Widening the Gap? Temperature and Time Allocation between Men and Women

Yang Jiao[*], Yixuan Li[†], Mengdi Liu[‡]

Abstract

Gender differences in time use have been documented in the literature, but knowledge about the nature of such gender gaps remains limited. This study aims to examine whether changes in temperature, affect gender differentials in time allocation and the potential mechanisms through which the responses might operate. Based on the time use survey data, we find that, relative to men, women decrease their labor supply by approximately one hour during days with extremely high temperatures, despite having fewer working hours than men over the entire distribution of temperature. However, gender differentials in the time allocated to housework and leisure change little with temperature. Our further investigation indicates a substantial part of the gender gap can be explained by gender disparity in family responsibilities due to marriage and parenthood. The gender gap in supply to the market work is more pronounced for those with young children.

JEL: J2, Q5

Keywords: temperature; gender gap; time allocation; labor supply

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[*] Economics and Finance Department of Business and Public Policy, Young Harris College.

[†] Department of Economics, University of Arizona.

[‡] School of International Trade & Economics, University of International Business and Economics.

1 Introduction

While the literature documents gender differences in time use, the nature of the obstacles that prevent women from providing more market work remains unclear. Several constraints faced by women have been examined, including the lack of flexible substitutes for household production (Cortes & Tessada 2011), social norms about women's role in family and housework (Bertrand et al. 2015, Fortin 2005), and the glass ceiling faced by women in the workplace. The focus of previous literature on gender differences has, in general, been on the social environment, while social responses to the natural environment have received less attention. The present study fills this gap by exploring the causal relationship between changes in temperature and gender differentials in time allocation.

Two research questions are addressed in this paper. First, do men and women allocate their time differently in response to changes in temperature? We assume that both men and women divide their time into market work, recreational activities and home production activities. To capture the nonlinear relationship between temperature and an individual time allocation, we flexibly include a series of indicators of 10-degree Fahrenheit temperature bins in all specifications, with the lowest bin below $20°F$ and the highest bin above $100°F$.[1] Using data from the 2004-2017 American Time Use Survey (ATUS), we find that except for days with extremely cold temperature, women usually spend less time on paid work than men. Notably, our results indicate a significant gender gap in labor supply such that men and women react differently to hot weather. On extremely hot days, women reduce their working hours substantially more than men do, and the gap is nearly one hour per day. In terms of time devoted to other activities, women, in general, spend more time doing housework and less time on leisure than men. However, the differences in time allocated to housework and leisure between men and women do not vary substantially with temperature.

Second, we also examine factors contributing to the gender differentials in time allocation when temperature changes. We first investigate whether our results can be explained by occupational division by gender, because men and women may choose different types of jobs and gender segregation in occupations are well-documented (such as Anker 1997). Although including occupation and industry fixed effects in the regression helps to control for differences in career choice between men and women, we also conduct another test and divide the samples into outdoor and indoor paid work based on the job's exposure to heat.[2] Compared to the work environment of indoor occupations, outdoor jobs are more likely to be affected by weather (like heatwaves, storms, tropical cyclones, etc). If job segregation is the main driver of the gender gap, we would expect that temperature would have a greater effect on workers in outdoor occupations. However, upon separating the sample into outdoor and indoor occupations, we find counter-intuitive results. The gender gap in labor supply is significantly larger for indoor

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[1] The temperature range converting to equivalent Celsius is from $-6.67°C$ to $37.78°C$, with a temperature of $5.55°C$ in each bin.

[2] In the sample, we indeed find that men are over-represented in outdoor occupations, such as fishing, construction, installation, and transportation while women are concentrated in indoor occupations like office assistant/associates.

workers but not significant for outdoor workers. This suggests that the effect of temperature on gender must be due to causes other than gender differences in occupational exposure to temperature.

We then explore the role of family responsibility in shaping individual behavior across gender in response to changes in temperature. Extreme weather could alter an individual's preferences for work and leisure, and gender preferences about time use may vary over the life cycle. We examine the impact of two important life-changing events: marriage and parenthood. For unmarried men and women, the gender gap is not statistically significant when the temperature changes. For the married group, the result is striking as relative to their married partners, married women are more likely to reduce working hours and increase leisure time on extremely hot days. There is some evidence that women may change their attitude about working after marriage in part because of bearing a greater family burden. The probability of being absent from work to care for family members and provide childcare on extremely sweltering days is three times higher for married women than for men. This is especially true when care-giving provided by married women is essential for providing a backbone of support to younger, older or disabled family members. Heatwaves can trigger a variety of heat stress conditions, such as fatigue, heat stroke, and even death. Married women are likely to devote more time to sick family members under such conditions. We further study the impact of parenthood and finds that married women with young children spend more time taking care of family members when the temperature rises above $80°F$, lending support to the notion that extreme weather events (such as exceedingly high temperatures) demand more (less) time invested in the home (market work) for women. Married women and mothers indeed spend more time with younger children, who are more likely to be affected and become ill during excessive heat events (Bunyavanich et al. 2003, Philipsborn & Chan 2018).

Our identification explores the variations in time allocation across regions in the United States from 2004 to 2017. The cross-region variation helps control for trends over the sample period that were common to all regions, such as changes in behaviors due to rising temperatures across all regions over the period of study. For example, to reduce fatigue, hyperthermia and other heat-related illnesses during summer, more companies are offering flexible working hours to their employees. The cross-time difference helps eliminate intrinsic features of activities that were stable over the decade, such as the higher prevalence of outdoor activities in hot regions versus indoor activities in cold regions. We also control for state-season fixed effects, which refer to the variation in temperature effects across states for different seasons.

The present study relates to two strands of the literature. It complements the studies of the weather effect of individual time allocation. Past literature has focused on the impact of rainfall (Connolly 2008) and temperature (Graff Zivin & Neidell 2014, Krüger & Neugart 2018) on labor supply. We depart from these studies in several aspects. Firstly, we focus on gender differences in time spent on different activities. Considering the importance of inherent gendered division in the market and domestic work, which is often overlooked in the climate change literature, our study, to the best of our knowledge, is the first to investigate the impact of marriage, parenthood and gender roles in the family on an individual's time allocation decision in response to climate change. Our findings indicate that climate change (temperature, in particular) could reinforce the gender division in housework chores and family responsibility, which may prevent women, especially married women with young children, from supplying more time to market work. Our work has profound policy implications as a better understanding of gender differences in time allocation could aid the formulation of climate change policies that aim to promote better work–life balance for men and women. Secondly, our model includes time spent on home production, which is usually omitted in the literature but is a substantial part of daily life for everyone. Given that women are disproportionately shouldering housework chores, ignoring its impact in economic models may lead to bias estimates on time allocation analysis, especially for women. Thirdly, our study covers a wider time range than other works also based on American time use data.[3] Over our sample period, the United States experienced three waves of rising temperature (as shown in A2). The comprehensiveness of the data not only allows us to identify short-run temperature effects but also enables us to control for the cyclical trends. Finally, we classify jobs based on the flexibility of time schedules and the intensity of weather exposure to explain the gender difference in the response to temperature change.

Our research also relates to the literature on gender differences in adaptation to climate change. Previous studies investigate how men and women cope with hurricanes, floods, and other natural disasters, but most focus on developing countries (Denton 2002, Vincent 2007). Gender differences in adaptive capacity to temperature are under-researched, especially in developed countries. One reason is that women in more industrialized countries are believed to have more resources and access to protect themselves from climate change relative to women living in underdeveloped countries. Although different from women in agriculture-based developing countries that are severely affected by high temperatures, we find that women in the United States, a highly developed country, still work less hours than men in high temperatures. This is mainly due to differences in preferences brought about by social norms and differences in family roles. In addition to people whose lives are largely dependent on agriculture, our research highlights the short-run implications, sheds new light on the role of gender differences in adaptation to climate change, and calls for special attention to the impact of climate change on women in industrialized countries.

The rest of this paper is organized as follows. We first review the literature and related studies in Section 2 and introduce the data sets and describe the methodology in Section 3. Section 4 discusses the main findings and is followed by a discussion of the mechanisms behind the main findings in Section 5. We further discuss the adaptation to heatwaves from both the time and space dimensions in Section 6. In Section 7, we test our main findings with alternative sub-samples and specifications. Finally, Section 8 concludes the paper.

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[3] In comparison, one year of time diary data (2003) are used in Connolly (2008) and four years (between 2003-2006) are used in Graff Zivin & Neidell (2014).

2 Background and Related Literature

2.1 Climatic Impact is Not Gender Neutral

There is strong evidence that the earth's climate has changed considerably over the last century, mainly due to human activities. Increasing temperatures, rising sea levels, and the increases in the intensity and frequency of disasters and extreme events are expected to have largely adverse effects on human behavior and well-being. Men and women may respond differently to environmental changes due to their biological and preferential differences, variation in social roles, and the gender division of labor. According to the United Nations Framework Convention on Climate Change (UNFCCC), the degree to which people are affected by climate change is a function not only of their socioeconomic status, income, culture, and political power but also gender.[4] Therefore, climatic impact is not gender neutral, and women face additional risks and greater burdens than men, due in large part to gender inequities that result in women disproportionately bearing the brunt of disaster impacts.

Studies examining the climatic impact on women have focused on the areas of income generation activities (Cannon 2002), labor productivity and health (Sorensen et al. 2018). In most societies, women are primarily responsible for household tasks and caring for family members in additional to the role of secondary earners in the household. During extreme weather events, children (especially young children) are at greater risk of becoming sick (Bunyavanich et al. 2003, Knowlton et al. 2008). The dual role that women play makes them more vulnerable to climate change. Climate change will also place additional burdens on women's health because their particular physical vulnerabilities, their roles as carers in families, and the additional work that is required of them due to depletion of environmental conditions may lead to health damage. Women and men are not homogenous groups but include people of various ages, ethnicity and education and income levels. These social categories also relate to differences in influence, attitude and contribution to climate change, to how people are affected by it and what opportunities they posses to adapt to climate change.

2.2 Climatic Impact and Gender Difference in Time Use

How women and men spend their time is one of the most important but least understood in economics, partly because most countries do not collect time use data on a regular basis. Despite their limited availability across the world, time use surveys provides a unique perspective when analyzing how men and women allocate their time and thus enhance our understanding of the factors leading to gender inequalities in access to economic opportunities and well-being as well as implications for policy making. A growing body of evidence shows that across countries (i) women specialize in housework and care activities, while men focus on market work (Apps

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[4] In 2013, the Intergovernmental Panel on Climate Change (IPCC) further clarified the role of human activities in climate change when it released its Fifth Assessment Report. The full report can be retrieved at https://www.ipcc.ch/site/assets/uploads/2018/02/WG1AR5_all_final.pdf.

2004, Ferrant et al. 2014); (ii) women work longer hours than men when one aggregates the total amount of time spent on paid work, housework and care activities (Sayer 2005); and (iii) life cycle milestones such as marriage and parenthood are important drivers of the gender gap in time use patterns (Apps & Rees 2005).

A small but increasing number of papers have examined the impact of weather on time allocation. Connolly (2008) employs a intertemporal labor supply model and predicts that unpleasant weather (such as heavy rains) is associated with reduced enjoyment of leisure, effectively increasing wages and hours worked. According to her model, weather influences one's earnings through two channels: by altering the hours worked and unit prices. She then tests the model using data from the ATUS, supplemented with daily weather data. The results confirm that on rainy days, men shift approximately half an hour from leisure to work. However, the author does not find evidence of women substituting away from paid work to leisure. Graff Zivin & Neidell (2014) use short-term temperature shocks to study how temperatures affect individuals' allocation of time between labor and leisure using data from the ATUS. They report that additional warming at high temperatures reduces labor hours but that these impacts are primarily concentrated in industries exposed to climate. They also provide evidence that individuals may acclimatize to higher temperatures or adapt through temporal substitution of activities. Krüger & Neugart (2018) test an intertemporal labor supply model with German time use data. Their main identification strategy is to use changes in weather as exogenous shocks and estimate the weather effect on two consecutive days, which should make omitted variable bias less of an issue. Their findings showed some evidence of an interday labor supply substitution effect for women but not for men. Moreover, the small effects of weather on time allocation seem not to be driven substantially by restrictions arising from inflexible working contracts. Thus far, few studies have systematically examined gender differentials in the impact of climate on time use.

2.3 Simple Theoretical Analysis

Our theoretical analysis of temperature effects on individual time allocation to different activities is based on the theoretical model in Connolly (2008), who introduces a weather element into the conventional intertemporal labor supply model.

In her original model, an individual optimally choose the amount of leisure to maximize his or her utility. The worker is assumed to flexibly allocate different amounts of his/her time to paid work between one day and another, as long as the total income reaches the lower bound that he/she desires. Time constraint faced by the worker is that total daily time is divided into time devoted to leisure and paid work. Connolly (2008) further assumes that weather affects one's utility obtained from leisure and that weather conditions are a random event determined by nature. A testable implication derived from her model is that the ratio of the marginal utilities of today and tomorrow's leisure is equal to the ratio of the today and tomorrow's wages divided by the weather conditions on the same date. Assuming that there is no change in wages over such a short period, the substitution rate between today and tomorrow's leisure solely depends on the change in weather quality between two days. In other words, if a worker wakes up one day and observes that the weather is nicer today than it will be tomorrow, he/she will optimally substitute present for future leisure by increasing leisure today and decreasing entertainment tomorrow.

In light of Connolly (2008)'s framework, we modify her model by incorporating the role of gender and including time spent on housework (including care activities provided to family members) in individual time constraint. An individual's utility function therefore depends on his/her leisure and the consumption of home domestic goods.[5] To differentiate between men and women's utility, we assume that women value home domestic goods more than men do. We also assume that weather affects one's utility not only through one's leisure enjoyment but also the "intrinsic" value of home produced goods. As discussed above, individuals may need to spend additional time caring for sick family members caused by intense weather, such as a heatstroke due to excessive sweating temperature. Because of the complexity of the effect of weather on the utility function, it is difficult to predict whether bad weather would increase (or decrease) leisure time. For example, if today's weather is extremely unpleasant, individuals may decrease their leisure time, while bad weather requires more time to be devoted to care activities. As a result, decreasing leisure time may be offset by an increase in time spent on housework and does not necessarily increase one's labor supply. However, our theoretical framework can be used to explain gender differences in the time allocated to different activities.

