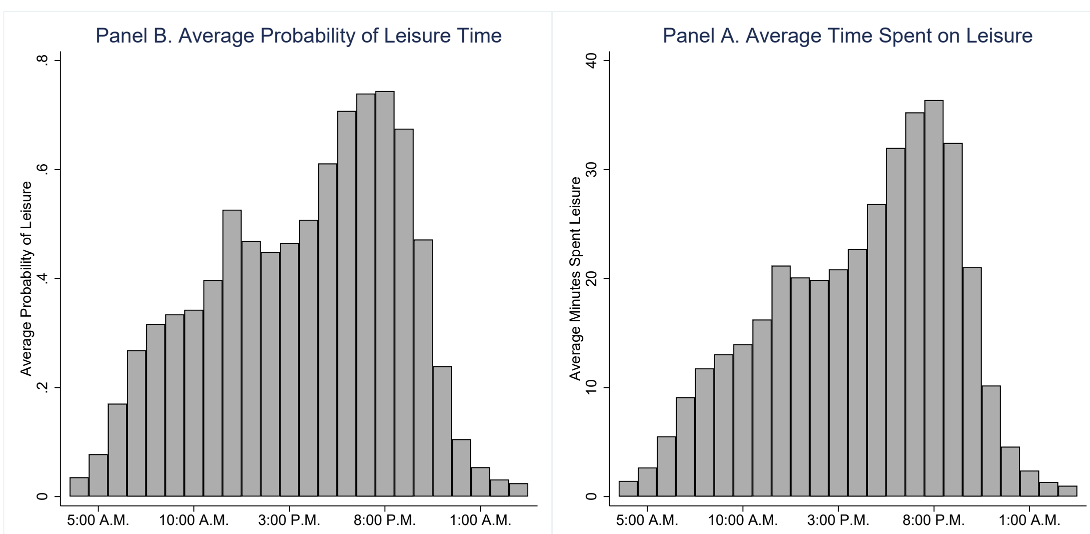
B Time Allocation

Figure B.1: Working by Time of the Day



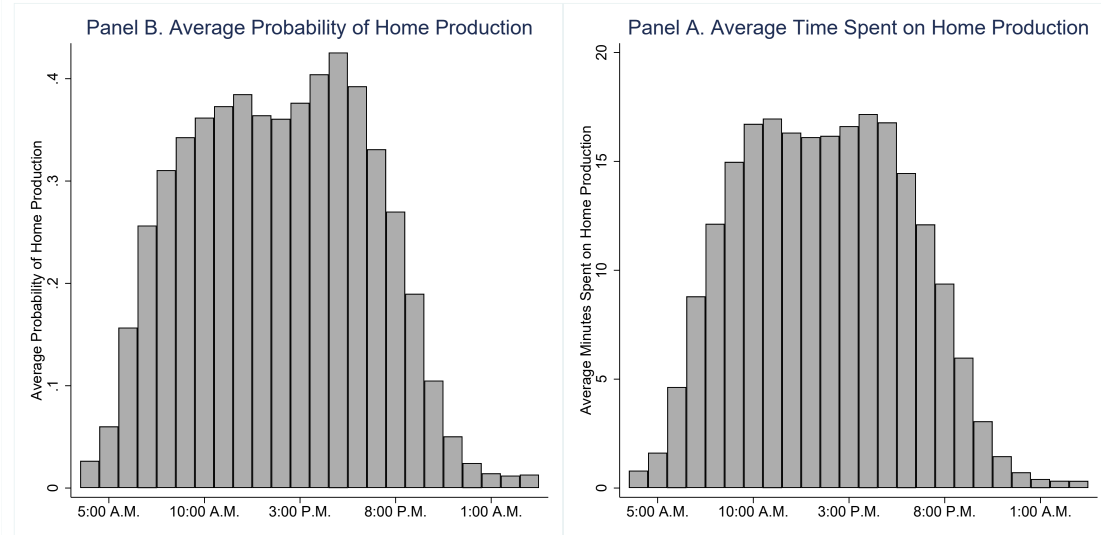
Notes: Panels A and B of the figure present the average probability of working and the average amount of time spent working in the different parts of the day, respectively. The sample consists of individuals who work on the diary date.

Figure B.2: Leisure by Time of the Day



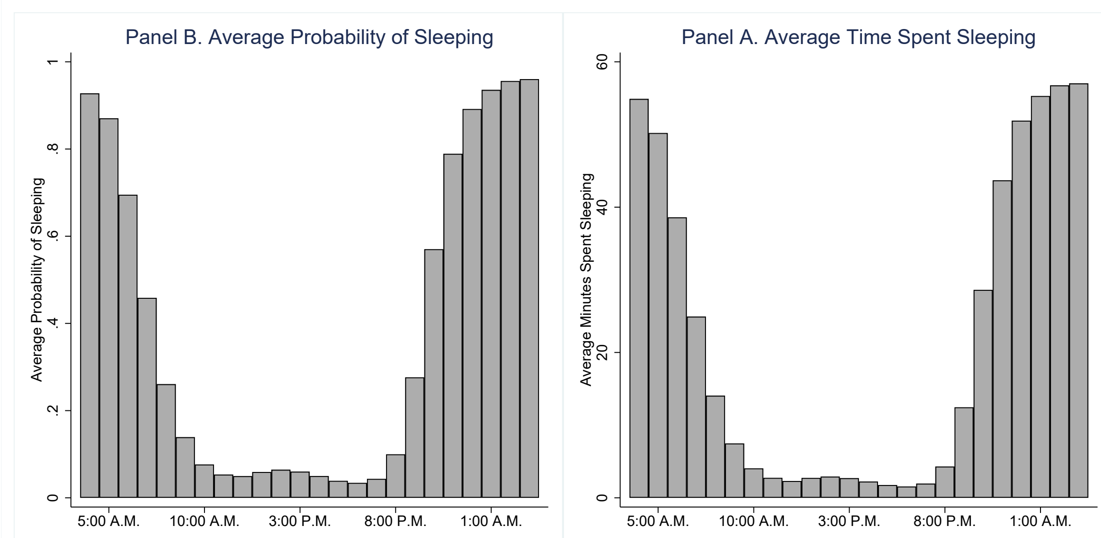
Notes: Panels A and B of the figure present the average probability of being enjoying leisure time and the average amount of time spent on leisure in the different parts of the day, respectively. The sample consists of individuals who work on the diary date.

Figure B.3: Home Production by Time of the Day



Notes: Panels A and B of the figure present the average probability of being doing home production and the average amount of time spent on home production in the different parts of the day, respectively. The sample consists of individuals who work on the diary date.

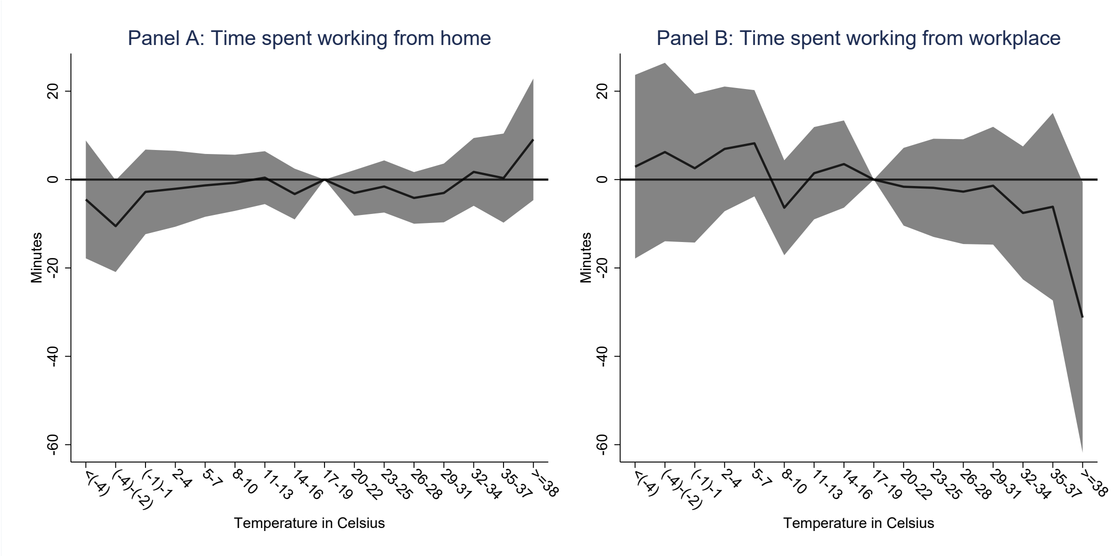
Figure B.4: Sleeping by Time of the Day



Notes: Panels A and B of the figure present the average probability of sleeping and the average amount of time spent sleeping in the different parts of the day, respectively. The sample consists of individuals who work on the diary date.