Given that women's utility is partly determined by the quality of home production goods, a disaster caused by bad weather will be more detrimental to women than men. Therefore, to avoid the loss of utility, women will spend more time on home production, including providing care services to family members. Our assumption internalizes women's social role as family care-givers in their time allocation. Therefore, our **first hypothesis** can be tested empirically: *women with substantial family responsibilities (such as married women and mothers with younger children) are more likely to increase the time spent on housework in the presence of extremely hot weather than men*.

Analogous to the analysis of Connolly (2008), the time allocated to leisure depends on the marginal value of weather quality today versus tomorrow to each individual. Here we assume no difference in men and women's preferences over the substitution rate of marginal value of weather, and thus, we should observe little gender differentials in leisure time. Taken from our first hypothesis, women spend more time on housework but enjoy the same leisure as men in extreme weather conditions, and their supply of paid work should be lower than that of men. Therefore, the **second hypothesis** from our theoretical analysis is that *there will be a larger gender gap in labor supply to market work given extremely high temperatures*.

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[5] Examples of domestic home-produced goods include home cooked meals, a nice garden in the backyard, and well-behaved children.

3 Data and Methodology

3.1 Data

3.1.1 Time Use Data

The time allocation data used in this study are based on data from the American Time Use Survey (ATUS), a nationally representative time use survey sponsored by the Bureau of Labor Statistics (BLS). The ATUS measures the amount of time people spend on various activities during a designated 24-hour period and classifies these activities based on content. ATUS participants are randomly drawn from households who have completed their eighth and final month of interviews for the Current Population Survey (CPS). Survey participants must be older than 15 years of age.

ATUS is a continuous cross-section survey that started in 2003, and the sample used in this study covers the period from 2004 to 2017.[6] ATUS respondents were asked to record all activities, their locations, duration, and the start and stop times. There are eighteen major categories of activities, including Personal Care Activities, Household Activities, Caring For & Helping Household Members, Work & Work-Related Activities, Education, and Household Services. In each major category, there are several second-tier categories. Taking Household Activities as an example, it includes ten second-tier activities, such as essential Housework, Food & Drink Preparation, Presentation & Clean-up, Exterior and Interior Maintenance, Repair & Decoration, Lawn, Garden, and Houseplants. Within each second-tier category, there are various detailed activities identified with a six-digit code.[7]

A possible concern related to our sample arises from selection bias. Because not all households selected to participate in ATUS are available on the designated interview date, the respondent's time diary report may violate random selectivity. We therefore check the distribution of respondents and separate them by gender over weekdays and weekends. Although the response rates are higher during weekends, the observations are evenly distributed across weekdays. The sample distribution by day of the week by gender can be found in Appendix Figure A1, and the distribution across different days is comparable between men and women. Furthermore, Graff Zivin & Neidell (2014) also demonstrate the randomness of the responses by comparing the demographics of respondents and non-respondents who are chosen as participants in the survey.

To detect the mechanism that drives the gender difference in response to temperature changes, one useful practice is to examine what activities individuals substitute and to what extent. We calculate time allocated to work as a broad measure by including total time (in minutes) spent

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[6] The reason for excluding the 2003 wave is that the code for Metropolitan Statistical Areas (MSAs) was updated based on the 2000 Census MSA definitions from the BLS. There is some incompatibility in MSA coding across 2003 and later waves.

[7] More information about the ATUS activity classification can be found at https://www.bls.gov/tus/lexiconnoex0317.pdf.

on all jobs and time spent on other work-related activities.[8] Our measurement of work time also includes the time spent on traveling to work because the length of the commute represents an important opportunity cost of work. Time spent on commuting is directly affected by weather conditions and may affect people's decisions to work on specific days, especially during extreme weather events.[9] We classify personal shopping, eating and drinking, socializing, relaxing and recreation (arts and entertainment, exercising, sports, reading, etc.) as leisure activities. An individual's time spent on home production includes the time spent on household activities (cleaning, laundry, food and drink preparation, interior/exterior maintenance, lawn and garden, caring for pets and animals, home management, etc.), caring for and helping household and non-household members, grocery shopping, household services, and telephone calls with household service providers. Full lists with ATUS activity codes for work, leisure, and home production activities can be found in Appendix Table A1.

3.1.2 Weather Data

Our meteorological data (including temperature, precipitation, wind speed, snow and snow depth) are from the National Climatic Data Center (NCDC). To calculate the temperature, precipitation and other climatic data for a given county on a specific day, we take the average of the valid measures from all weather stations located in a county. For counties that do not have any weather stations and thus no weather data, we use the observed data from the nearest weather station outside of the county border.

It is possible that the entry or exit of a station could make our measurements incomparable over time. To circumvent this potential inconsistency, we include only the stations with annual observed weather data covering the entire sample period. Following this measurement, we successfully collect data from approximately 6,500 stations across the country.

Because our interest is in examining whether and how temperate changes an individual's time allocation, our primary weather element is daily maximum temperature. Figure A2 in the Appendix plots the annual average maximum temperature from 2004 to 2017 in the United States. During the period of study, cyclical changes in the annual temperature across the year are observed. Notably, temperature increases substantially over a certain period of time and reaches its periodical maximum in 2006, 2012, and 2016, followed by a sharp decline where the temperature hits its minimum in 2009 and 2014. The cyclical pattern of temperature over the sample period suggests that a year dummy should be included in the specification. We also calculate the average annual maximum temperature for each county over our sample period. Figure 1 depicts our calculation using 2017 as an illustration. Substantial regional variation across the states is also noted, with the hottest temperature in the Southwest and the coldest temperature in the Northeast. The geographic disparity suggests that state/county

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[8] Other work-related activities include rest periods, coffee and lunch breaks or transport during work activities.

[9] Considering that men tend to spend more time commuting than women and that their hours worked may increase more than women's under extreme weather conditions when commuting is included, we also exclude commuting time in a robustness check.

fixed effects should be included. We further compare the sample distribution of men and women by temperature and find similar patterns, indicating that our sample is unlikely to suffer from selectivity and that the response rate across gender is not temperature sensitive.[10] In addition to the maximum temperature, we further control for other weather elements in all specifications, such as the minimum temperature within a day, precipitation, and average wind speed. The calculation of other climatic elements is similar to the measurement of the maximum temperature.

Daylight is positively correlated with the maximum temperature during the day and may also affect individuals' labor supply and other related labor market activities (Graff Zivin & Neidell 2014). As a result, we include daylight in our estimation as a confounding factor.[11] Our daylight data come from Graff Zivin & Neidell (2014) and include the detailed daily sunrise time, sunset time and total daylight hours for each county. The computation is based on the astronomical algorithms used in Meeus (1991), which uses the latitude and longitude of the county centroid, adjusted for daylight saving time.

3.2 Matching Weather Data with Time Use Survey Data

To link the climatic information with ATUS data, the respondent's residential location must be identified. Although ATUS records the state of residence of all observations, we only have partial information about MSAs (15.02% unknown, 71.34% in the metropolitan area, 13.65% in non-metro area). For those who live in a metropolitan area, 96.05% of their residences are reported with an exact MSA code: the remaining 3.95% report missing MSA information. For those whose residence can be identified at the MSA level, 56.75% have residence information at the county level, while the remaining 43.25% do not have accurate residence information at the county level. For those who report living outside of a metropolitan area, only 2.98% have residence information at the county level.

After identifying the residential location to all individuals included in our sample, three steps are conducted to match the location to the weather variables for an appropriate county. In the first step, we drop observations whose residences are outside of metropolitan areas. We also exclude those who reported living inside a metropolitan area but had no information about MSA codes. After the first step, the sample size is reduced to 68.52% of the original, but we can fully identify the observation's residential location at the MSA level. In the second step, we match the weather data of an observation's residual county on the day when the observation's residence information at the county level is recorded (approximately 56.75% of the observations whose residences are successfully identified at the MSA level report their county information). In the third step, other individuals whose locations can only be identified at the MSA and not the county level are assigned to the most populous county in the MSA in which the individual lives. [12]

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[10] The sample distribution of temperature by gender can be found in Appendix Figure A3.

[11] In a robustness check, we also exclude the effect of daylight and find little impact on the main results.

[12] We also conduct a robustness check by excluding individuals whose locations can only be identified at the

3.2.1 Sample Restriction and Control Variables

To better serve the purpose of our paper, we restrict our sample to employed individuals between 15 and 65 years of age because they constitute the majority of the workforce. In addition, senior employees may respond differently to temperature due to health issues, which is not the focus of this paper. We further exclude individuals who are unpaid family workers, as they may have distinct patterns of time allocation compared with employees who work for pay.[13] Individuals who are in the armed forces are also excluded because their work time lacks flexibility in time allocation compared with the civilian labor force. Note that self-employed individuals are included in the main analysis, but the results change little when they are excluded from the sample.

To control for individual and family factors that may affect time allocation among different activities, we include the following variables: age, age squared, race, educational attainment, marital status, indicator of family income, number of household children under 18, spouse's employment status, and hourly pay of spouse. Marital status is either married, unmarried cohabitants, or single and others. ATUS respondents report their household incomes in one of sixteen income categories ranging from $5,000 and below to $150,000 and above. We include all income categories in the regressions. We also include individuals' job-related characteristics such as job types, part-time employment indicators, and hourly wage rate.[14]

3.2.2 Summary Statistics

After imposing the above restrictions and merging with the weather data, our final sample contains 70,038 observations, among which 49.5% are male and 50.5% are female workers. Approximately 60.6% of the sample report that they have spent at least one hour at work on the day the survey was taken. Table A2 in the Appendix documents the sample distribution by gender. The educational attainment and race distributions are quite similar for male and female respondents. Men and women also have similar age distributions. Compared with female workers, men are more likely to work in outdoor occupations and be self-employed. In terms of family characteristics, men have higher family income. Men are also more likely to marry than women and have a lower rate of single status. Finally, the rate of parenthood status is similar between men and women.

Table 1 details the summary statistics of time spent on market work, home production and leisure. We divide the sample by gender and report the time allocation of men and women separately. The gender gaps in time use for various activities across different groups are all statistically significant.

Panel A shows the time use according to job characteristics and individual and family attributes,

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MSA level.

[13] Unpaid workers account for only 0.09% of employed workers.

[14] ATUS classifies jobs into the following types: federal government jobs, state government jobs, local government jobs, for-profit private jobs, non-profit private jobs, incorporated self-employed, and unincorporated self-employed.

and Panel B presents the statistics of the weather variables. On average, an employed male worker spends 53.61 minutes more on market work and 39.02 minutes more on personal leisure per day than their female counterparts. However, men devote 55.84 fewer minutes to domestic housework and home production than do women. Because many workers in our sample report zero working hours, we exclude workers reporting zero working hours from our full sample and run the regression for workers with working hours separately as a robustness check; the results are still consistent with the full sample.[15] Therefore, our main analysis focuses on the full sample, including workers with both zero and positive working hours.

At the top panel of Table 1, we separate workers based on job flexibility into self-employed and other employed workers. Gender differences in time allocation are notable across different groups of workers. Self-employed men work the longest hours and spend the least time on both leisure and housework activities. However, self-employed women work the least hours and spend the most time on housework. The gender gap in housework between self-employed men and women is 90 minutes per day. We also classify workers based on their job content into outdoors versus indoors and report their time use individually. Both indoor male and female workers spend (less) more time on paid work (leisure) than their outdoor counterparts.

According to their family characteristics, we compare the time use for married, unmarried but cohabitants, and single workers and for workers with and without young children (less than 6 years old). Consistent with other findings (such as Blau & Kahn 2007), a larger gender gap in hours worked is observed in the married group. Specifically, a married female worker works 71.18 minutes less than a married male worker and 24.4 minutes less than a single female worker. However, a married female worker spends 34.57 and 18.37 minutes less on leisure than a married male worker and a single female worker, respectively. The forgone leisure and market work time are added to housework for married female workers. Both parents with young children spend less time on market work and leisure but more time on housework. Mothers with young children spend substantially less time on paid work and leisure but significantly more time on housework. The family gap in time devoted to housework production between mothers and fathers is 80.73 minutes per day.

In terms of gender differentials in time allocation by individual characteristics, the least educated workers and those between 31 and 50 years of age have the largest gap in hours worked. Relative to other races, the gender gap in labor supply is largest among whites. Not surprisingly, the gender gap in working hours is slightly larger for higher income families, suggesting a larger elasticity of labor supply for this group of women.

3.3 Econometric Specification

According to Connolly (2008), people adjust their time allocated to different activities in response to temperature changes to maximize utility. The utility of market work relative to the utility of leisure and other activities changes in the presence of weather shocks. People choose

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[15] The sample distribution and regression results of positive working hours are available upon request.

their work hours based mainly on the marginal substitution rate between paid work and leisure [16].

As discussed, in light of the framework of Connolly (2008), we assume that the impact of temperature on time allocation differs between men and women because they have distinctive preference functions for different activities due to differences in the marginal wage loss of reducing work time (e.g., more flexible jobs allow a temporary work time decrease without affecting wage), marginal gains from leisure and other activities, and tolerance to levels of discomfort caused by extreme weather. To evaluate the impact of temperature on the gender differences in time use in different activities, we construct the following specification:

$$Y_{ict} = \beta_1 \sum_{<=20}^{>100} Female_i \times Tempbin_{ct} + \beta_2 \sum_{<=20}^{>100} Tempbin_{ct} + \gamma Z_{ct} + \theta X_i + \alpha_c + T_t + \eta_{ss} + \mu_{jt} + \omega_{ot} + \epsilon_{it}. \quad (1)$$

Here, the outcome variable Y_{ict} denotes the time allocation of individual i residing in county c at date t to market work, leisure and home production. We run regressions for the three broad categories of activities separately. To capture the nonlinear relationship between temperature and time allocation, we include ten daily maximum temperature bins $Tempbin_{ct}$ ranging from lower than $20°F$ to above $100°F$, with $10°F$ in each bin.Because $75°F$ is considered to be the most comfortable temperature for human activity in the literature (such as Graff Zivin & Neidell 2014, Krüger & Neugart 2018), we choose the $70°F - 80°F$ (or $21.11°C - 26.67°C$) temperature bin as the reference in all specifications. The variable of interest is the interaction term between the female dummy $Female_i$ and the temperature bins, which evaluates the gender difference in response to temperature change. The individual and family characteristics listed in Table 1 are included in the vector X_i. We also include other weather variables (including minimum temperature, length of daylight, average wind speed, and precipitation) in vector Z_{ct}. All weather elements are estimated at the county level.