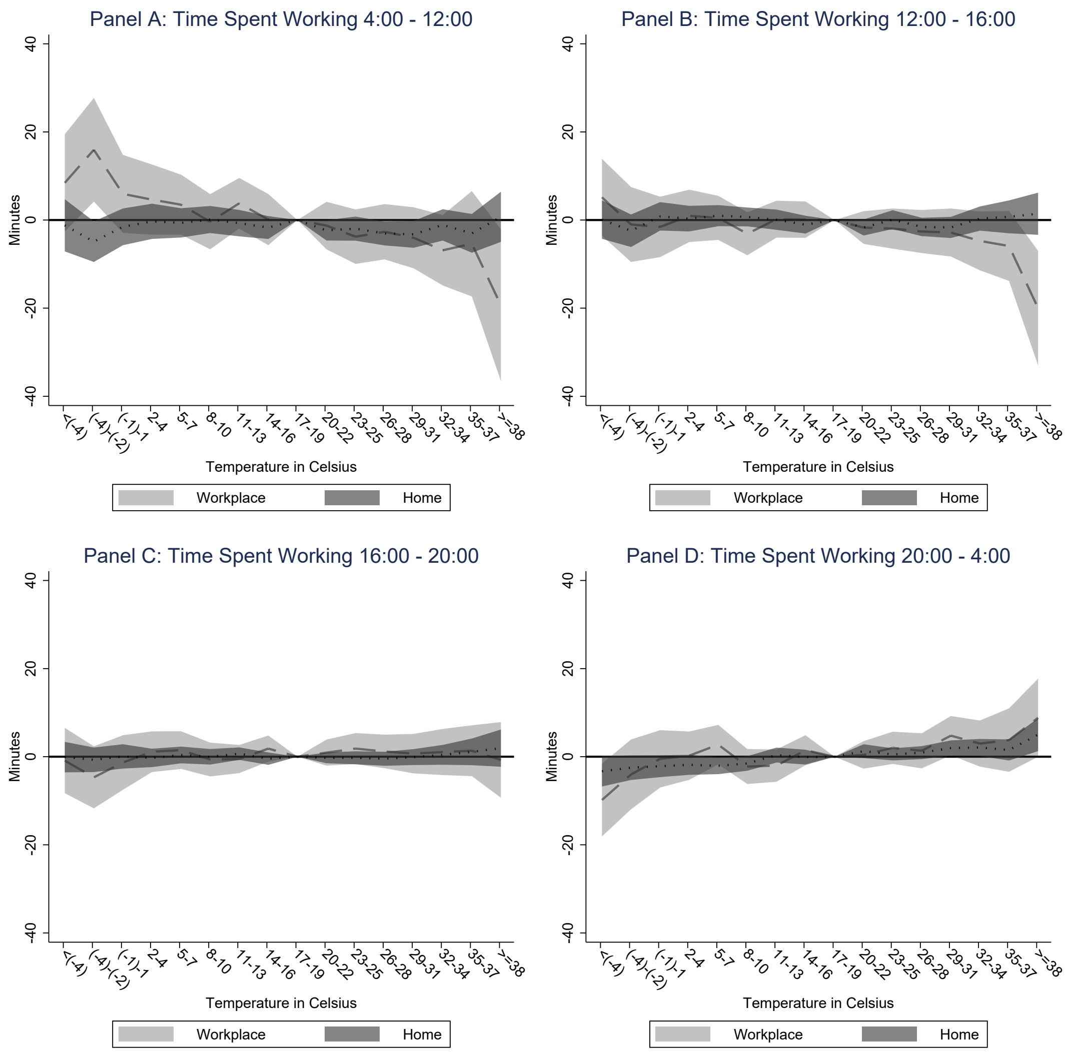
C The Place of Work

Figure C.1: Working Time by Place of Work



Notes: The figure presents the estimates of a set of indicators of whether temperature in a county-day falls within specific 3-degree Celsius intervals. The set of dummies covers the full temperature distribution and we use as the benchmark the interval between 17 and 19 Celsius degrees. We use as the dependent variables the time (in minutes per day) that individuals spend working from home and their workplace. The sample consists of individuals who work on the diary date.

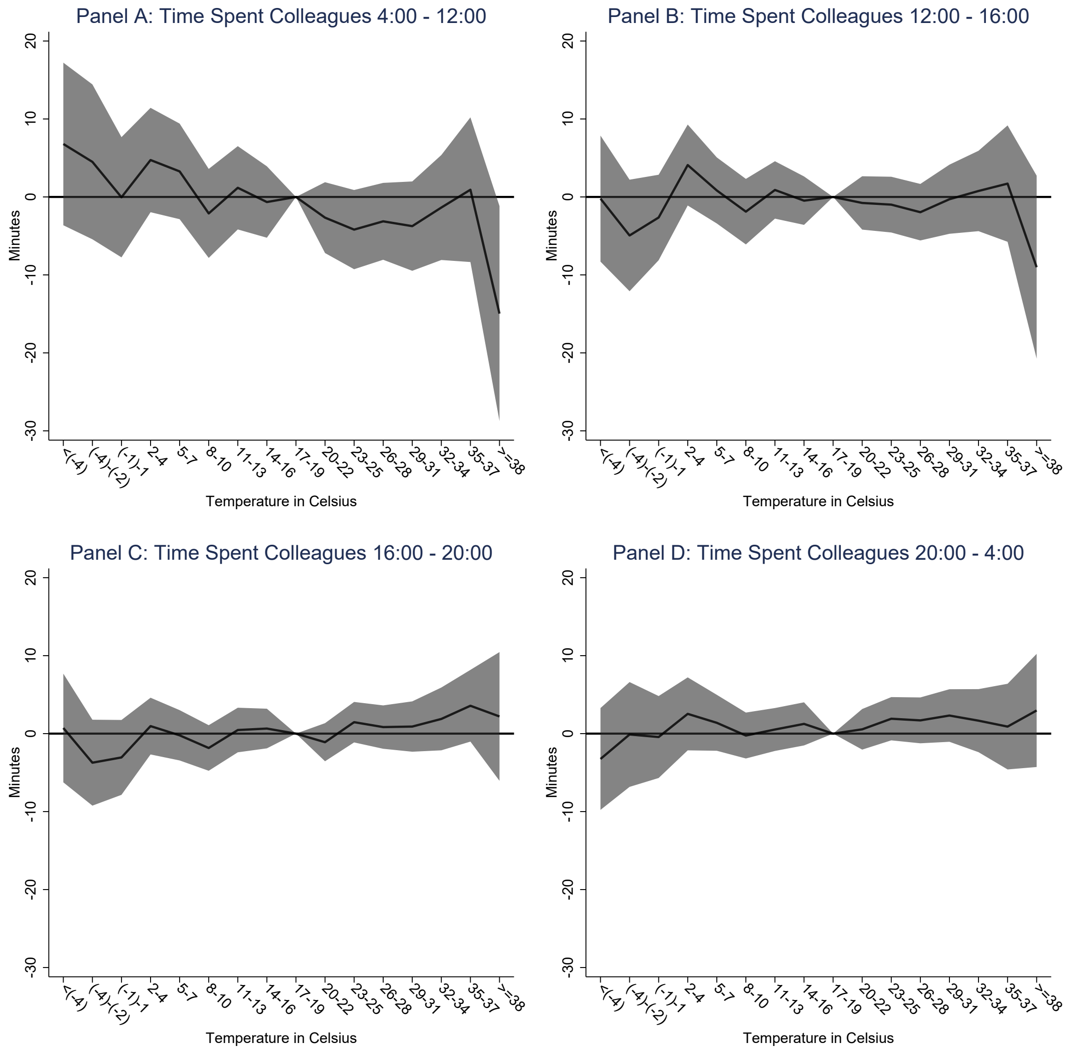
Figure C.2: Working Time by Part of the Day and Place of Work



Notes: The figure presents the estimates of a set of indicators of whether temperature in a county-day falls within specific 3-degree Celsius intervals. The set of dummies covers the full temperature distribution and we use as the benchmark the interval between 17 and 19 Celsius degrees. We use as the dependent variables the time (in minutes per day) that individuals spend working from home and their workplace in the following intervals of the diary day: 4:00 A.M.–12:00 P.M., 12:00 P.M.–4:00 P.M., 4:00 P.M.–8:00 P.M., and 8:00 P.M.–4:00 A.M.. The sample consists of individuals who work on the diary date.

D Time Spent with Colleagues by Part of the Day

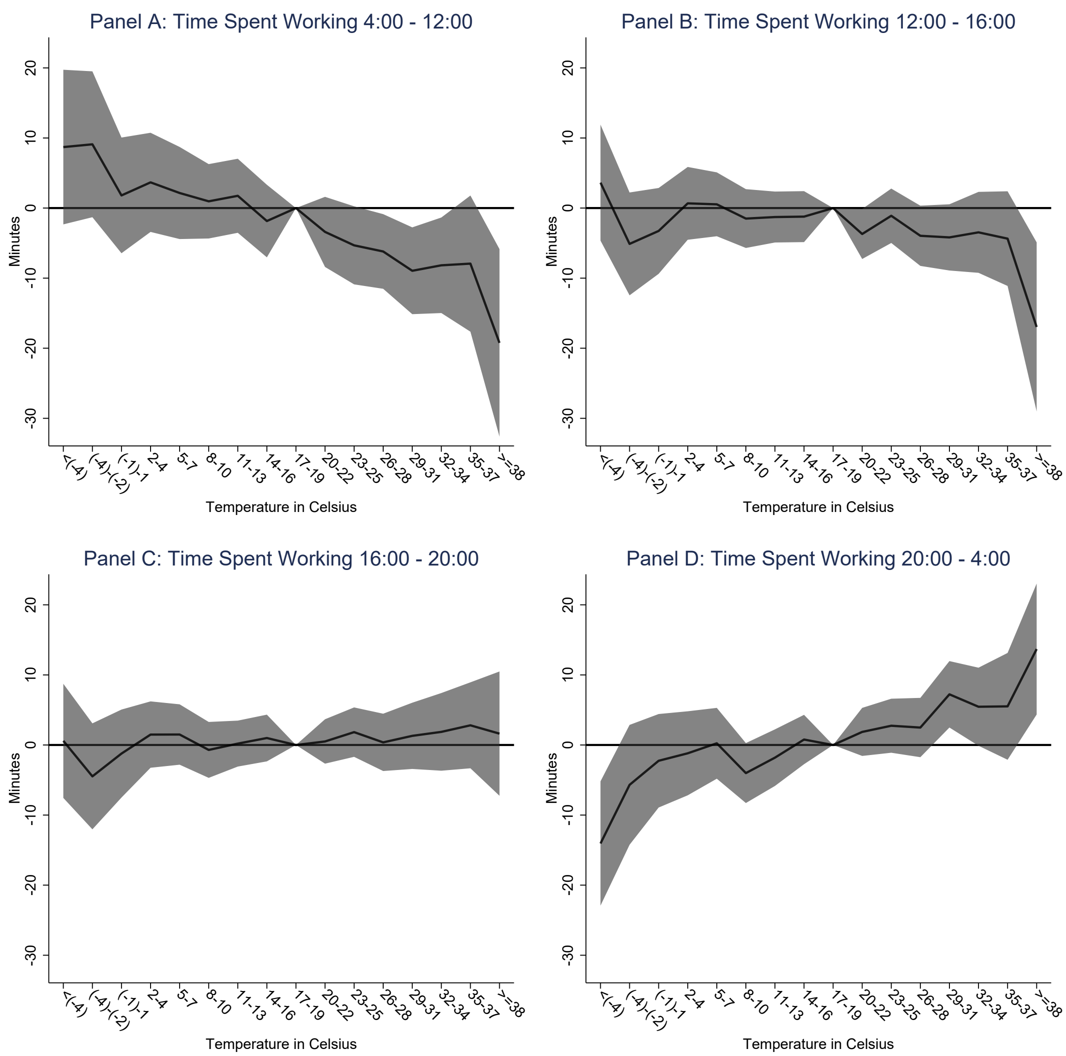
Figure D.1: Time Spent with Colleagues by Part of the Day



Notes: The figure presents the estimates of a set of indicators of whether temperature in a county-day falls within specific 3-degree Celsius intervals. The set of dummies covers the full temperature distribution and we use as the benchmark the interval between 17 and 19 Celsius degrees. We use as the dependent variables the time (in minutes per day) that individuals spend with colleagues in the following intervals of the diary day: 4:00 A.M.–12:00 P.M., 12:00 P.M.–4:00 P.M., 4:00 P.M.–8:00 P.M., and 8:00 P.M.–4:00 A.M.. The sample consists of individuals who work on the diary date.