To take into account the regional and time variation of temperature, our specification also controls for county fixed effects (α_c) and year and month fixed effects (included in T_t). We also control for state-season fixed effects (η_{ss}) to allow for weather changes within a year across regions[17]. The time allocation may vary between workdays and weekends and holiday seasons; therefore, day-of-week fixed effects and holiday fixed effects (included in T_t) are included. Because men and women may choose different types of jobs that have seasonal patterns of labor demand due to occupation or industry differences, we include industry-month (μ_{jt}) and occupation-month (ω_{ot}) fixed effects in all regressions. Standard errors are clustered at the state level.

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[16] Generalized leisure rather than specific leisure activities defined in the paper.

[17] We group December, January, and February as winter; March, April, and May as spring; June, July, and August as summer; and September, October, and November as fall.

4 Empirical Findings

4.1 Main Effects

Figure 2 displays baseline results. The lines represent gender differentials in time allocation to market work, leisure and home production. The gender gap in labor supply becomes more prominent and significant when temperature rises despite that women generally work fewer hours than men, except in extremely cold weather.[18] On extremely hot days, women decrease their working hours substantially more than do men. This gender gap in time allocated to market work is approximately 58 minutes per day. On the other hand, women, on average, spend more time doing housework and less time enjoying leisure than men. However, the difference in time spent on housework and leisure between men and women does not vary substantially with changes in temperature. The findings call for further investigation into why women substantially reduce their labor supply during heatwaves, which is important for assessing the potential impacts of climate change and especially for predicting gender differences in the future.

Even though the conclusion is consistent even when we exclude workers who report zero working hours in the regression, we are still interested in knowing whether their absence from work is related to temperature. More importantly, we would like to know whether the reasons that men and women choose not to work are weather related. ATUS includes one question about why a person is absent from work, and the responses include vacation, illness, childcare, family obligation, training, and military duty. We utilize the information from this question in combination with the temperature when the interview was conducted. We further classify the reasons for being absent from work into three categories: personal absence, absence due to family reason, and other.[19] The results indicate that the primary reasons for both men and women to take leave in extremely hot weather are personally related, such as taking a vacation (over 50%), which is consistent with our main results that both men and women significantly increase their leisure time on days with an unpleasant temperature. The secondary reason for not going to work for both men and women is illness (approximately 20%), which also supports the findings in the existing literature that heatwaves have a considerable impact on health-related incidents (Giorgini et al. 2017, Patz et al. 2005). Last but most interestingly, we find that for women, the probability of being absent from work due to taking care of family members and providing childcare on extremely hot days is three times higher than that for men. Although the sample size is too small to conduct a regression estimate, we believe that this simple statistic highlights the importance of the gender division in family responsibility as a possible source of the gender difference in time allocation. In the next section, we will discuss the underlying mechanisms.

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[18] The impact of temperature on men's time allocation is presented in Appendix Figure A4. Men significantly reduce their hours worked when temperatures are exceedingly low or high. Most of the forgone working hours are added to leisure, which shows a highly asymmetric U-shaped pattern.

[19] Family-related reasons include taking care of household and non-household family members and providing childcare.

5 Tests of Mechanisms

As illustrated in Section 4, we observe substantial male-female differences in time use when the temperature changes, which largely reflect fewer hours worked by women than men on extremely hot days. In this section, we investigate several possible explanations.

5.1 Occupational Exposure to Temperature

One possible cause for the gender difference in labor supply is that men and women sort themselves into occupations with differences in climatic and heat exposure. Figure A5 in the Appendix shows the occupational distribution of all workers by gender. A clear gender division is observed in the occupations and industries in which men and women are employed. Male workers are more likely to be employed in the industries of construction and manufacturing. If those industries are more exposed to the weather, the labor supply of outdoor workers will be more sensitive and vulnerable to climate change. By contrast, women are more likely to work in sales and administrative assistant positions, which are generally less affected by weather conditions. Our baseline estimation controls for occupation- and industry-month fixed effects, which may help to solve such job segregation by gender. The significant impact of temperature, especially extremely high temperature, on the difference in time allocation between men and women suggests that our results are less likely to be caused by occupational division.

To further examine the impact of occupational exposure to climate on one's labor supply, we classify all jobs into indoor or outdoor based on work environment and exposure to weather. If our main results are mostly driven by the gender segregation in occupation and female workers are more likely to take indoor positions where the indoor environment is more sheltering against temperature, we would expect the gender gap in labor supply to be not significant in indoor occupations. The determination of indoor and outdoor work conditions follows the occupational outlook handbook of the BLS.[20] Our occupational classification provides an accurate measure of the extent of a job's exposure to different weather conditions. In particular, our outdoor occupations include farming, fishing, and forestry, construction and extraction, installation, maintenance, and repair, production, transportation, and material moving. Other occupations, such as management, business and financial operations, sales, office and administrative support, legal, education, training and entertainment, healthcare practitioner and healthcare support, food preparation and serving, personal care and others are classified as indoor jobs.

We run separate regressions for indoor and outdoor workers respectively. The coefficients are plotted in Appendix Figure A6. Most of the coefficients for workers who are employed in outdoor occupations are not statistically significant, indicating little gender differentials in hours worked. However, female indoor workers decrease their working hours more than male indoor workers when the temperature exceeds $100°F$. The coefficients of the gender gap are significant for most of the temperature bins (except for the lowest bin). The gender gap in the

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[20] The reference of our classification can be found at https://www.bls.gov/ooh/.

labor supply of indoor workers is approximately 70 minutes per day, which is larger than our baseline results.

However, these results need to be interpreted with caution because approximately one-fifth of male workers in our sample work outdoors, while this ratio is only 4% for female workers. The lower representation of female outdoor workers indicates their unwillingness to take this type of work probably due to an unpleasant work environment, lack of flexibility, or longer working hours. Another possible reason is discrimination, that is, these jobs are usually dominated by men, and women are not always welcomed by colleagues or supervisors. If that were the case, our estimates only underestimate the true effect of temperature on women's labor supply. Therefore, our results for outdoor workers would be considered as the upper bound.

In sum, the gender differentials in hours worked is not driven by unpleasant work environment, and we do not find significant gender gap in the labor supply for climate-exposed occupations. By contrast, we observe a substantial male-female difference in hours worked for indoor workers when the temperature is extremely hot, which demands further examination of alternative explanations.

5.2 Impact of Marriage

In this section, we investigate how marriage affects gender differentials in time allocations. Prevalent social norms may affect gender differences in time use, as men and women perceive issues of balancing paid work and family differently. The balance between work and family may be even more difficult for married women. Despite women's human capital accumulation, increasing labor market participation, and presence in civil and political activities, the traditional division of gender-based family roles remains persistent. Statistical evidence indicates that working wives perform approximately two thirds of total housework, i.e., 20-30 hours per week, while working husbands spend, on average, 6-14 hour per week (Hersch 2009). Although husbands have increased their participation in housework, gender division in domestic tasks remains, and the ultimate responsibility for homemaking continues to be shouldered by women (see Anxo et al. 2011, Bianchi 2011).

We first divide the sample into married and unmarried individuals and run the regression separately. Figure 3 depicts the coefficients for time allocated to market work, leisure and housework at different temperature bins. Consistent with the findings documented in Matulevich & Viollaz (2019), based on a cross-country study, that married women tend to allocate more time to household chores than their single or widowed and separated or divorced counterparts, while married men work longer hours in the labor market than single men. Moreover, the gender gap in hours worked is larger for married workers across the entire temperature distribution. This could be due to the fact that either married women reduce their working hours or married men increase their hours worked when the temperature is above $100°F$ or higher. Together with the estimated results for married men, we do not find evidence that married men increase their labor supply on extremely hot days. The results are reported in Figure A7 in the Appendix.

Moreover, the patterns of time spent on work are very similar between married and unmarried men.[21] Both facts indicate that the substantial reduction in the labor supply of married women is attributable to a larger male-female differential in hours worked at the higher end of the temperature distribution .

The panel in the middle shows the time allocated to leisure for both married and unmarried workers. Men, on average, enjoy more time on entertainment activities compared with women. The gender gap in leisure decreases as temperature rises for married people. For married men, Figure A7 in the Appendix shows a U-shaped pattern between leisure time and temperature, indicating that men increase their time on leisure when the temperature is either exceedingly low or high. Taken together, these results indicate that the gap in leisure between married men and women is smaller because married women increase their leisure by an even substantially larger amount when the temperature is high. One possible explanation for this increase in leisure time for women is simply their increased preference for entertainment after marriage. To obtain a better understanding on what types of entertainment activities women are more likely to enjoy when the temperature is exceptionally high, we break down the leisure time into shopping, personal care, and sleep and run the respective regressions. We find that women substantially increase their hours on sleep when the temperature rises.[22]

The right panel in Figure 3 shows a clear pattern that women specialize and contribute more time to unpaid domestic housework regardless of their marital status. The gender gap in time allocated to housework is even pronounced for married people and when temperatures are extremely cold (below $20°F$). Even though married men also increase their time in housework when temperatures are extremely cold, a large gap persists between women and men. In addition, men and women tend to concentrate their household labor on different tasks, with women doing most of the "feminine" household tasks, like cooking and cleaning, while men do most of the work outside the home, such as yard work and car repairs (Blair & Lichter 1991).

In brief, marital status plays an important role in determining how men and women allocate their time, especially when the temperature is high. As illustrated, the gender gap between unmarried men and women is not statistically significant. However, married women are more likely to reduce their time at work substantially and increase their time to leisure on extremely hot days. However, we do not find that heatwaves statistically influence the gender difference in time devoted to housework tasks.

5.3 Impact of Parenthood

Another important life event is becoming a parent and having children. Parenthood often reinforces the crystallization of gender roles, with an increase in female time devoted to childcare as well as a decrease in leisure time (Lundberg & Rose 2002). The active presence of working

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[21] Appendix Figure A7 is estimated for the male sample only. Following Graff Zivin & Neidell (2012), the reference temperature group used in the regression is $70-80°F$.

[22] The results of time allocation to different types of entertainment of married women are available upon request.

mothers both at home and in the labor market produces the so-called dual burden. Combining paid employment and parenthood is more difficult for mothers than fathers. In fact, having children can seriously jeopardize women's job opportunities and careers (Mincer & Polachek 1974). Gender roles in family responsibilities may cause men and women to devote different efforts and time to work and to behave differently in response to temperature changes. For example, during extreme weather events, children (especially young children) are at greater risk of getting sick (Bunyavanich et al. 2003, Knowlton et al. 2008), and school may be temporally suspended due to severe weather conditions. In such cases, female household members usually provide childcare by decreasing their work time (Checkley et al. 2000).

Considering the importance of the parenthood, we divide the sample into people with a child under the age of six years and those that do not have a young child and run the regressions individually. Figure 4 presents the results. The time use patterns are notably different between these two groups. Compared with people without young children, the gender gap in work time is larger for those who have. Our findings align with those documented in Matulevich & Viollaz (2019). Moreover, men's labor supply to market work, as shown in Figure A8 in Appendix, does not vary across different temperatures regardless of their marital status. In addition, the time devoted to leisure and housework activities does not differ between men with and without younger children.

Even though parenthood substantially changes time use among women and men, mothers are more penalized in terms of decreased labor market participation, lower leisure time and increased unpaid domestic work. Additionally, their time spent with family members increases on extremely hot days. When the temperature rises above $100°F$, employed mothers with young children significantly reduce their work time. Heatwaves increase the likelihood of fatigue and other health issues for younger children, and during such conditions, mothers spend more time at home providing child care. In Appendix Figure A9, we plot the gender gap in caring time for married people with and without younger children. The results confirm that mothers spend more time caring for family members at extreme low or high temperatures when a young child is present at home. On the other hand, men are not necessarily penalized for being a father and sometimes even benefit from it. We find some evidence that the reduction in time allocated to work is mostly transferred to the fathers' leisure time. Moreover, fathers' time caring for family members is not sensitive to temperature regardless of the presence of younger children.

When we compare actual time spent on domestic work between men and women in the sample, women spend 6.5 more hours per week caring for family members and doing family chores than their male counterparts. Our statistics are in line with the study of Bianchi (2000), who show that employed mothers spend at least twice as much time as employed fathers with their children. Although the gender gap in family chores has decreased, a large gap remains in the time allocations of men and women in terms of family responsibility.

In summary, our results provide evidence that gender division in family responsibility is another important determinant of time allocation choices, especially when the temperature is exceedingly high.

6 Gender Differentials in Adaptation

Our analysis thus far suggests that both marriage and parenthood are important sources of the observed differences. We would like to know whether such changes in time use are temporary and how well people adapt to heatwaves, considering the global warming phenomenon. In this section, we focus on the differentials in hours worked between men and women because they are more sensitive to the temperature changes as demonstrated above. To preview our findings, we first document hours worked by regions, and the patterns appear strikingly different for hot/cold regions. People living in different regions respond in different ways to changes in temperature. We then test the variation between hot/cold months and notice that the gender differentials are more pronounced on hot days, especially when the monthly temperature is high overall. In the last test, we investigate the impact of sustained hot days on time allocation.

6.1 Effect for Cold/Hot Regions

Thus far, evidence for the adaptation of individuals to changes in temperature are mixed, and the existing literature has focused primarily on agriculture, health and human capital (Deschênes & Greenstone 2011, Bleakley & Hong 2017, Graff Zivin et al. 2018). In the present study, we first examine how people adapt to temperature changes across different regions.