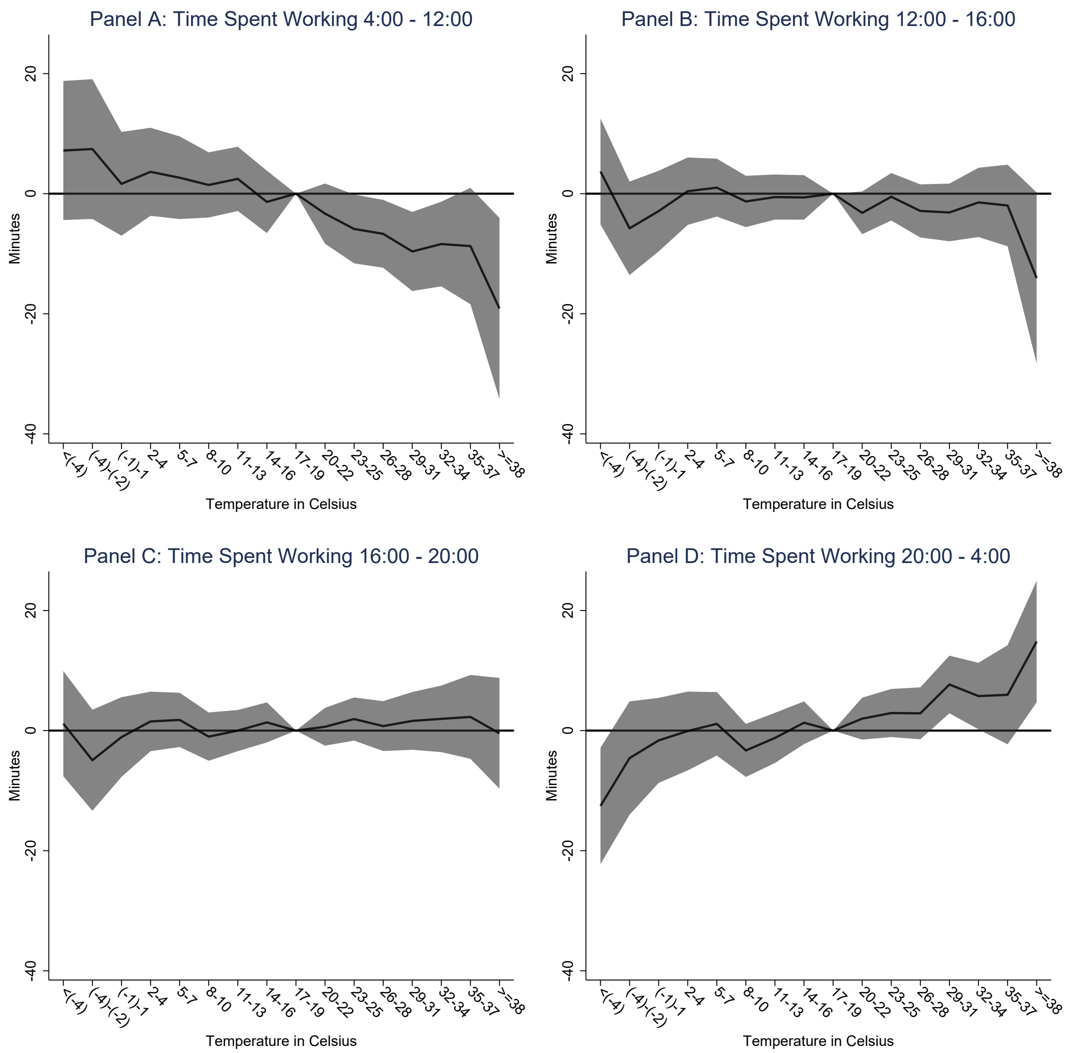
E Robustness Tests

Figure E.1: Accounting for State-year Shocks



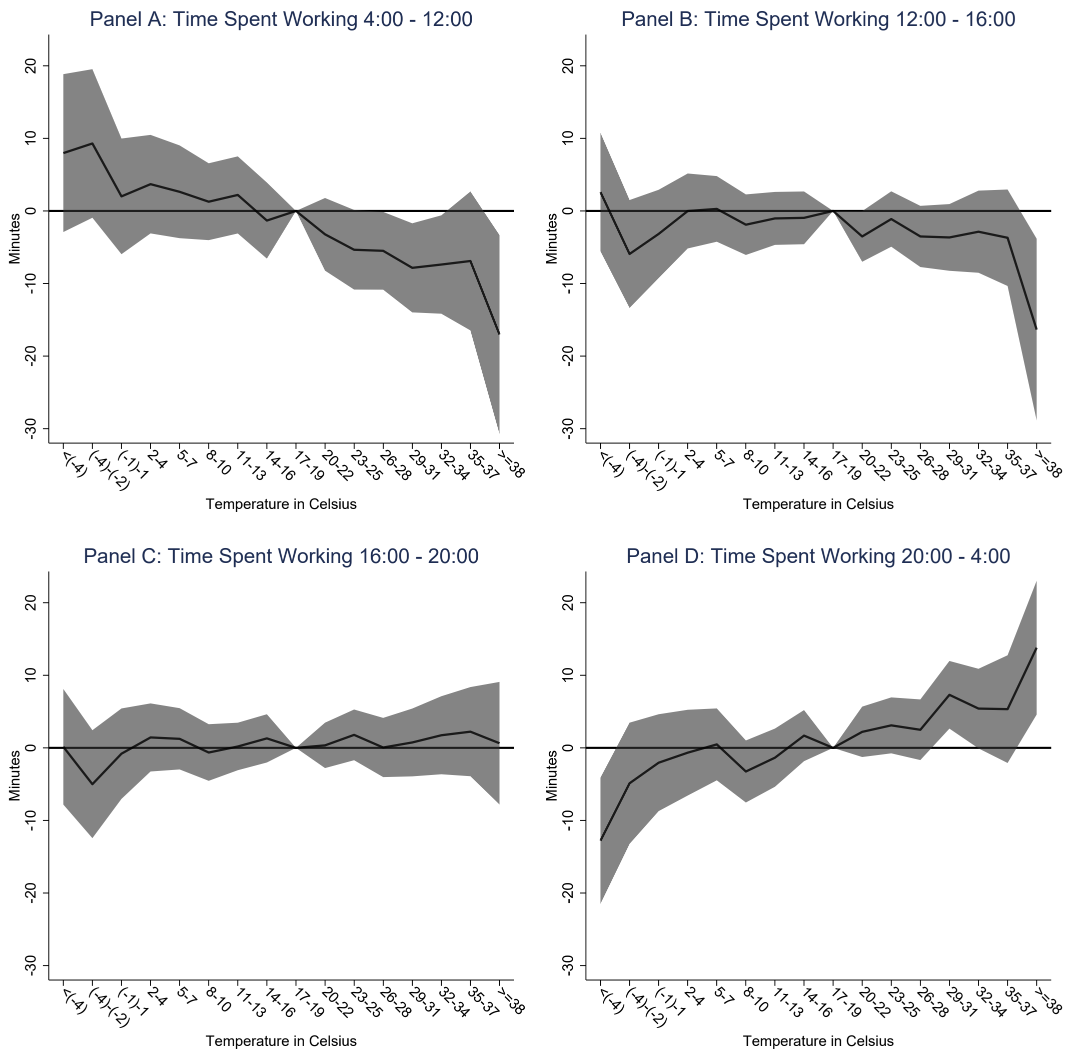
Notes: The figure presents the estimates of a set of indicators of whether temperature in a county-day falls within specific 3-degree Celsius intervals. The set of dummies covers the full temperature distribution and we use as the benchmark the interval between 17 and 19 Celsius degrees. We use as the dependent variables the time (in minutes per day) that individuals spend working in the following intervals of the diary day: 4:00 A.M.–12:00 P.M., 12:00 P.M.–4:00 P.M., 4:00 P.M.–8:00 P.M., and 8:00 P.M.–4:00 A.M.. We estimate the baseline model but also control for state-year dummies. The sample consists of individuals who work on the diary date.