We first compute the number of days with the temperature exceeds $95°F$ for all states each year over the sample period of study and then classify them into three categories according to their position in the hot day distribution. States in the top (bottom) 25 percentile are classified as hot (cold) regions, whereas states whose average number of days over 95 degrees is between the 25 percentile and 75 percentile are classified into the third category.

The results presented in Figure 8 are strikingly different across different regions. For cold regions (the bottom 25 percentile), the gender gap in labor supply increases with temperature, meaning that women reduce their hours worked more relative to men as temperatures rise. Surprisingly, when the temperature is lower than $30°F$, we do not find statistically significant differences in working hours between men and women. By comparison, the pattern of male-female differentials in hot regions (the top 25 percentile) is completely different. The gender gap in labor supply decreases steadily when the temperature rises until it reaches $80°F$, even though men still work more than their female counterparts. However the gap increases slightly when the temperature exceeds $90°F$. Our findings suggest that gender adaption to heat exposure in time allocation varies across regions. Our results are also robust to an alternative measurement of climate regions defined by Karl & Koss (1984). The results are reported in Appendix A10.

One potential concern about the validity of our results arises from the threat that extreme weather may cause migration across regions, which has been omitted in this paper. Using annual migration and labor market data from the United States, Mullins & Bharadwaj (2015) find that extreme temperatures in a given area are associated with small and moderate increases in out-migration from that area. We cannot rule out the possibility that part of our results is driven by the fact that some people who cannot tolerate hot weather migrate to cooler areas. Therefore, our results are downward biased. Because it is not possible to differentiate climate migration from other types of migration, we exclude states with massive migration over the period of study. Excluding states with historically large flows of migration does not invalidate our previous results.[23]

6.2 Effect of Hot Seasons

We would also like to know whether men and women adapt in different manners when transitioning to seasons with high frequencies of heatwaves. Humans have a remarkable ability to adapt to heat stress given adequate water and protection from the sun. Typically, adaptation occurs through morphological, chemical, functional, and genetic adjustments that decrease physiological strain under stress (Bligh 1973). Physiological adaptation arises through numerous channels, including changes in skin blood flow, metabolic rate, oxygen consumption, and core temperatures. The time period of the adaptation process varies depending on the physical condition of the individual. It only takes up to two weeks to adapt, with shorter periods for healthy individuals but longer periods for unhealthy individuals or those experiencing passive exposure (Armstrong & Maresh 1991).

Although most physiological adaptation occurs within a short period of time, the process may vary by gender. A recent study by Notley et al. (2017) documented that the heat response changes depending on the ratio between body surface area and mass, which varies by gender. They also find evidence that the "mass-specific surface, a significant determinant of vasomotor and sudomotor responses in men and women", could explain up to 48% of the individual thermoeffector variance. If men and women respond in varied ways to heat due to biological and physical differences, we would expect time use patterns to vary across seasons, especially when transitioning from cool to hot seasons.

We assess the impact of short-run acclimatization by estimating separate temperature responses from July to September. Since hot days are a relatively new phenomenon in late June or early July but quite common by August, a diminished response to high temperatures in September should be viewed as evidence of acclimatization. Our specification includes both county and year fixed effects and therefore identifies the short-run behavioral responses to temperature. The results of gender differentials in hours worked are presented in Figure 6. The gender differential in labor supply on extremely hot days ($>100°F$) increases as people are exposed to more hot days. In particular, the difference is not statistically significant in July, increases to approximately 75 minutes in August and further rises to 150 minutes in September. Interestingly, men's labor supply does not vary much with temperature over these three months, and their labor

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[23] We exclude the following states with net migration of more than 10,000 between 2000 and 2017: Arizona, California, Colorado, Connecticut, Florida, Georgia, Illinois, Massachusetts, Nevada, New York, New Jersey, North Carolina, Oregon, South Carolina, Tennessee, Texas, and Washington and re-run our regression. The results change little compared with our baseline. Source: U.S. Census Bureau. https://www.census.gov/data/tables/time-series/demo/geographic-mobility/state-to-state-migration.html. The results are available upon request.

supply only decreases slightly in the transition to the hot season but remains unchanged when incidents of heatwaves occur in August and September (as shown in Figure A11 in the Appendix). Compared with their male counterparts, women are more sensitive or less adaptive to heat, especially when they are exposed to an increasingly hot environment.

6.3 Effect of Sustained High Temperatures

Sustained high temperatures may have different impacts on individuals' allocation of time, as men and women adapt differently to cope with such heatwaves. An official report from the Intergovernmental Panel on Climate Change (IPCC) provides evidence of gender differences in adaptations to climate change due to biological differences; specifically, women face a higher risk in coping with hot weather (see McCarthy et al. 2001). It is important to estimate gender differences in adaptation, especially as global temperatures continue to rise. To explore whether and how continuous high temperature could change our results, we first identify observations for which the temperature over the past three days exceeds $100°F$ and define them as sustained high temperature days (or heatwaves). We then exclude them from our main sample. The purpose of doing so is to disentangle the impact of heatwaves from an unanticipated day of hot weather. The results presented in Figure 7 suggest that the findings are not driven by several days of high temperature and dropping heatwave observations has a limited impact. Furthermore, the magnitude of extremely high temperature from the estimation without heatwaves is larger, indicating that women are more vulnerable and less adaptive to unexpected heat.

7 Robustness Checks

In this section, we examine the sensitivity of our results by running several robustness tests. First, we use different sets of fixed effects to demonstrate the other possible channels that could influence the time allocation decision when temperature changes. The third column of Table 2 displays the baseline results, which include year fixed effects, month fixed effects, county fixed effects, state-season fixed effects and industry- and occupation-month fixed effects.[24] Most of the coefficients are significant for various temperature bins, and females decrease their work time the most in the highest bin. The first column excludes job-related fixed effects. We then add daylight dummies in the second column. In the fourth column, we add snowfall and snow depth to exclude effects from snow because of its correlation with temperature. The decrease in work time of females under extreme hot weather is even larger and still significant. In the fifth column, we replace the year fixed effects and month fixed effects with Year-by-Month fixed effects, which allows each month in the sample period to have distinct fixed effects. The results are still robust. In the last column, we further control for state trends in case time allocation has specific trends. According to Table 2, our results survive a series of stricter robustness checks, adding more confidence to our conclusions.

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[24] The coefficients of the temperature effect for male workers (the reference group) are reported in A3.

In our second experiment, we exclude self-employed workers from the sample because their characteristics differ from those of other workers. Additionally, the characteristics of self-employed workers are gender-specific. Women who choose full-time self-employment have personal characteristics that are less highly valued in the marketplace than women who work full-time in wage-and-salary employment. The reverse is true for men(Clain 2000). Such heterogeneity in the nature of time preferences between male and female self-employed workers would bias and over-estimate our baseline temperature effects of time use. Analyzing the industrial distribution of self-employment by gender, we notice that self-employed men are more likely to be involved in construction, manufacturing and other outdoor industries. By contrast, women are more likely to be self-employed in personal care, education, and healthcare support. The extent of exposure to weather indeed varies greatly between self-employed males and females. Therefore, we would expect the magnitude of our baseline results to become smaller if we restrict our analysis to non-self-employed workers. In Figure A12 of the Appendix, we run the regression with the baseline specification for the workers who are not self-employed. The graphs look very similar and consistent with our baseline results. However, we should point out that this pattern may reflect the lack of representation of self-employed workers because only 12% of males and 8% of females are self-employed in our sample. We should interpret this result with caution.

As discussed in our theoretical analysis, individuals may shift activities between hotter and cooler days (interday substitution). For instance, an anticipated extremely high temperature on the next day may encourage people to remain home (due to one's own or a family member's poor health or to discomfort). Moreover, to compensate for the reduction in hours worked, individuals may have to increase their contemporary labor supply on the current day. Considering both ex-post and ex-ante effects, we include one day in the past and the next day in Table 3. The results presented in the even columns include indicators for both the previous and the next day if the maximum temperature exceeds $100°F$. In comparison, the results in the odd columns are taken from our baseline estimation. Our main findings remain robust to including previous and anticipated hot weather. A closer examination of the lagged and lead impacts suggests that when high temperatures are expected tomorrow, women increase their labor supply (and thus yield a smaller gender gap) by reducing their leisure. The findings also lend some support to our argument that women may need to supply more time caring for sick family members and less time on market work if a hot day is expected. To cope with family and work, they may appear to substitute their time allocated to leisure for paid work.

We exclude commuting time from work time and run another regression as a robustness check. The results are presented in Appendix Figure A14. The pattern of gender differences in labor supply barely changes when temperature rises. We also conduct another robustness check by restricting observations to those whose locations can be identified at the county level (or when removing the last three observations during data processing). The figure reported in Appendix A13 shows similar results to our baseline findings.

8 Conclusions

Climate change has far-reaching effects on all aspects of society, and there has been considerable scientific interest in characterizing its multifarious impacts on agriculture, industry, and ecosystems. In this paper, we examine whether time allocations are different for men and women in the face of climate change. Our results are striking and show a large gender difference in time allocated to different activities, especially hours worked. Even though both male and female workers reduce their labor supply when the temperature increases, hours worked decrease more for women. The gender gap in working hours reaches approximately one hour when the temperature exceeds $100°F$. The further exploration shows that the marriage and parenthood are important determinants. Finally, we estimate the gender differences in coping with changes in temperature and find that women have greater difficulty adapting to hot temperatures in cold regions and when heatwaves occur more frequently.

Given the climate change challenges that the world is facing, economists are studying how people, businesses, and governments can cope with evolving climate risks. The accumulation of greenhouse gases in Earth's atmosphere is poised to raise global temperatures considerably in a relatively short period of time. The results from the present study have several profound implications. The potential effects of high temperatures on the gender differentials in the allocation of time and the underlying mechanisms have important implications for preparing for climate change and assessing the social costs of greenhouse gas emissions. As shown above, climate change impacts women's lives differently than men's lives. Consequently, adaptation policies and measures must be gender-sensitive: restricted access to economic resources may lead to fewer possibilities to adapt to climate change. Our results also lend some support to notion that people cope with increasing temperature differently. If they can anticipate that future summers will be hotter, what steps can be taken now to protect themselves (i.e., adapt)? Furthermore, what determines their adaptive capacity? These fundamental questions are the focus of this paper; however, further investigations are required to examine the long-term impact of temperature change on individual time allocation.

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Tables and Figures

Table 1: Summary Statistics

Panel A. Time use	Mean (Work time)			Mean (Leisure time)			Mean (Housework time)		
	Male	Female	p (Difference)	Male	Female	p (Difference)	Male	Female	p (Difference)
A. Mean Value									
	312.72	259.11	0.00	392.13	353.11	0.00	140.26	196.10	0.00
B. By Job Characteristics									
Self-employed workers	324.90	242.04	0.00	383.96	342.55	0.00	139.54	229.61	0.00
Non-self-employed workers	311.05	260.58	0.00	393.25	354.03	0.00	140.36	193.20	0.00
Outdoor workers	307.88	252.85	0.00	397.69	357.83	0.00	138.31	199.51	0.00
Indoor workers	314.67	259.37	0.00	389.20	352.95	0.00	142.00	195.87	0.00
C. By Family Characteristics									
Marital status									
Married	317.90	246.72	0.00	378.24	343.67	0.00	161.88	233.99	0.00
Unmarried but Cohabitants	315.26	268.69	0.00	404.10	363.20	0.00	134.37	184.58	0.00
Single and Others	304.11	271.12	0.00	413.11	362.04	0.00	106.17	157.82	0.00
Parenthood status									
Having children<6	307.87	243.38	0.00	359.63	311.25	0.00	188.17	268.90	0.00
No children<6	314.54	264.41	0.00	404.29	367.22	0.00	122.34	171.57	0.00
D. By Individual Characteristics									
Educational attainment									
High school and below	304.59	250.12	0.00	398.90	355.80	0.00	123.36	186.00	0.00
Some college	320.30	260.10	0.00	390.09	352.60	0.00	138.78	191.75	0.00
College graduate and above	314.11	264.17	0.00	388.32	351.76	0.00	153.86	205.61	0.00
Race									
Non-Hispanic White	310.98	252.83	0.00	392.90	361.05	0.00	151.32	206.21	0.00
All others	316.10	270.13	0.00	390.62	339.19	0.00	118.87	178.34	0.00
Age									
Young (15-30)	292.28	252.33	0.00	405.19	358.08	0.00	99.79	151.75	0.00
Prime age (31-50)	319.40	256.89	0.00	380.43	340.12	0.00	155.94	222.48	0.00
Old (51-65)	315.67	270.19	0.00	407.23	374.51	0.00	137.20	178.62	0.00
Family income									
Family income >= $75,000/yr	304.54	260.89	0.00	396.24	340.95	0.00	113.04	180.39	0.00
Family income < $75,000/yr	315.49	263.88	0.00	389.53	352.70	0.00	144.35	194.63	0.00

Panel B. Weather	Mean	Std.Dev.	[Min, Max]
Max temperature (degrees Fahrenheit)	67.33	19.16	[-5.89, 113.24]
Min temperature (degrees Fahrenheit)	47.15	17.58	[-35.10, 88.99]
Precipitation (mm)	2.78	7.87	[0, 451.10]
Snowfall (mm)	1.96	14.35	[0, 493.67]
Snow depth (mm)	27.25	133.48	[0, 2464.00]
Daylight (h)	12.12	1.84	[6.58, 19.28]

Notes: Data source: 2004-2017 American Time Use Survey and 2004-2017 National Climatic Data Center meteorological data.