Figure E.2: Accounting for State-month Shocks



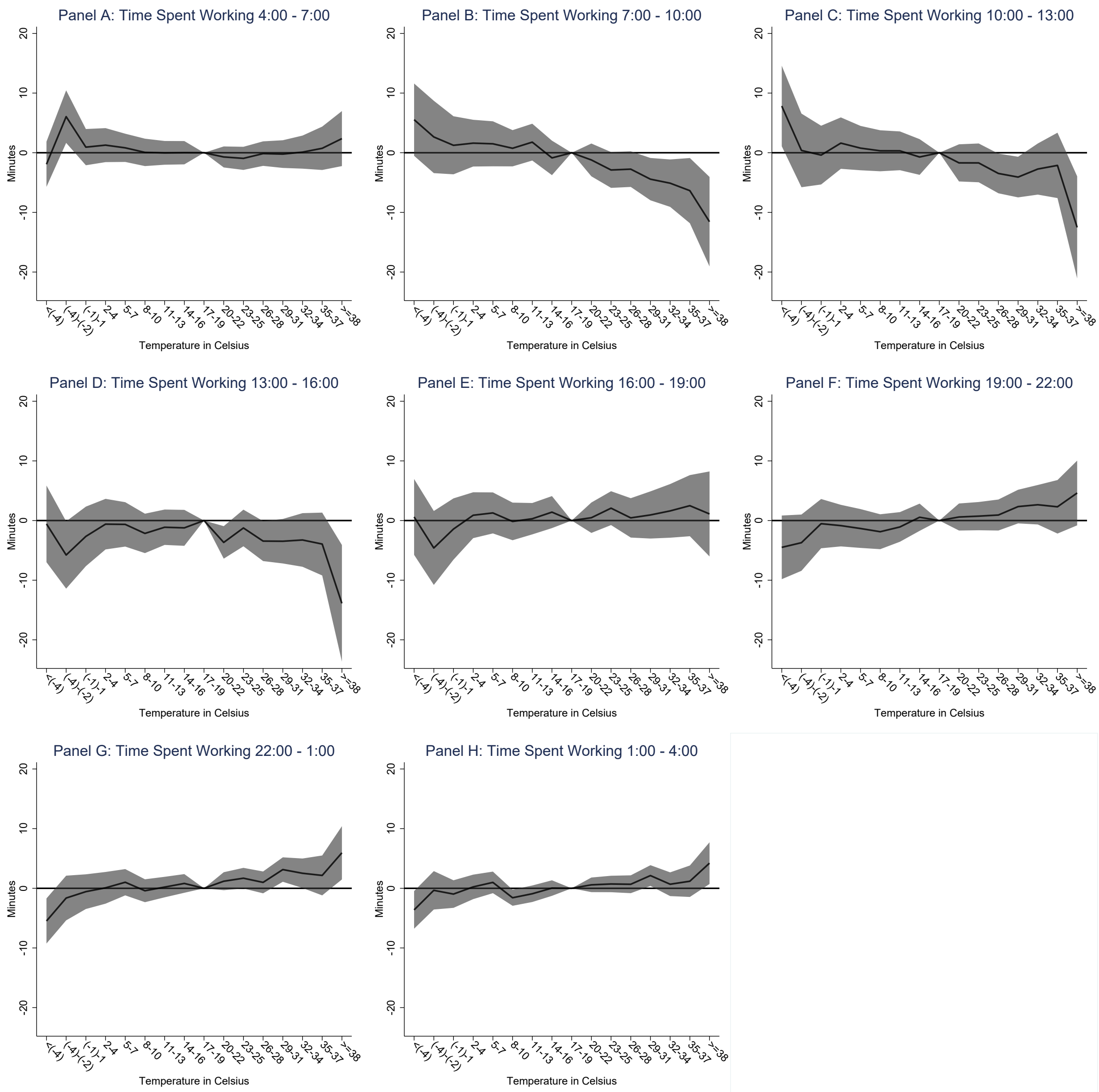
Notes: The figure presents the estimates of a set of indicators of whether temperature in a county-day falls within specific 3-degree Celsius intervals. The set of dummies covers the full temperature distribution and we use as the benchmark the interval between 17 and 19 Celsius degrees. We use as the dependent variables the time (in minutes per day) that individuals spend working in the following intervals of the diary day: 4:00 A.M.–12:00 P.M., 12:00 P.M.–4:00 P.M., 4:00 P.M.–8:00 P.M., and 8:00 P.M.–4:00 A.M.. We estimate the baseline model but also control for state-month dummies. The sample consists of individuals who work on the diary date.

Figure E.3: Alternative Specification



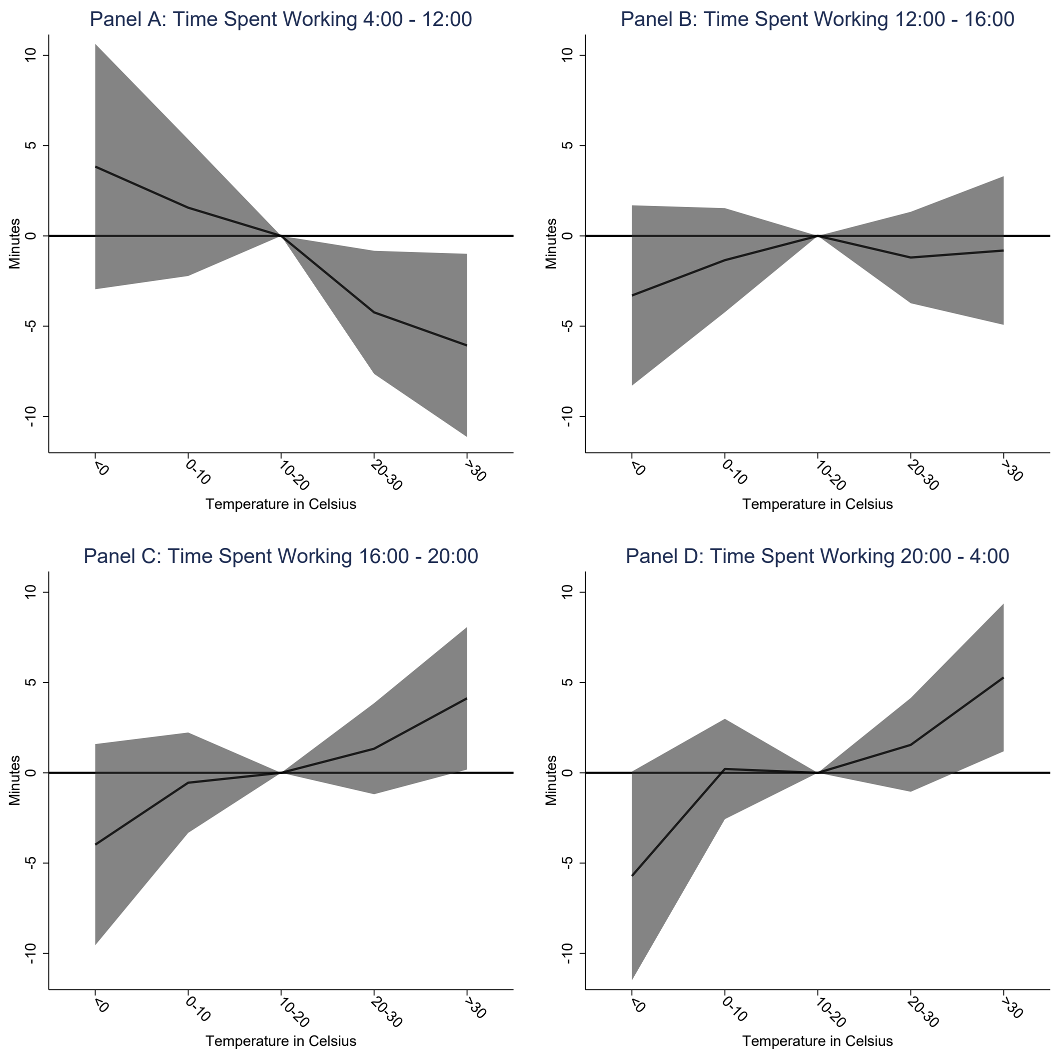
Notes: The figure presents the estimates of a set of indicators of whether temperature in a county-day falls within specific 3-degree Celsius intervals. The set of dummies covers the full temperature distribution and we use as the benchmark the interval between 17 and 19 Celsius degrees. We use as the dependent variables the time (in minutes per day) that individuals spend working in the following intervals of the diary day: 4:00 A.M.–12:00 P.M., 12:00 P.M.–4:00 P.M., 4:00 P.M.–8:00 P.M., and 8:00 P.M.–4:00 A.M.. We estimate the baseline model but control for individual characteristics using sets of dummies. The sample consists of individuals who work on the diary date.

Figure E.4: Alternative Dependent Variables



Notes: The figure presents the estimates of a set of indicators of whether temperature in a county-day falls within specific 3-degree Celsius intervals. The set of dummies covers the full temperature distribution and we use as the benchmark the interval between 17 and 19 Celsius degrees. We use as the dependent variables the time (in minutes per day) that individuals spend working in the following intervals of the diary day: 4:00 A.M.–7:00 A.M., 7:00 A.M.–10:00 A.M., 10:00A.M.–1:00 P.M., 1:00 P.M.–4:00 P.M., 4:00 P.M.–7:00 P.M., 7:00 P.M.–10:00 P.M., 10:00 P.M.–1:00 A.M., and 1:00 A.M.–4:00 A.M.. The sample consists of individuals who work on the diary date.

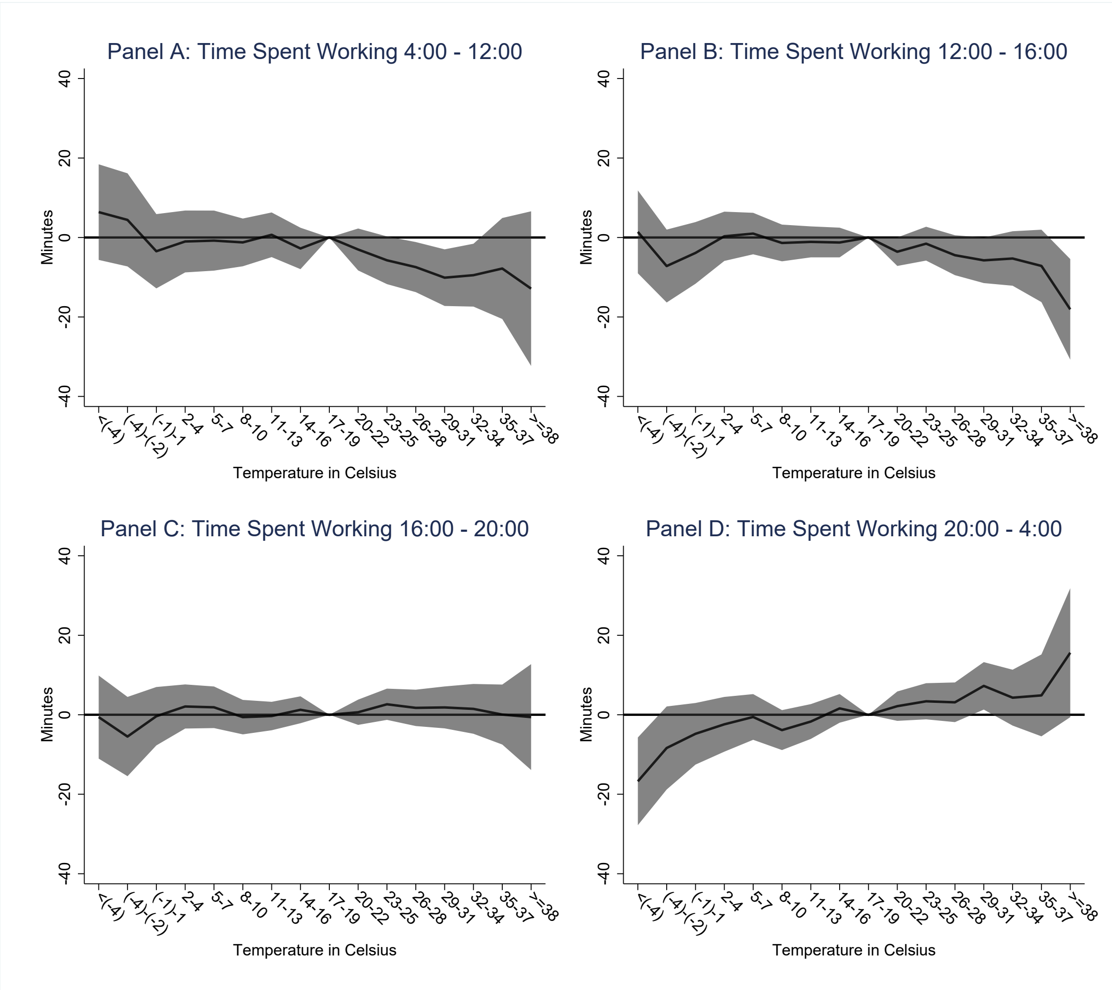
Figure E.5: Alternative Specification



Notes: The figure presents the estimates of a set of indicators of whether temperature in a county-day falls within specific temperature intervals. The set of dummies covers the full temperature distribution and we use as the benchmark the interval between 10 and 20 Celsius degrees. We use as the dependent variables the time (in minutes per day) that individuals spend working in the following intervals of the diary day: 4:00 A.M.–12:00 P.M., 12:00 P.M.–4:00 P.M., 4:00 P.M.–8:00 P.M., and 8:00 P.M.–4:00 A.M.. The sample consists of individuals who work on the diary date.