Table 2: The Effects of Temperature on Gender Differences in Work Time

VARIABLES: Work Time	(1)	(2)	(3)	(4)	(5)	(6)
Female*Max Temp (≤20)	-15.619	-15.587	-14.593	-10.119	-14.743	-14.649
	(21.708)	(21.722)	(22.567)	(23.041)	(22.105)	(22.327)
Female*Max Temp (20-30)	-19.022**	-18.941**	-20.353**	-20.390**	-20.210**	-20.393**
	(8.822)	(8.812)	(9.275)	(9.659)	(9.175)	(9.109)
Female*Max Temp (30-40)	-36.853***	-36.820***	-34.024***	-34.353***	-33.599***	-33.315***
	(6.837)	(6.843)	(7.392)	(7.639)	(7.263)	(7.270)
Female*Max Temp (40-50)	-26.887***	-26.896***	-27.135***	-27.361***	-27.154***	-27.140***
	(5.242)	(5.250)	(4.519)	(4.830)	(4.496)	(4.495)
Female*Max Temp (50-60)	-23.855***	-23.853***	-23.590***	-24.492***	-23.553***	-23.524***
	(4.607)	(4.614)	(4.666)	(4.949)	(4.586)	(4.604)
Female*Max Temp (60-70)	-27.924***	-27.929***	-28.206***	-27.124***	-27.846***	-27.679***
	(4.517)	(4.512)	(4.740)	(5.258)	(4.745)	(4.713)
Female*Max Temp (70-80)	-37.432***	-37.422***	-37.432***	-37.533***	-37.224***	-37.104***
	(4.118)	(4.123)	(4.238)	(4.087)	(4.268)	(4.267)
Female*Max Temp (80-90)	-35.803***	-35.801***	-34.798***	-34.026***	-34.661***	-34.640***
	(3.378)	(3.373)	(3.341)	(3.639)	(3.385)	(3.374)
Female*Max Temp (90-100)	-23.668***	-23.686***	-22.661***	-22.698***	-22.639***	-22.940***
	(6.719)	(6.717)	(6.591)	(6.485)	(6.592)	(6.552)
Female*Max Temp (>100)	-58.183***	-58.275***	-54.161***	-62.817***	-53.205***	-53.226***
	(8.685)	(8.686)	(10.223)	(10.264)	(10.625)	(10.628)
Observations	70,389	70,389	70,389	64,214	70,389	70,389
R-squared	0.403	0.403	0.418	0.420	0.419	0.412
Year FE	×	×	×	×		
Month FE	×	×	×	×		
County FE	×	×	×	×	×	×
State-Season FE	×	×	×	×	×	×
Daylight		×	×	×	×	×
Industry-Month FE			×	×	×	×
Occupation-Month FE			×	×	×	×
Snowfall and Snow Depth				×	×	×
Year-Month FE					×	×
State Linear Trend						×

Notes: This table presents the results of the impact of temperature on the gender gap in labor supply with different specifications. The coefficients in Column (3) are our baseline results. Data: (1) Time use data are from the 2003-2017 American Time Use Survey. (2) Weather data are from the National Climatic Data Center (NCDC). Robust standard errors in parentheses.*** p<0.01, ** p<0.05, * p<0.1.

Table 3: Effects of Lagged (Expected) Temperature on Gender Differences in Time Allocation

VARIABLES	Work Time		Leisure Time		Housework Time	
	(1)	(2)	(3)	(4)	(5)	(6)
Female*Max Temp (≤20)	-14.593	-11.747	-43.608***	-43.267***	49.888***	49.345***
	(22.567)	(22.692)	(9.841)	(10.061)	(14.739)	(14.821)
Female*Max Temp (20-30)	-20.353**	-21.335**	-54.965***	-54.765***	53.757***	53.642***
	(9.275)	(9.685)	(8.296)	(8.418)	(7.160)	(7.024)
Female*Max Temp (30-40)	-34.024***	-34.175***	-45.797***	-45.912***	50.830***	50.634***
	(7.392)	(7.406)	(6.677)	(6.641)	(5.065)	(4.992)
Female*Max Temp (40-50)	-27.135***	-27.426***	-50.052***	-49.844***	49.603***	49.560***
	(4.519)	(4.486)	(4.911)	(4.856)	(3.545)	(3.431)
Female*Max Temp (50-60)	-23.590***	-23.599***	-52.009***	-52.476***	48.5918***	49.025***
	(4.669)	(4.620)	(4.805)	(4.762)	(3.636)	(3.650)
Female*Max Temp (60-70)	-28.206***	-28.422***	-43.419***	-43.524***	51.207***	51.311***
	(4.740)	(4.760)	(4.220)	(4.247)	(2.803)	(2.744)
Female*Max Temp (70-80)	-37.432***	-37.326***	-41.647***	-41.418***	49.359***	49.153***
	(4.238)	(4.184)	(3.310)	(3.282)	(3.216)	(3.230)
Female*Max Temp (80-90)	-34.798***	-34.867***	-44.051***	-44.030***	53.430***	53.478***
	(3.341)	(3.401)	(3.649)	(3.615)	(2.990)	(2.976)
Female*Max Temp (90-100)	-22.661***	-25.589***	-43.244***	-42.089***	47.038***	46.955***
	(6.591)	(6.310)	(3.280)	(3.266)	(3.289)	(3.292)
Female*Max Temp (>100)	-54.161***	-109.442***	-44.590***	-25.833	52.981***	57.226***
	(10.223)	(25.864)	(9.229)	(17.894)	(6.665)	(19.144)
Female*Lag1 (>100)		13.446		28.452		-20.267
		(23.685)		(23.724)		(18.148)
Female*Lead1 (>100)		59.010***		-52.668***		15.053
		(13.151)		(11.869)		(15.723)
Observations	70,038	70,038	70,038	70,038	70,038	70,038
R-squared	0.418	0.418	0.248	0.248	0.215	0.215

Notes: This table tests the impact of past and future temperature on the gender gap in time allocation. Lag1 (>100) and Lead1 (>100) are indicators taking value 1 if the temperatures on the previous or next day exceed 100°F, respectively. The coefficients of the baseline estimation are reported in the odd columns, and the coefficients with lagged and expected effects are reported in the even columns. Robust standard errors in parentheses.*** p<0.01, ** p<0.05, * p<0.1.

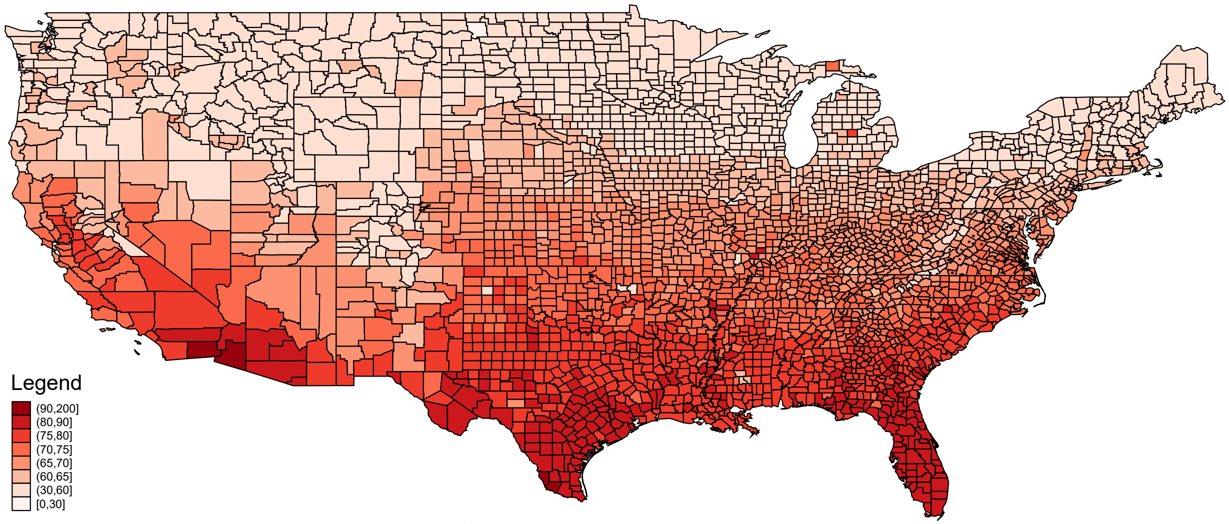

Figure 1: Average Annual Maximum Temperature Distribution in 2017

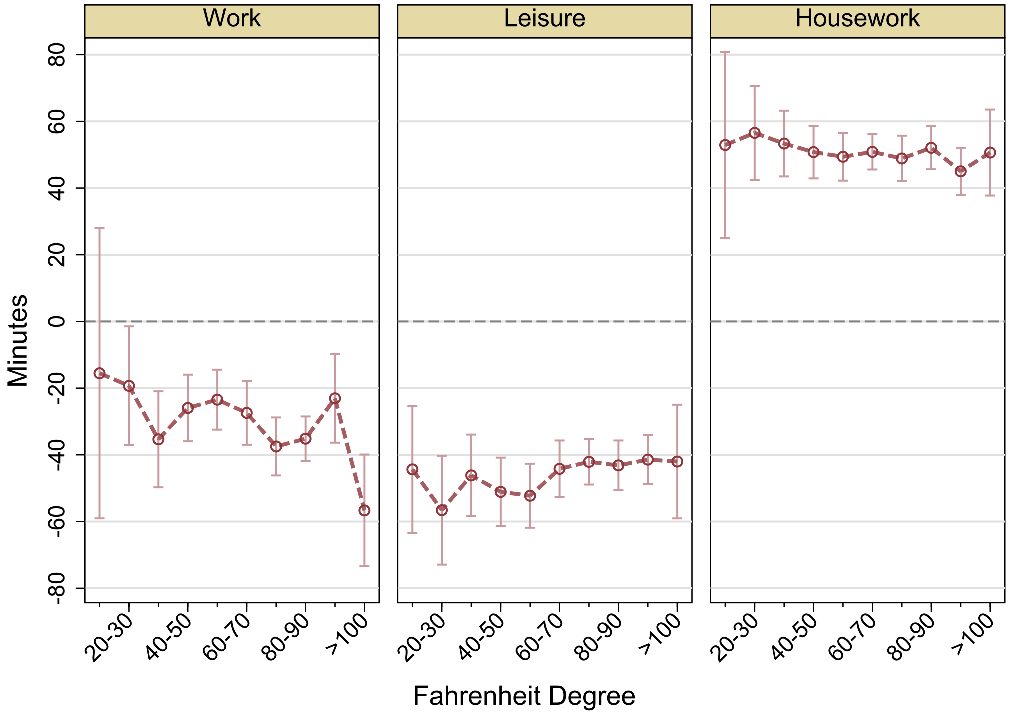

Figure 2: Temperature Effect of Gender Differentials in Time Allocation

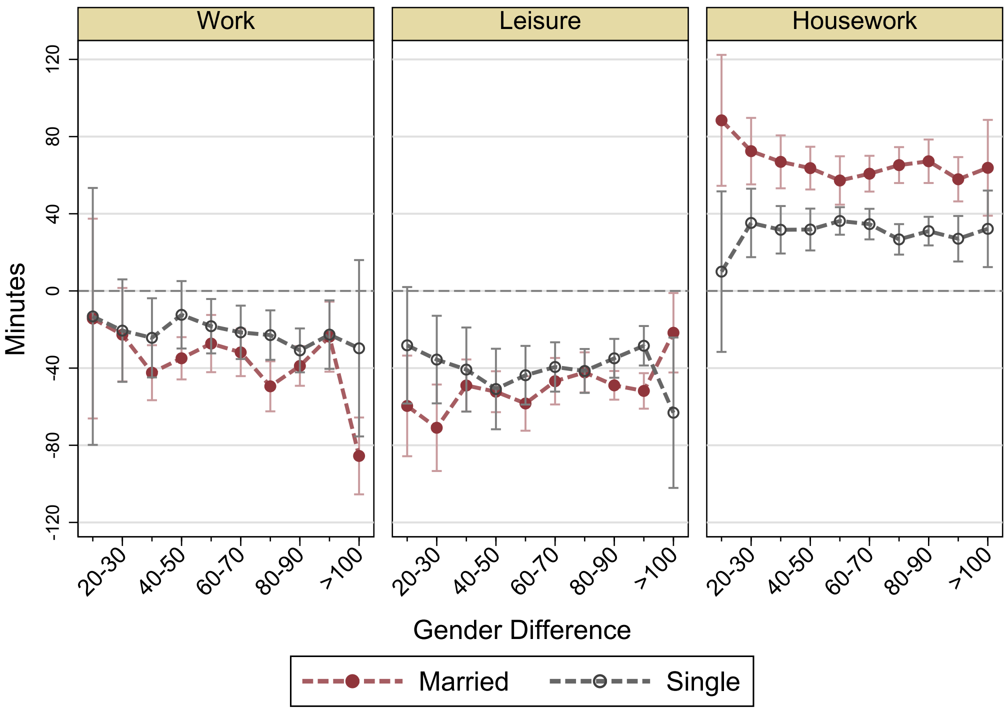

Figure 3: Temperature Effect of Gender Differentials in Time Allocation by Marital Status

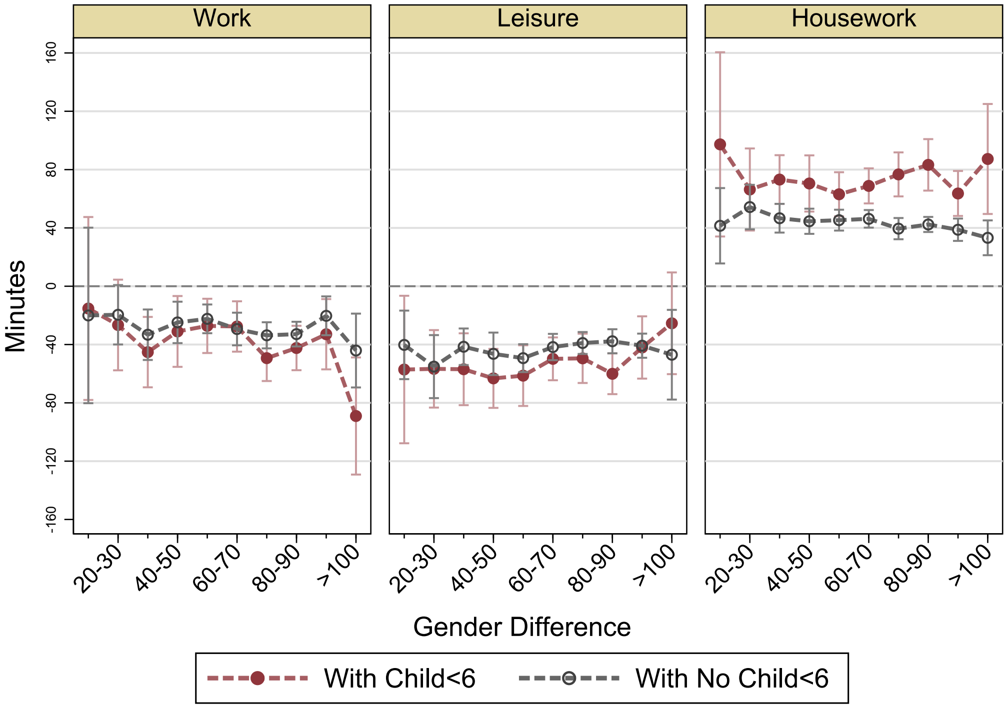

Figure 4: Temperature Effect of Gender Differences in Time Allocation by the Presence of Young Children

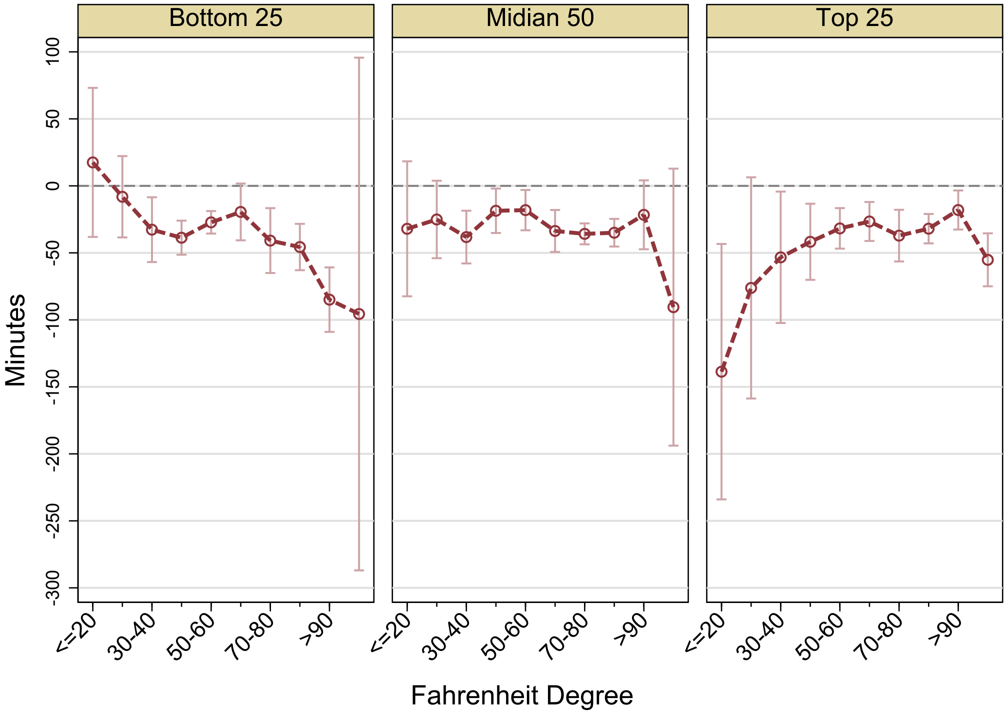

Figure 5: Effect of Temperature on Gender Gap in Working Hours by Climatic Regions
Note: States in the top (bottom) 25th percentile are classified as hot (cold) regions, whereas states with an average number of days over 100°F is between the 25th and 75th percentiles are classified in the third category.

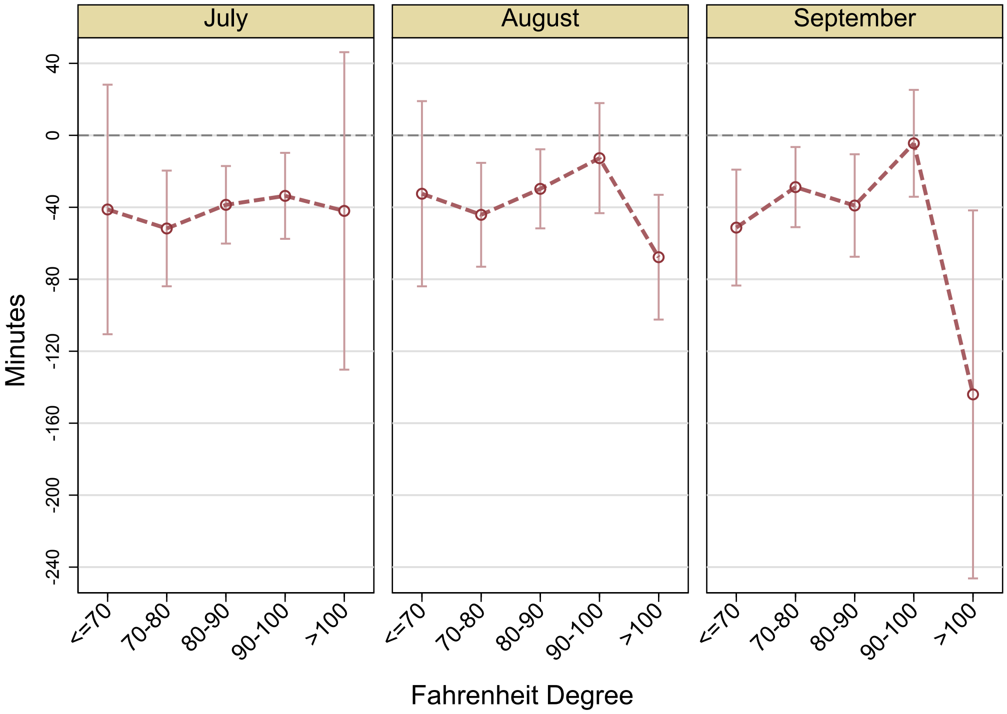

Figure 6: Effect of Temperature on Gender Gap in Working Hours for July, August, and September

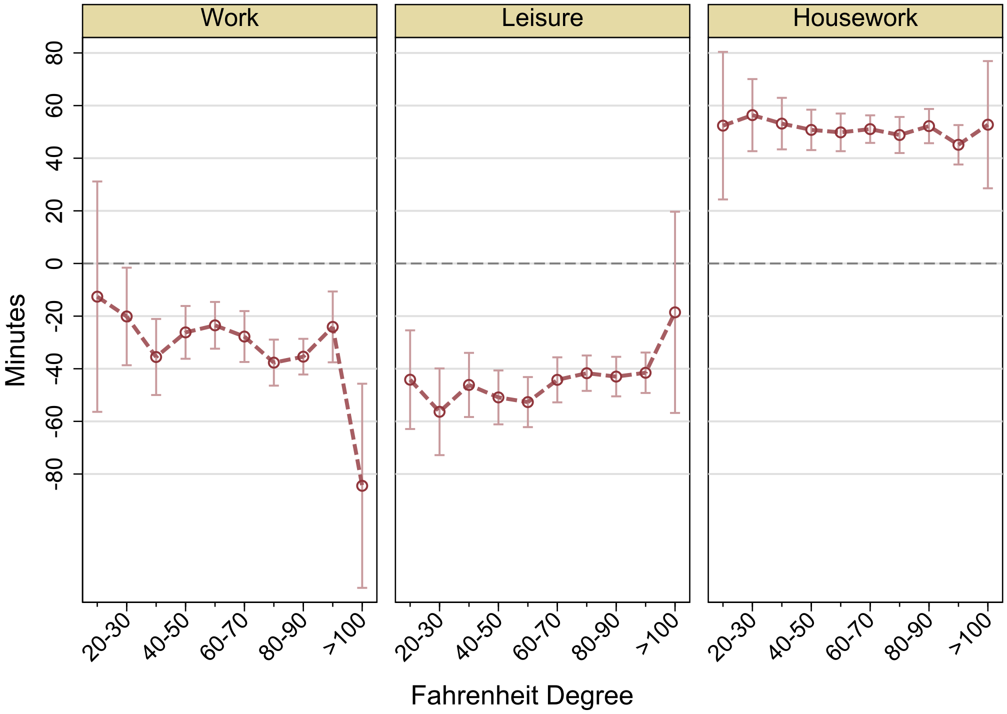

Figure 7: Heat Duration Impact on Gender Gap in Time Allocation

Note: The estimation depicted in this figure drops the observations when temperatures over the past three days are over 100°F are dropped.