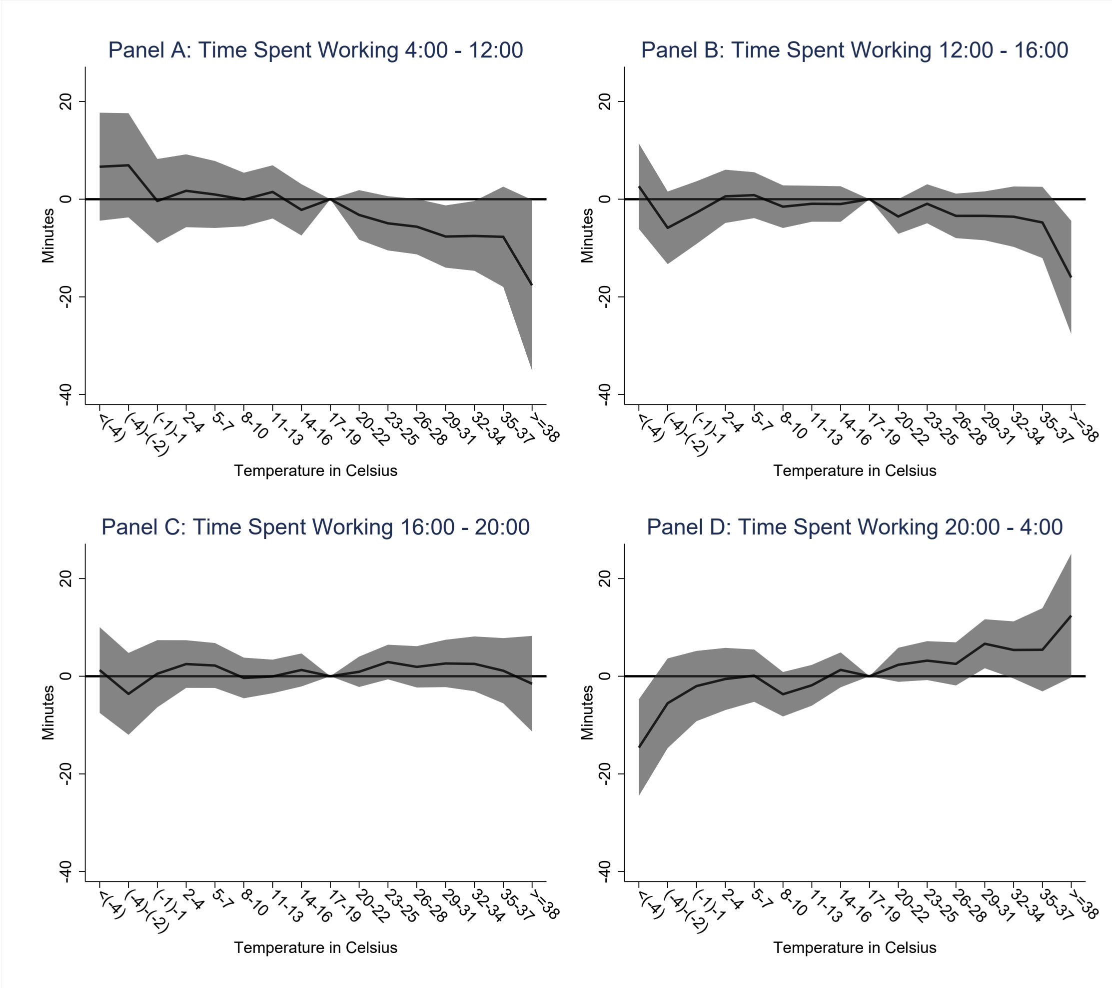
F Adaptive Behavior

Figure F.1: Controlling for the Temperature on the Day Before the Diary Date



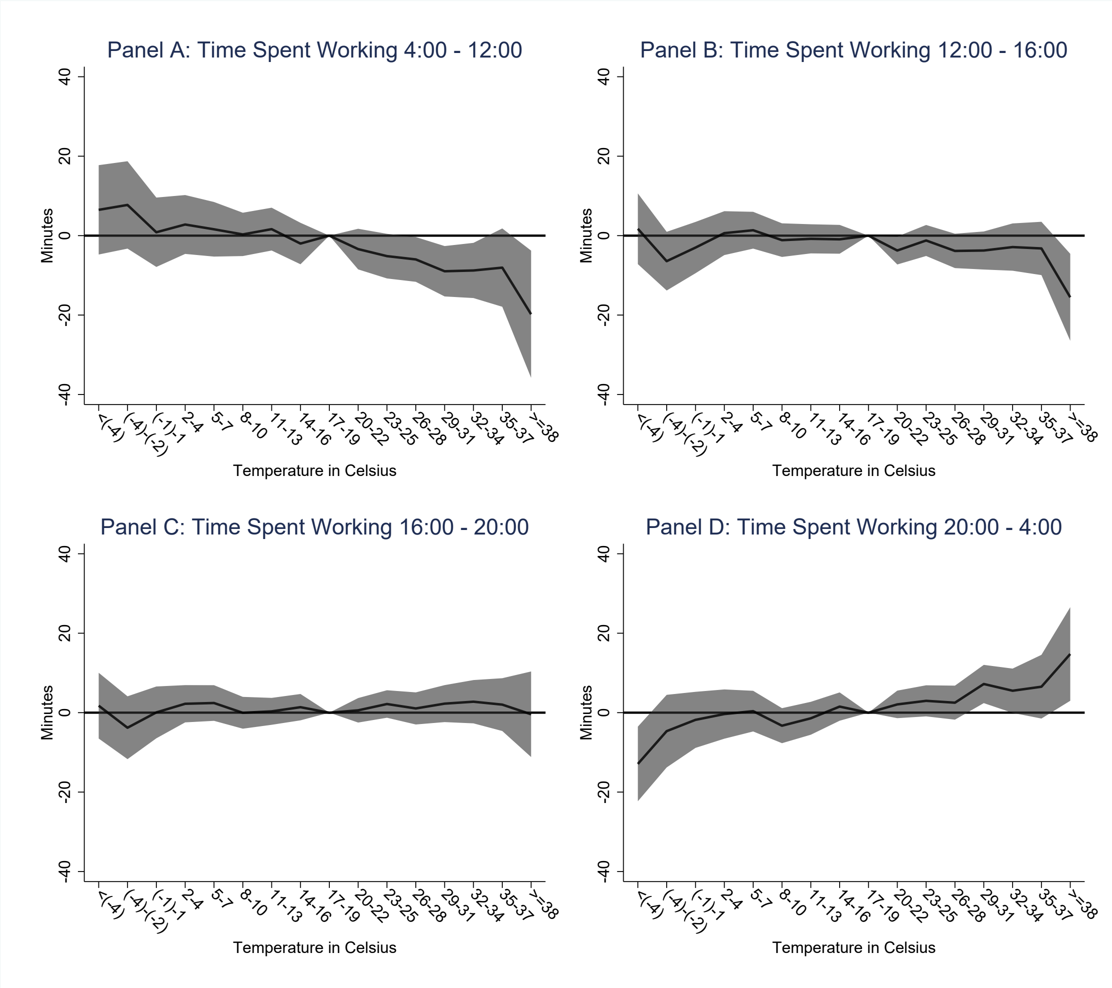
Notes: The figure presents the estimates of a set of indicators of whether temperature in a county-day falls within specific 3-degree Celsius intervals. The set of dummies covers the full temperature distribution and we use as the benchmark the interval between 17 and 19 Celsius degrees. We use as the dependent variables the time (in minutes per day) that individuals spend working in the following intervals of the diary day: 4:00 A.M.–12:00 P.M., 12:00 P.M.–4:00 P.M., 4:00 P.M.–8:00 P.M., and 8:00 P.M.–4:00 A.M.. The sample consists of individuals who work on the diary date. We estimate the baseline model but also control for a set of indicators of 3 Celsius degrees on the temperature conditions on the day prior to the diary date.