Appendix

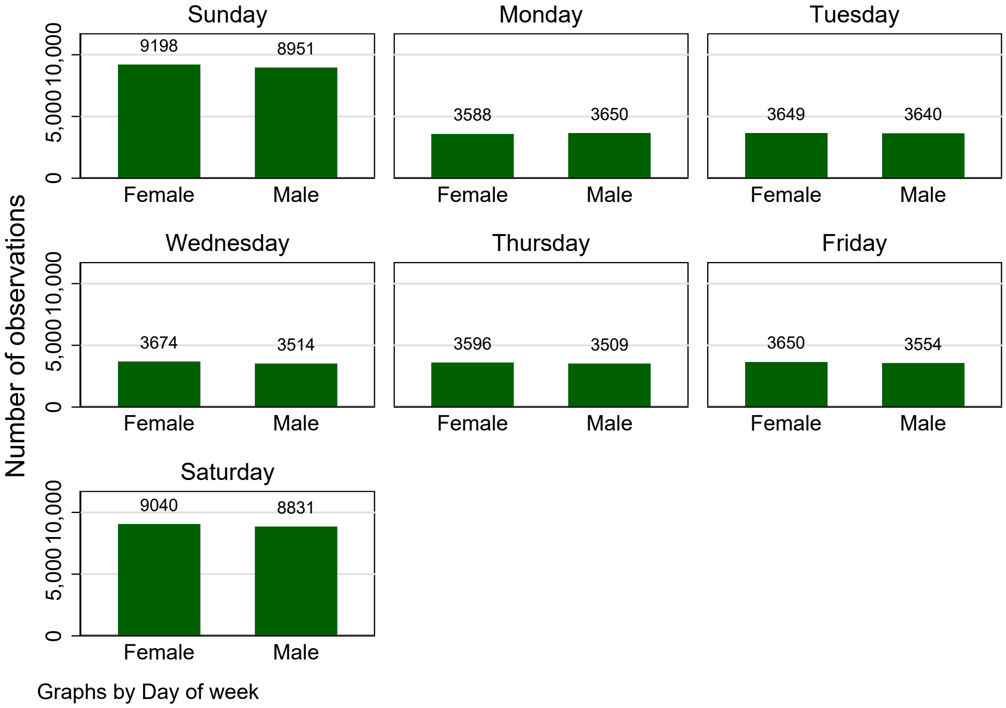

Figure A1: Sample Distribution by Gender and Day of Week

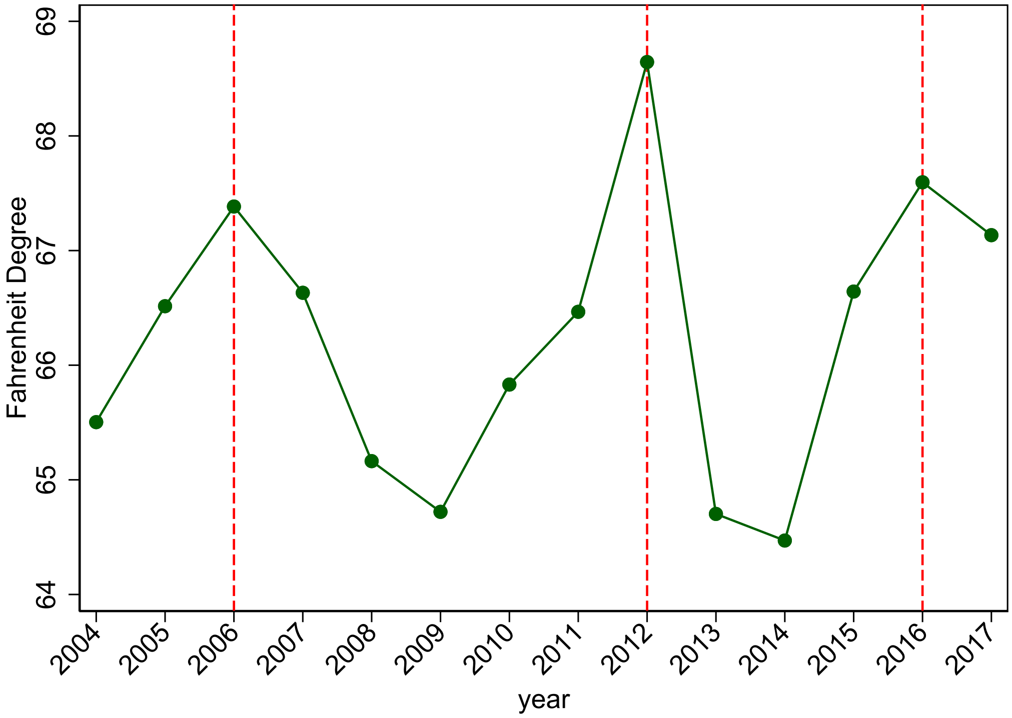

Figure A2: Average Annual Maximum Temperature from 2004 to 2017

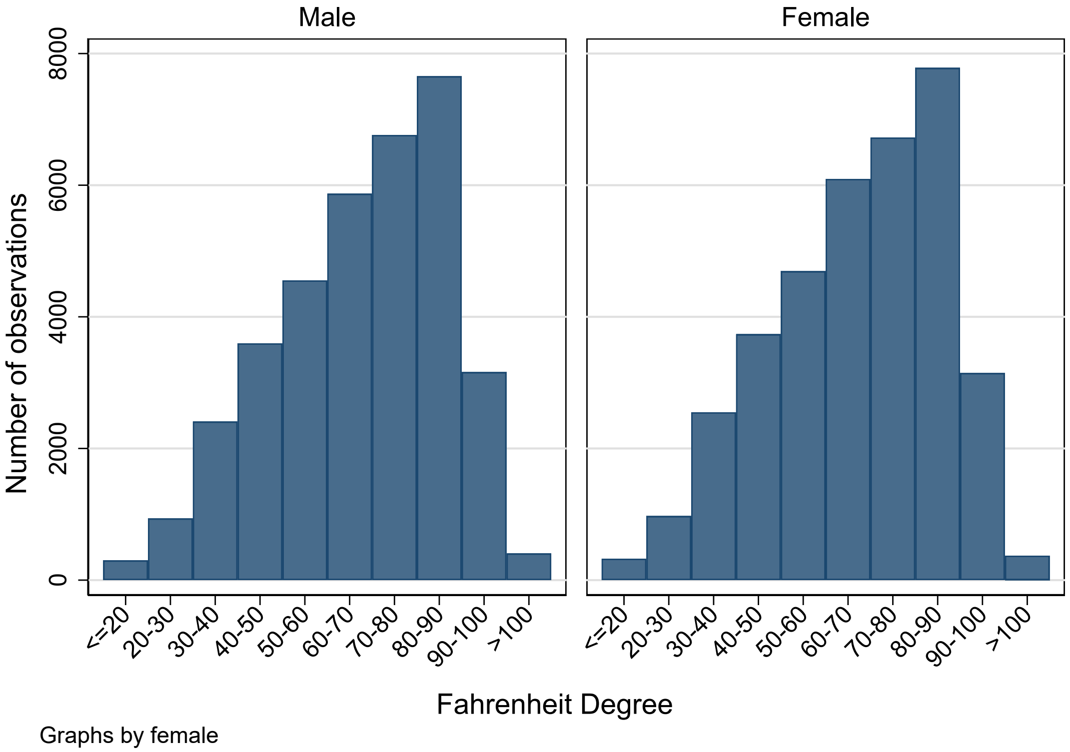

Figure A3: Sample Distribution by Temperature and Gender

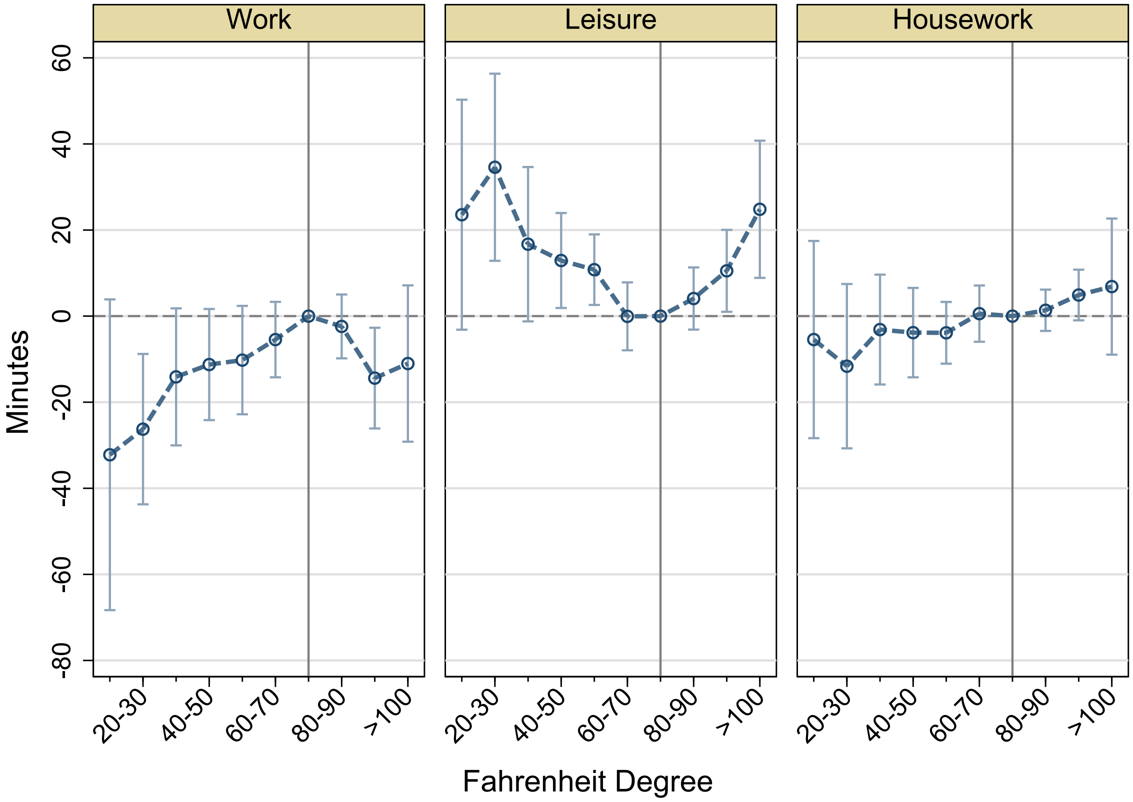

Figure A4: Effect of Temperature on Males' Time Allocated to Work, Leisure, and Housework

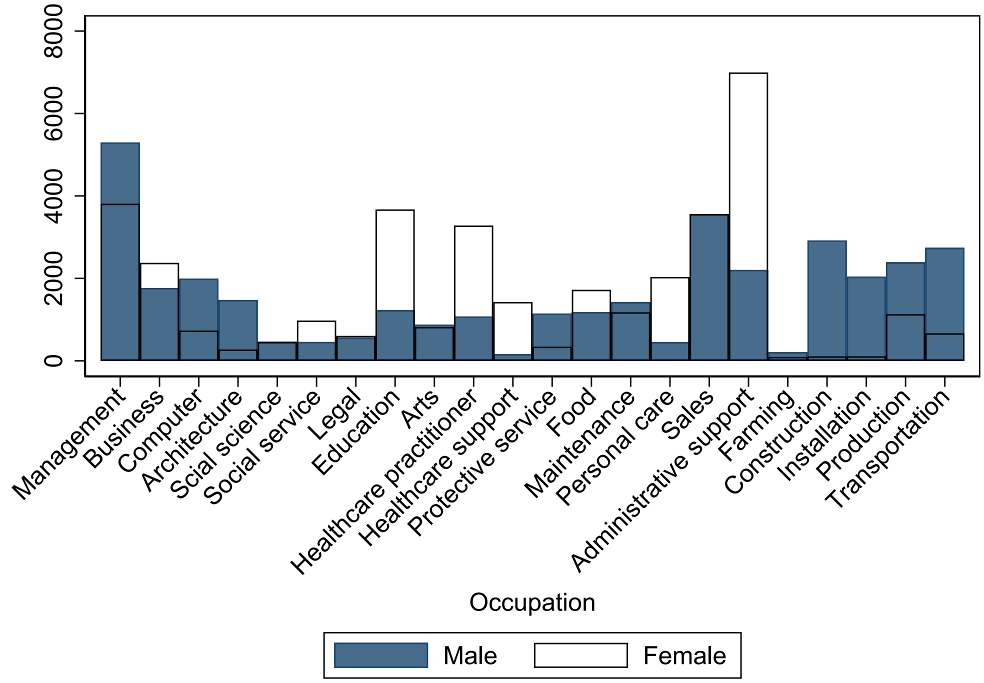

Figure A5: Occupation Distribution by Gender

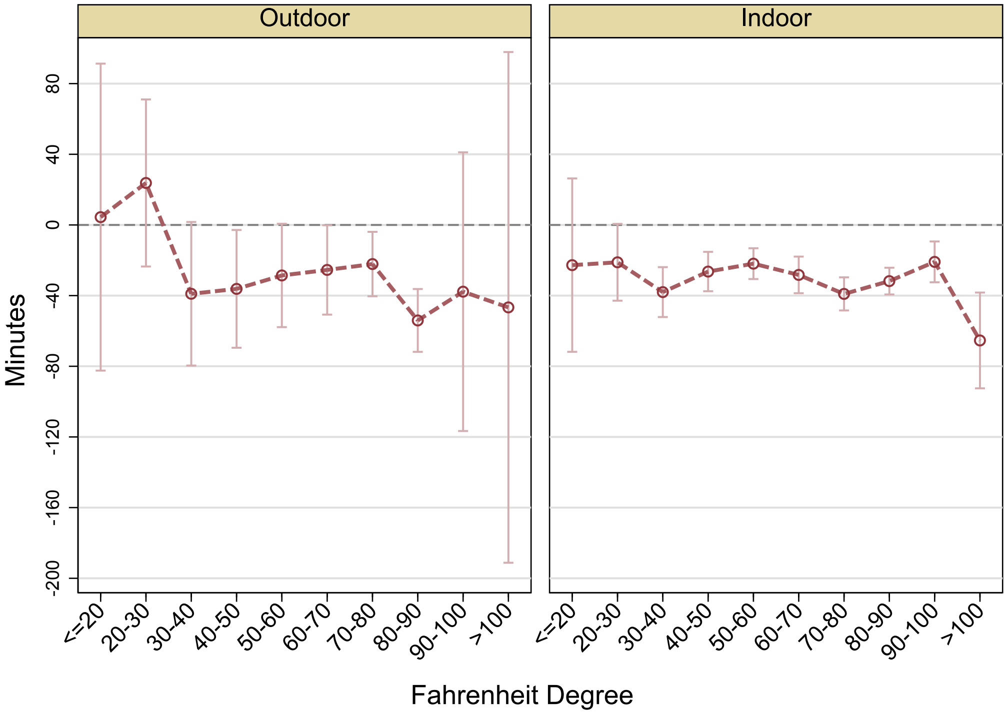

Figure A6: Impact of Temperature on the Gender Gap in Working Hours for Outdoor and Indoor Occupations

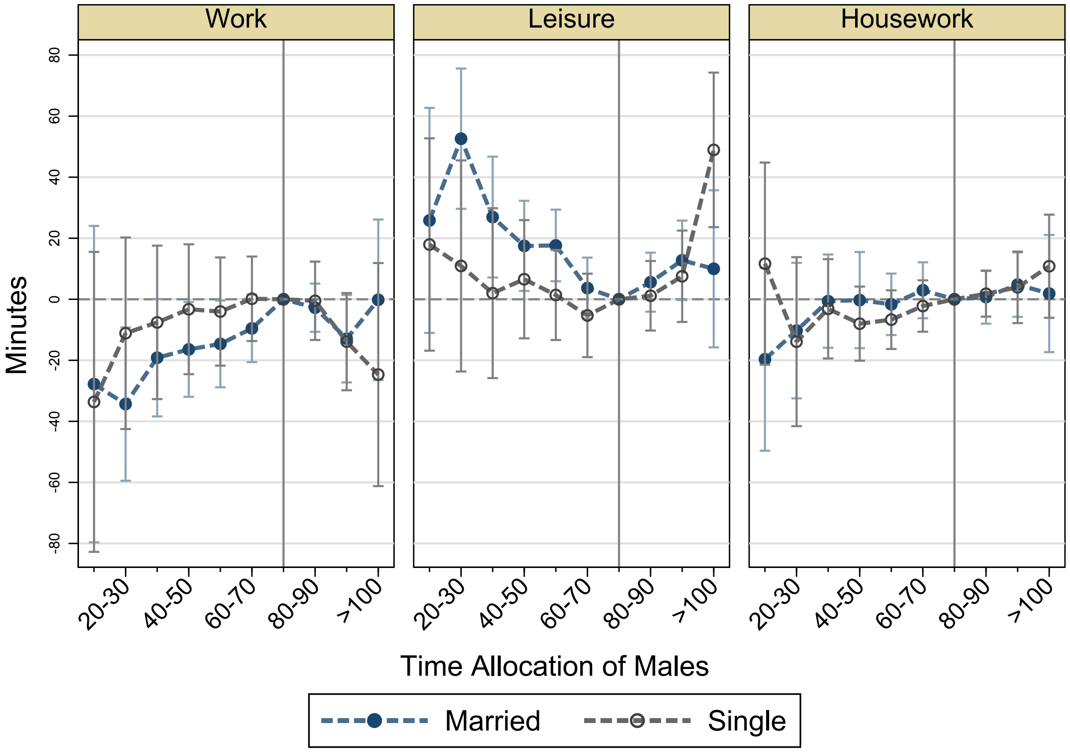

Figure A7: Effect of Temperature on Males' Time Allocation by Marital Status

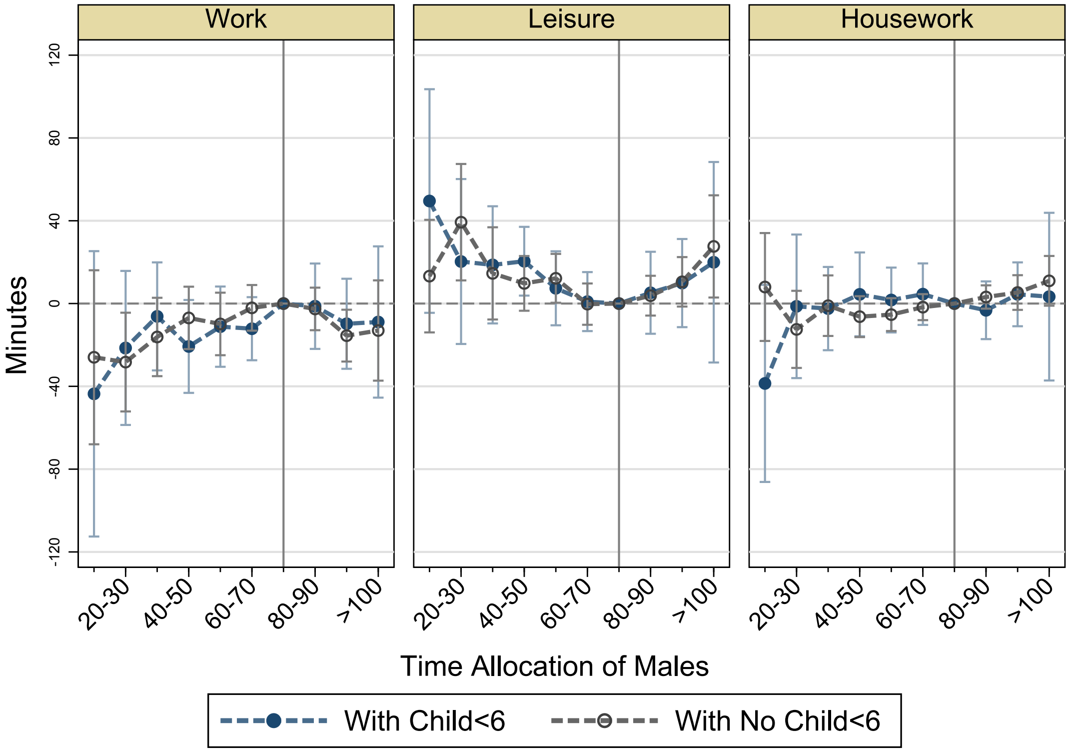

Figure A8: Effect of Temperature on Males' Time Allocation by Whether They Have Younger Children