Figure F.2: Controlling for the Temperature Two Days Before the Diary Date



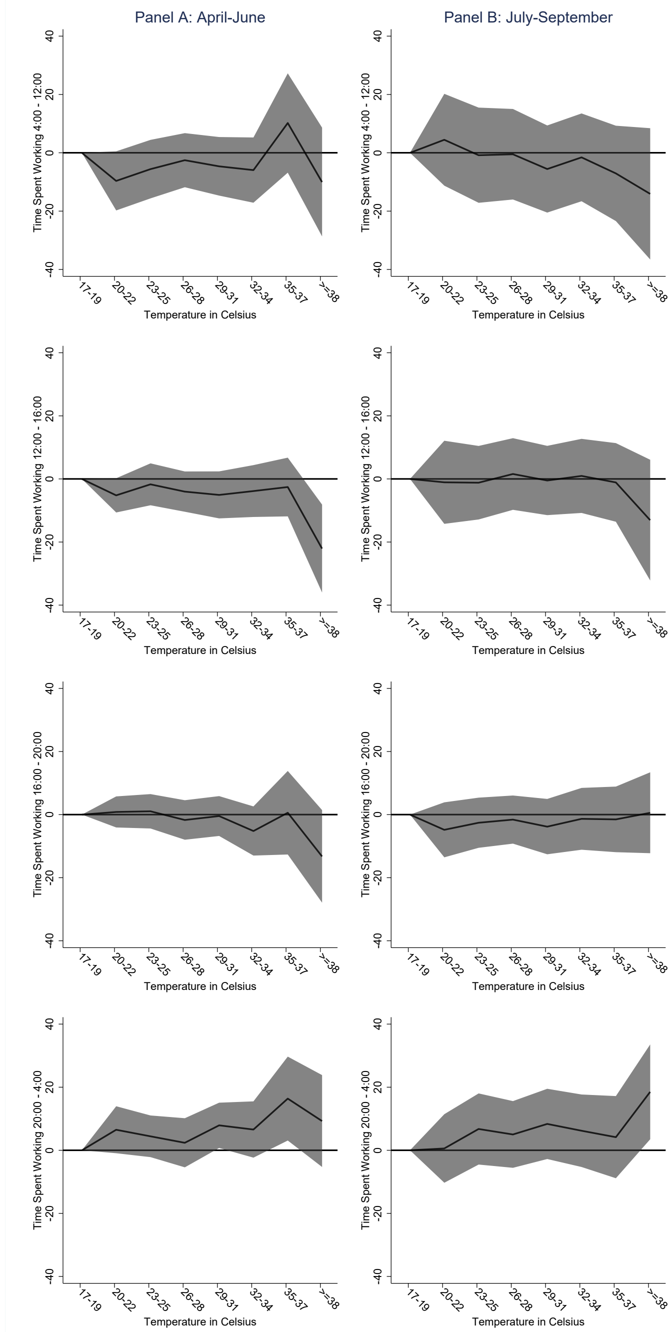
Notes: The figure presents the estimates of a set of indicators of whether temperature in a county-day falls within specific 3-degree Celsius intervals. The set of dummies covers the full temperature distribution and we use as the benchmark the interval between 17 and 19 Celsius degrees. We use as the dependent variables the time (in minutes per day) that individuals spend working in the following intervals of the diary day: 4:00 A.M.–12:00 P.M., 12:00 P.M.–4:00 P.M., 4:00 P.M.–8:00 P.M., and 8:00 P.M.–4:00 A.M.. We estimate the baseline model but also control for a set of indicators of 3 Celsius degrees on the temperature conditions two days prior to the diary date.

Figure F.3: Controlling for the Temperature Three Days Before the Diary Date



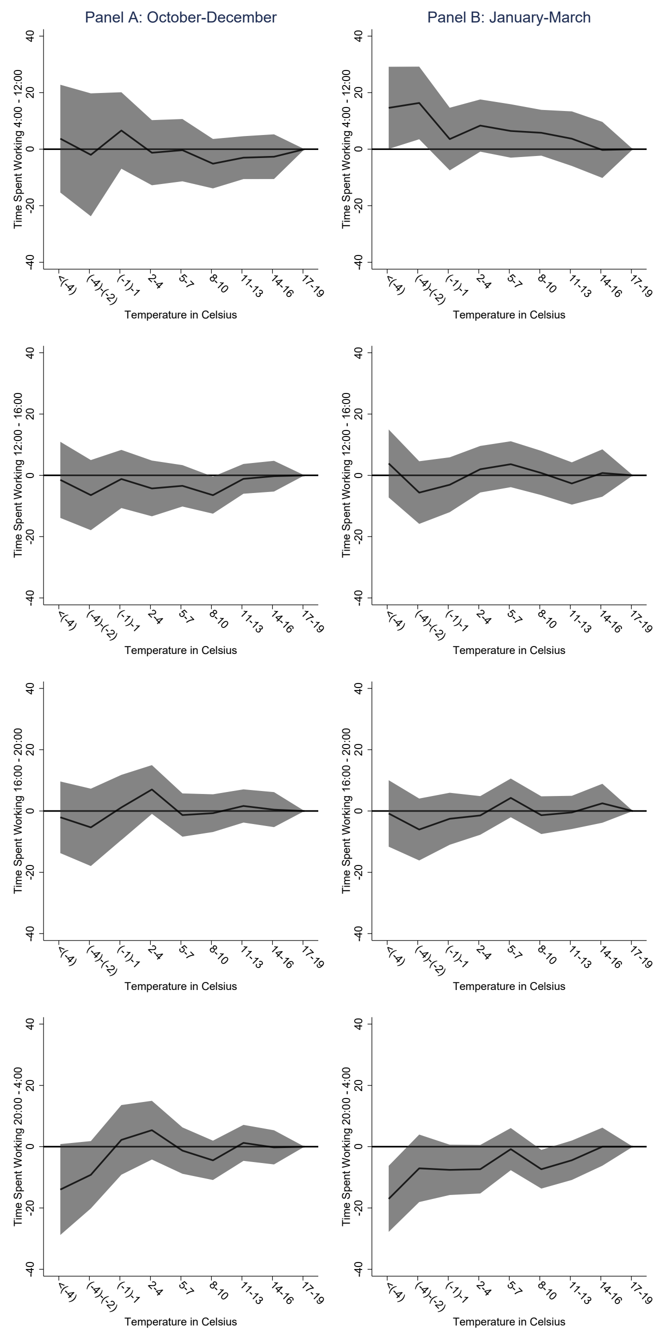
Notes: The figure presents the estimates of a set of indicators of whether temperature in a county-day falls within specific 3-degree Celsius intervals. The set of dummies covers the full temperature distribution and we use as the benchmark the interval between 17 and 19 Celsius degrees. We use as the dependent variables the time (in minutes per day) that individuals spend working in the following intervals of the diary day: 4:00 A.M.–12:00 P.M., 12:00 P.M.–4:00 P.M., 4:00 P.M.–8:00 P.M., and 8:00 P.M.–4:00 A.M.. We estimate the baseline model but also control for a set of indicators of 3 Celsius degrees on the temperature conditions three days prior to the diary date.

Figure F.4: Estimates April–June and July–September



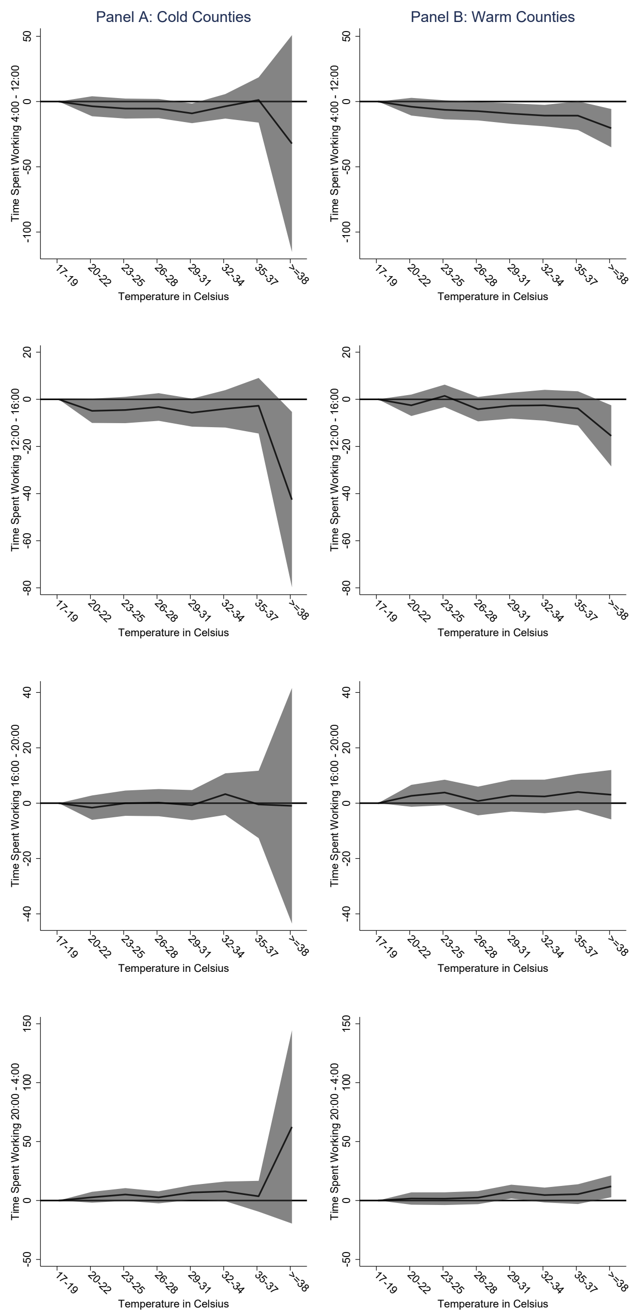
Notes: The figure presents the estimates of a set of indicators of whether temperature in a county-day falls within specific 3-degree Celsius intervals. The set of dummies covers the full temperature distribution and we use as the benchmark the interval between 17 and 19 Celsius degrees. The figure shows the estimates for warm temperatures only. We use as the dependent variables the time (in minutes per day) that individuals spend working in the following intervals of the diary day: 4:00 A.M.–12:00 P.M., 12:00 P.M.–4:00 P.M., 4:00 P.M.–8:00 P.M., and 8:00 P.M.–4:00 A.M.. The sample consists of individuals who work on the diary date during April, May, June, July, August, or September.

Figure F.5: Estimates October–December and January–March



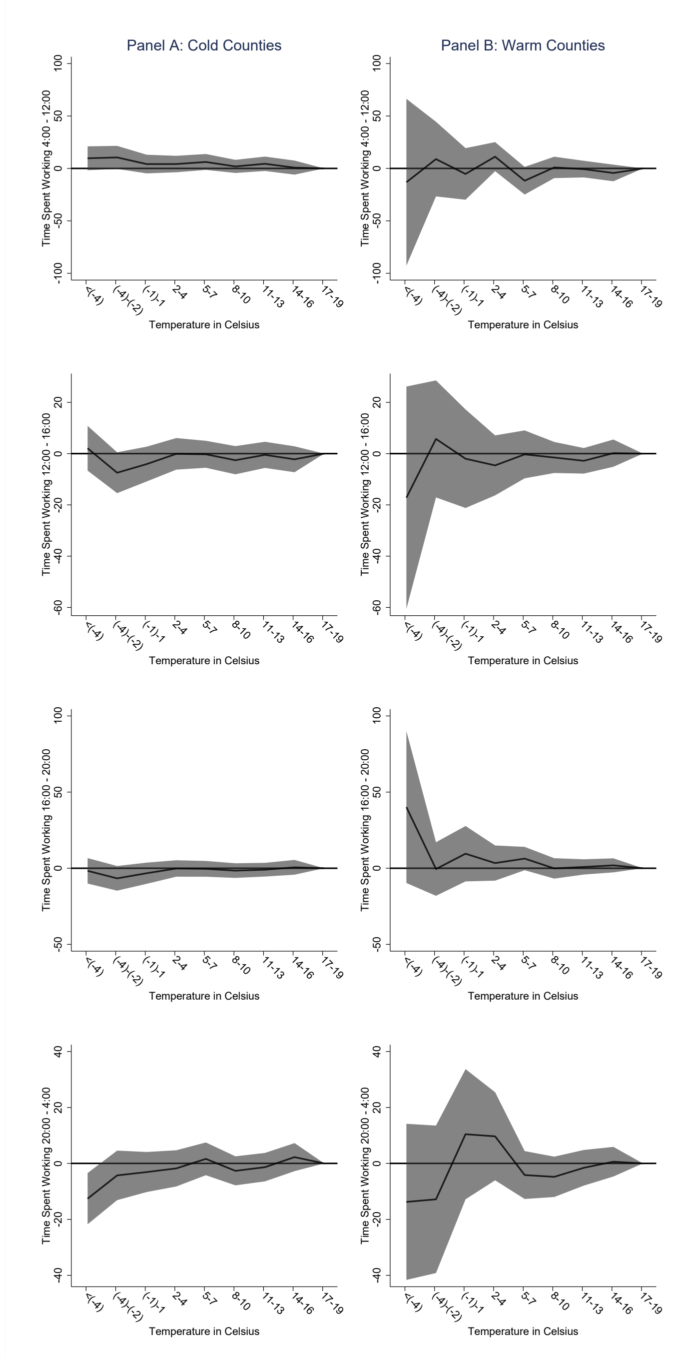
Notes: The figure presents the estimates of a set of indicators of whether temperature in a county-day falls within specific 3-degree Celsius intervals. The set of dummies covers the full temperature distribution and we use as the benchmark the interval between 17 and 19 Celsius degrees. The figure shows the estimates for cold temperatures only. We use as the dependent variables the time (in minutes per day) that individuals spend working in the following intervals of the diary day: 4:00 A.M.–12:00 P.M., 12:00 P.M.–4:00 P.M., 4:00 P.M.–8:00 P.M., and 8:00 P.M.–4:00 A.M.. The sample consists of individuals who work on the diary date during October, November, December, January, February, or March.

Figure F.6: Estimates for Warm Temperatures



Notes: The figure presents the estimates of a set of indicators of whether temperature in a county-day falls within specific 3-degree Celsius intervals. The set of dummies covers the full temperature distribution and we use as the benchmark the interval between 17 and 19 Celsius degrees. We use as the dependent variables the time (in minutes per day) that individuals spend working in the following intervals of the diary day: 4:00 A.M.–12:00 P.M., 12:00 P.M.–4:00 P.M., 4:00 P.M.–8:00 P.M., and 8:00 P.M.–4:00 A.M.. The sample consists of individuals who work on the diary date and who live in counties with an average temperature during the period of analysis higher than the mean temperature of the sample.

Figure F.7: Estimates for Cold Temperatures



Notes: The figure presents the estimates of a set of indicators of whether temperature in a county-day falls within specific 3-degree Celsius intervals. The set of dummies covers the full temperature distribution and we use as the benchmark the interval between 17 and 19 Celsius degrees. We use as the dependent variables the time (in minutes per day) that individuals spend working in the following intervals of the diary day: 4:00 A.M.–12:00 P.M., 12:00 P.M.–4:00 P.M., 4:00 P.M.–8:00 P.M., and 8:00 P.M.–4:00 A.M.. The sample consists of individuals who work on the diary date and who live in counties with an average temperature during the period of analysis lower than the mean temperature of the sample.

G Summary Statistics for Subsamples

Table G.1: Descriptive Statistics by Subgroup

	Economic Activity		Flexibility of the Job	
	Expansion	Recession	Does not Work from Home	Works from Home
Female	0.48	0.49	0.49	0.49
	(0.50)	(0.50)	(0.50)	(0.50)
Age	43.11	42.60	42.03	45.49
	(13.17)	(12.94)	(13.26)	(12.40)
White	0.80	0.80	0.78	0.84
	(0.40)	(0.40)	(0.41)	(0.36)
Education Level: Less than High-school	0.08	0.08	0.10	0.02
	(0.27)	(0.28)	(0.30)	(0.15)
Education Level: High-school	0.20	0.21	0.24	0.09
	(0.40)	(0.40)	(0.43)	(0.29)
Education Level: Some College	0.72	0.71	0.66	0.89
	(0.45)	(0.45)	(0.47)	(0.32)
Precipitation (tenths of mm)	28.71	27.83	28.52	28.48
	(75.58)	(72.83)	(75.93)	(72.39)
Snowfall (mm)	1.49	1.75	1.37	2.00
	(11.05)	(13.60)	(10.43)	(14.44)
Time Spent Working	430.57	423.50	467.68	328.38
	(199.86)	(204.59)	(162.44)	(250.50)
Time Spent Working 4:00 - 12:00	186.03	182.39	206.35	130.28
	(122.81)	(121.97)	(116.31)	(121.58)
Time Spent Working 12:00 - 16:00	143.18	139.90	156.61	105.60
	(86.45)	(87.74)	(79.55)	(93.59)
Time Spent Working 16:00 - 20:00	67.52	66.61	70.98	57.79
	(75.93)	(76.25)	(78.51)	(68.17)
Time Spent Working 20:00 - 4:00	33.84	34.60	33.74	34.71
	(84.39)	(85.96)	(90.87)	(66.25)
N	35363	10392	33037	12718

Notes: The table shows summary statistics of some socio-demographic characteristics and time use variables. Columns 1–2 present descriptive statistics for the subsamples of individuals who work during an economic expansion and recession, respectively. Columns 3–4 present descriptive statistics for the subsamples of individuals who do not work from home and work from home, respectively. We report the mean of these variables, and their standard deviations in parentheses.

Table G.2: Descriptive Statistics by Subgroup

	Exposure to Temperature		Presence of Children at Home at Home	
	High	Low	No	Yes
Female	0.23	0.55	0.48	0.49
	(0.42)	(0.50)	(0.50)	(0.50)
Age	43.82	42.74	47.21	38.88
	(11.98)	(13.36)	(14.53)	(9.99)
White	0.83	0.79	0.78	0.82
	(0.38)	(0.41)	(0.41)	(0.39)
Education Level: Less than High-school	0.11	0.07	0.06	0.10
	(0.31)	(0.26)	(0.24)	(0.30)
Education Level: High-school	0.29	0.18	0.21	0.19
	(0.45)	(0.38)	(0.41)	(0.39)
Education Level: Some College	0.60	0.75	0.73	0.71
	(0.49)	(0.43)	(0.44)	(0.45)
Precipitation (tenths of mm)	28.06	28.68	28.27	28.75
	(75.10)	(75.03)	(74.56)	(75.36)
Snowfall (mm)	1.38	1.60	1.50	1.59
	(10.09)	(12.12)	(11.57)	(11.80)
Time Spent Working	467.03	420.32	435.71	422.38
	(191.72)	(201.37)	(199.58)	(202.09)
Time Spent Working 4:00 - 12:00	224.30	175.37	186.29	184.15
	(125.88)	(119.41)	(122.95)	(122.30)
Time Spent Working 12:00 - 16:00	148.82	141.21	144.08	140.83
	(83.62)	(87.33)	(85.71)	(87.73)
Time Spent Working 16:00 - 20:00	59.03	69.81	70.64	64.07
	(71.80)	(77.01)	(77.20)	(74.67)
Time Spent Working 20:00 - 4:00	34.89	33.94	34.70	33.33
	(92.54)	(82.76)	(86.08)	(83.43)
N	9694	35801	22585	23170

Notes: The table shows summary statistics of some socio-demographic characteristics and time use variables. Columns 1–2 present descriptive statistics for the subsamples of individuals who have a high and a low risk of exposure to the ambient temperature at work, respectively. Columns 3–4 present descriptive statistics for the subsamples of individuals who do not live and live with a child at home, respectively. We report the mean of these variables, and their standard deviations in parentheses.

H Heterogeneity by Age and Number of Children

Table H.1: Heterogeneity by Age of the Youngest Child

	Age of Youngest Child < 10				Age of Youngest Child > 10			
	Time Working (mins) 4:00–12:00	Time Working (mins) 12:00–16:00	Time Working (mins) 16:00–20:00	Time Working (mins) 20:00–4:00	Time Working (mins) 4:00–12:00	Time Working (mins) 12:00–16:00	Time Working (mins) 16:00–20:00	Time Working (mins) 20:00–4:00
Temp < 0	-2.973	-6.976	-1.695	-1.121	18.436*	2.494	-8.046	-8.245
	(5.937)	(4.575)	(4.040)	(4.959)	(9.886)	(6.659)	(5.800)	(5.922)
Temp >= 0 & < 10	-0.639	-2.959	1.008	0.110	6.359	3.144	-5.396*	-0.658
	(3.379)	(2.600)	(2.311)	(2.809)	(5.163)	(3.667)	(3.206)	(3.660)
Temp >= 20 & < 30	1.059	0.597	2.879	-1.871	-8.218*	-1.237	-0.175	0.217
	(3.279)	(2.172)	(2.272)	(2.412)	(4.449)	(3.149)	(2.778)	(3.003)
Temp > 30	-1.150	1.679	6.726*	0.137	-4.909	1.911	6.066	4.162
	(5.058)	(3.505)	(3.506)	(3.827)	(6.647)	(5.325)	(4.699)	(5.159)
Time-varying cov	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Weather cov	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
County dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year-month dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	14,848	14,848	14,848	14,848	7,855	7,855	7,855	7,855

* p<0.10, ** p<0.05, *** p<0.01

Notes: Standard errors in parentheses. The table presents the estimates of a set of indicators of whether temperature in a county-day falls within specific temperature intervals. The set of dummies covers the full temperature distribution and we use as the benchmark the interval between 10 and 20 Celsius degrees. We use as the dependent variables the time (in minutes per day) that individuals spend working in the following intervals of the diary day: 4:00 A.M.–12:00 P.M., 12:00 P.M.–4:00 P.M., 4:00 P.M.–8:00 P.M., and 8:00 P.M.–4:00 A.M.. The subsamples consist of individuals who work on the diary date, and who live with a child younger and older than 10 at home, respectively.

Table H.2: Heterogeneity by Number of Children

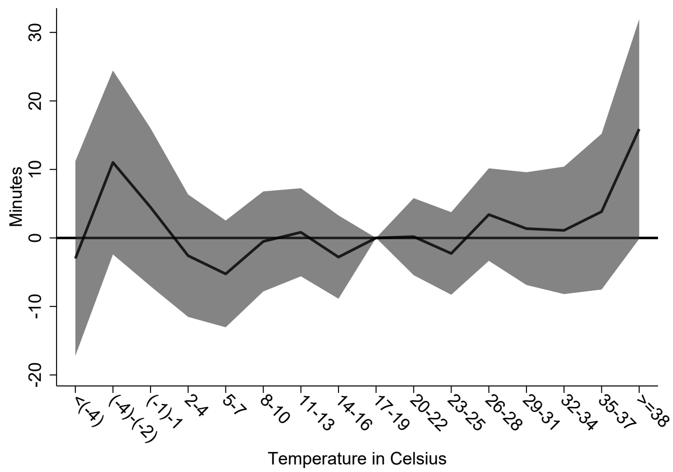
	One Child				Two or More Children			
	Time Working (mins) 4:00–12:00	Time Working (mins) 12:00–16:00	Time Working (mins) 16:00–20:00	Time Working (mins) 20:00–4:00	Time Working (mins) 4:00–12:00	Time Working (mins) 12:00–16:00	Time Working (mins) 16:00–20:00	Time Working (mins) 20:00–4:00
Temp < 0	12.503	0.884	-6.905	-14.545**	-0.424	-5.766	-2.102	2.481
	(8.799)	(5.602)	(6.090)	(5.719)	(6.620)	(4.742)	(4.223)	(5.155)
Temp >= 0 & < 10	6.231	-0.602	-5.593*	-4.999	-1.300	-1.783	1.226	2.765
	(4.302)	(2.932)	(2.919)	(3.345)	(3.412)	(2.838)	(2.700)	(2.946)
Temp >= 20 & < 30	-7.808*	-2.108	1.732	1.038	0.593	0.628	1.603	-1.693
	(4.367)	(3.045)	(2.908)	(3.060)	(3.389)	(2.334)	(2.325)	(2.477)
Temp > 30	-3.905	-0.997	6.729	2.957	-3.411	2.388	4.644	1.531
	(6.469)	(4.555)	(4.381)	(4.598)	(5.073)	(3.864)	(3.642)	(3.847)
Time-varying cov	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Weather cov	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
County dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year-month dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	9,445	9,445	9,445	9,445	13,267	13,267	13,267	13,267

* p<0.10, ** p<0.05, *** p<0.01

Notes: Standard errors in parentheses. The table presents the estimates of a set of indicators of whether temperature in a county-day falls within specific temperature intervals. The set of dummies covers the full temperature distribution and we use as the benchmark the interval between 10 and 20 Celsius degrees. We use as the dependent variables the time (in minutes per day) that individuals spend working in the following intervals of the diary day: 4:00 A.M.–12:00 P.M., 12:00 P.M.–4:00 P.M., 4:00 P.M.–8:00 P.M., and 8:00 P.M.–4:00 A.M.. The subsamples consist of individuals who work on the diary date, and who live with one child or at least two children at home, respectively.

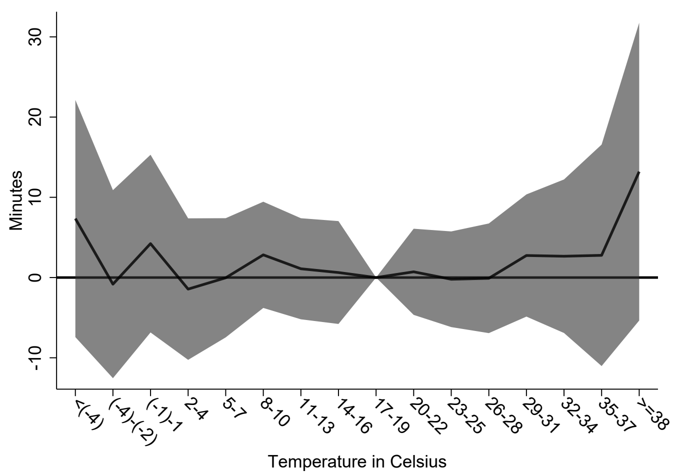
I The Effect of Temperature on Non-Working Time

Figure I.1: Leisure Time



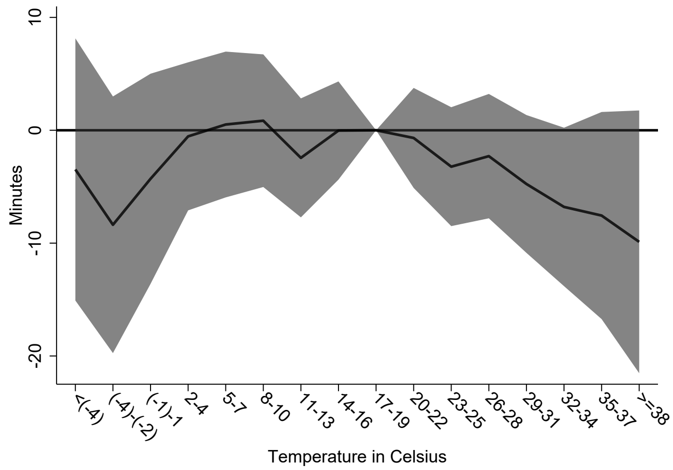
Notes: The figure presents the estimates of a set of indicators of whether temperature in a county-day falls within specific 3-degree Celsius intervals. The set of dummies covers the full temperature distribution and we use as the benchmark the interval between 17 and 19 Celsius degrees. We use as the dependent variable the time (in minutes per day) that individuals spend in leisure activities on the diary date. The sample consists of individuals who work on the diary date.

Figure I.2: Home Production Time



Notes: The figure presents the estimates of a set of indicators of whether temperature in a county-day falls within specific 3-degree Celsius intervals. The set of dummies covers the full temperature distribution and we use as the benchmark the interval between 17 and 19 Celsius degrees. We use as the dependent variable the time (in minutes per day) that individuals spend in home production activities on the diary date. The sample consists of individuals who work on the diary date.

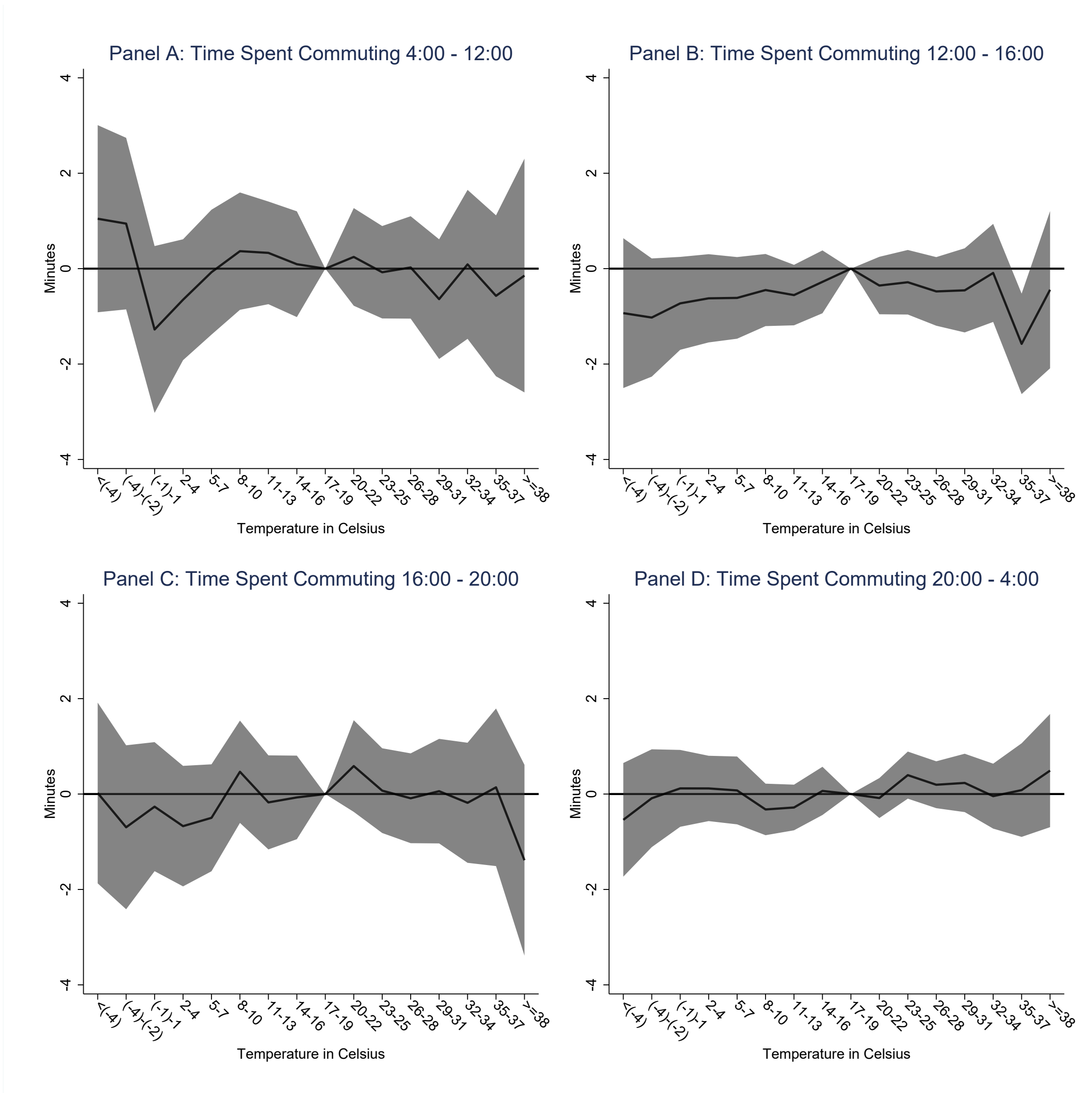
Figure I.3: Sleep Time



Notes: The figure presents the estimates of a set of indicators of whether temperature in a county-day falls within specific 3-degree Celsius intervals. The set of dummies covers the full temperature distribution and we use as the benchmark the interval between 17 and 19 Celsius degrees. We use as the dependent variable the time (in minutes per day) that individuals spend sleeping on the diary date. The sample consists of individuals who work on the diary date.

J Commuting Time by Part of the Day

Figure J.1: Commuting Time by Part of the Day



Notes: The figure presents the estimates of a set of indicators of whether temperature in a county-day falls within specific 3-degree Celsius intervals. The set of dummies covers the full temperature distribution and we use as the benchmark the interval between 17 and 19 Celsius degrees. We use as the dependent variables the time (in minutes per day) that individuals spend commuting in the following intervals of the diary day: 4:00 A.M.–12:00 P.M., 12:00 P.M.–4:00 P.M., 4:00 P.M.–8:00 P.M., and 8:00 P.M.–4:00 A.M.. The sample consists of individuals who work on the diary date.