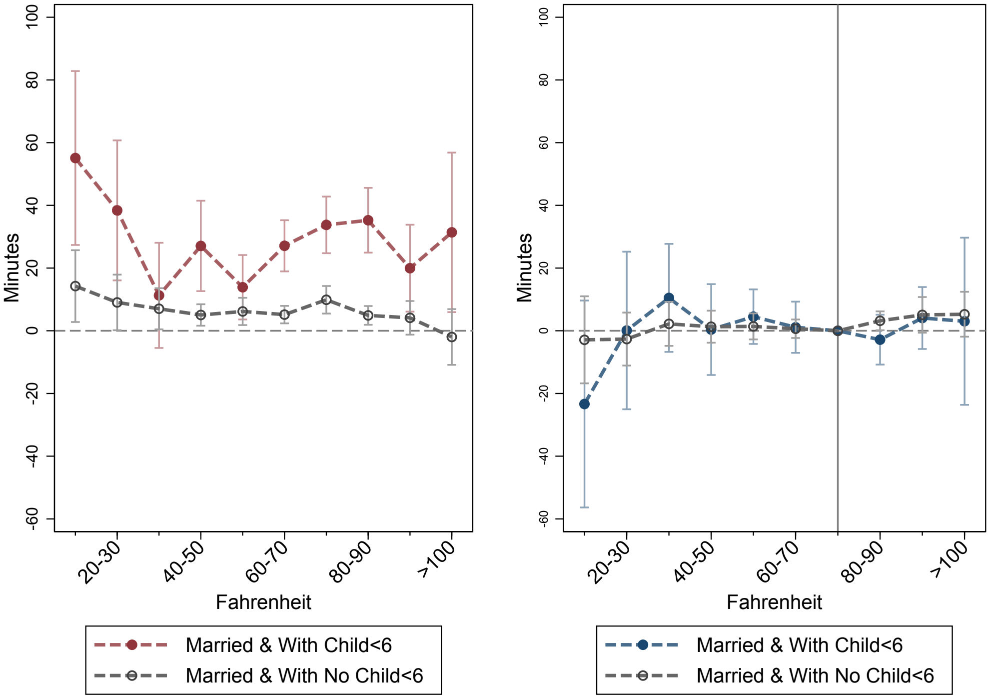

Figure A9: Effect of Temperature on Time Allocated to Caring Activities by Married Men and Women in the Presence of Young Children

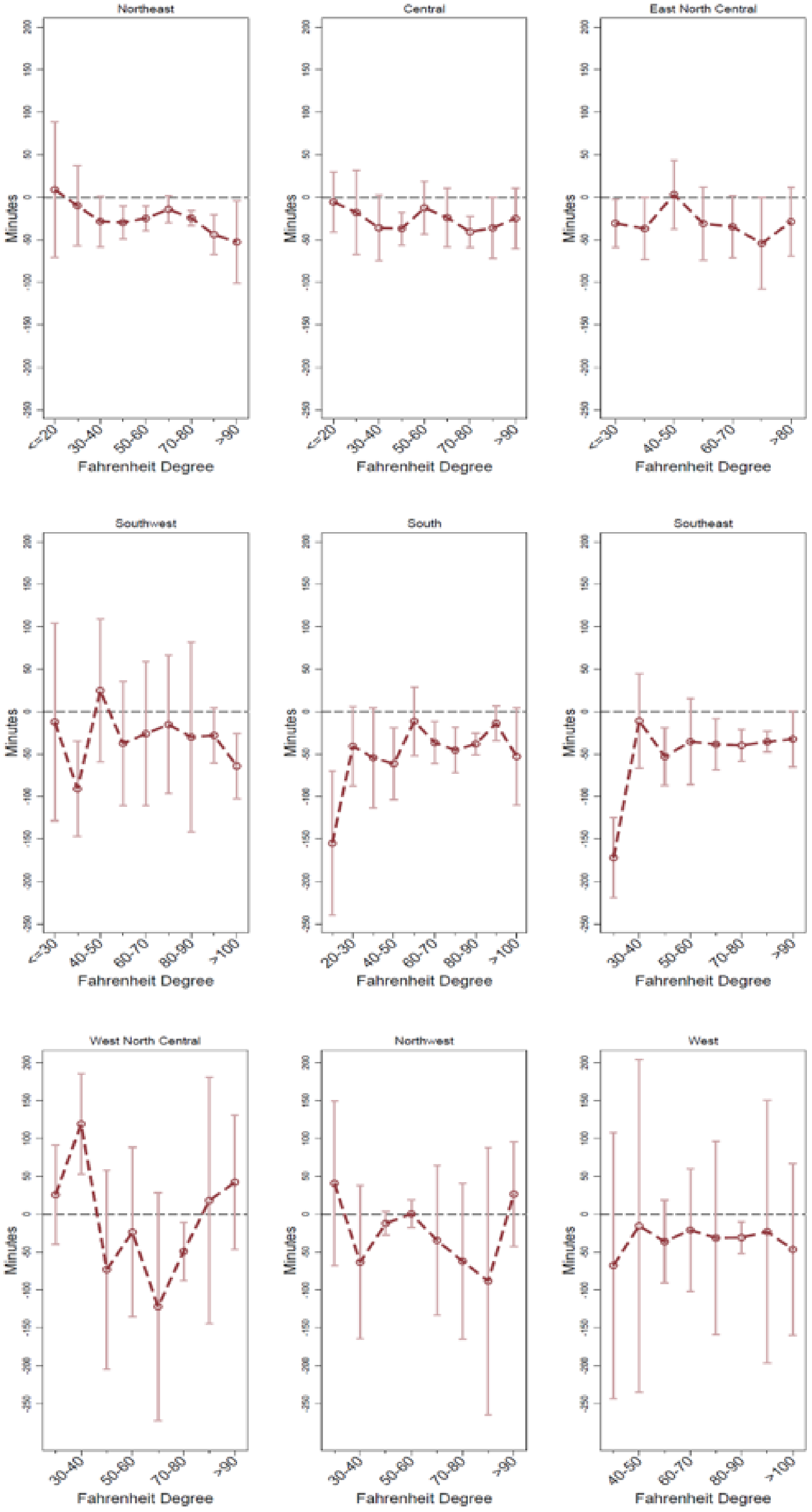

Figure A10: Effect of Temperature on Work Time Differences between Males and Females by Region

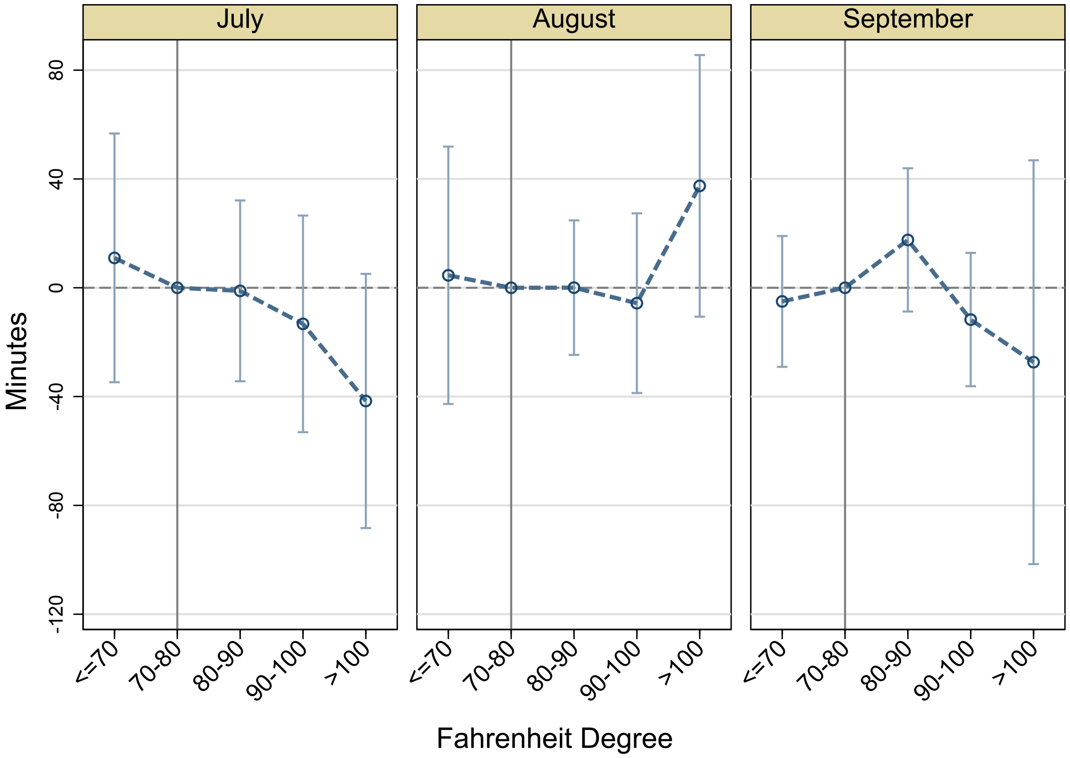

Figure A11: Effect of Temperature on Males' Work Time for July, August, and September

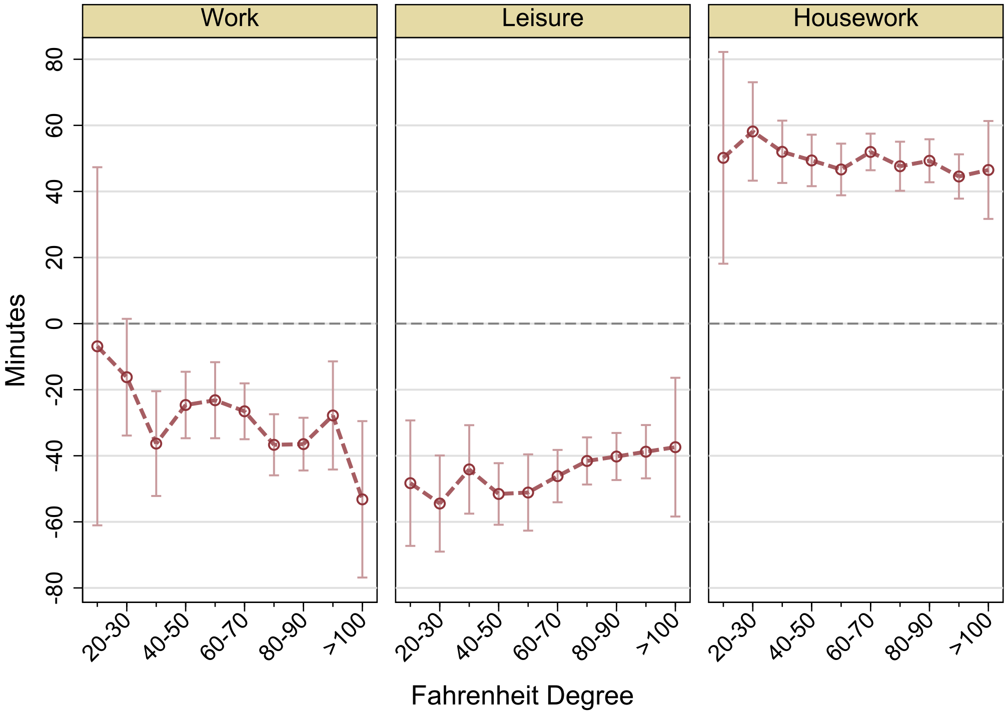

Figure A12: The Effect of Temperature on Time Allocation between Non-Self-Employed Males and Females

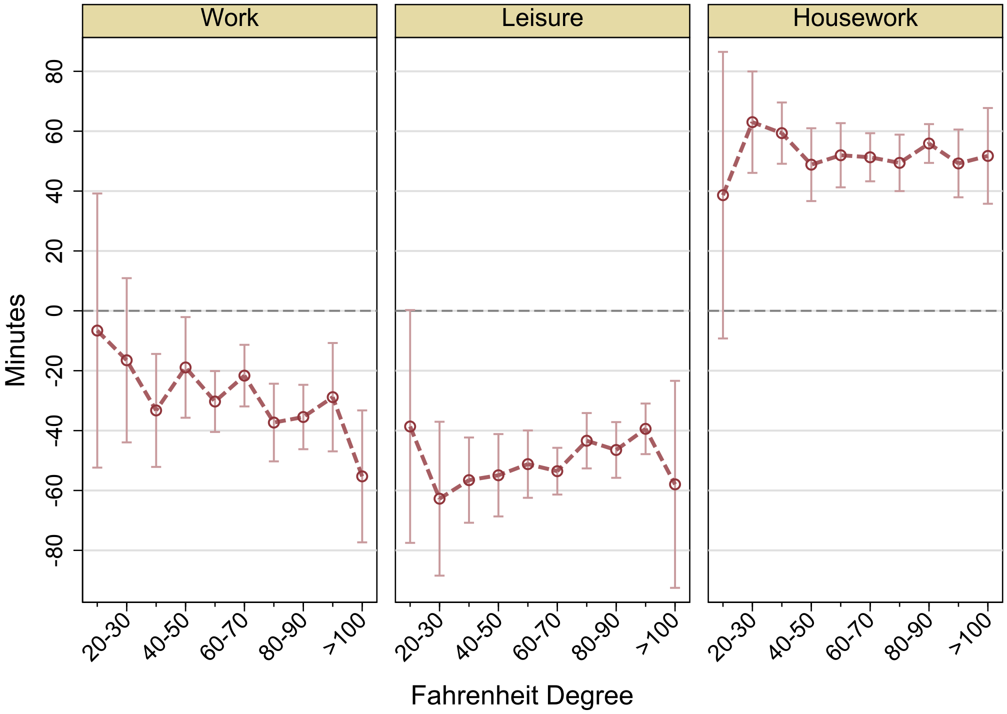

Figure A13: The Effect of Temperature on Time Allocation For Those Living in Identified Counties

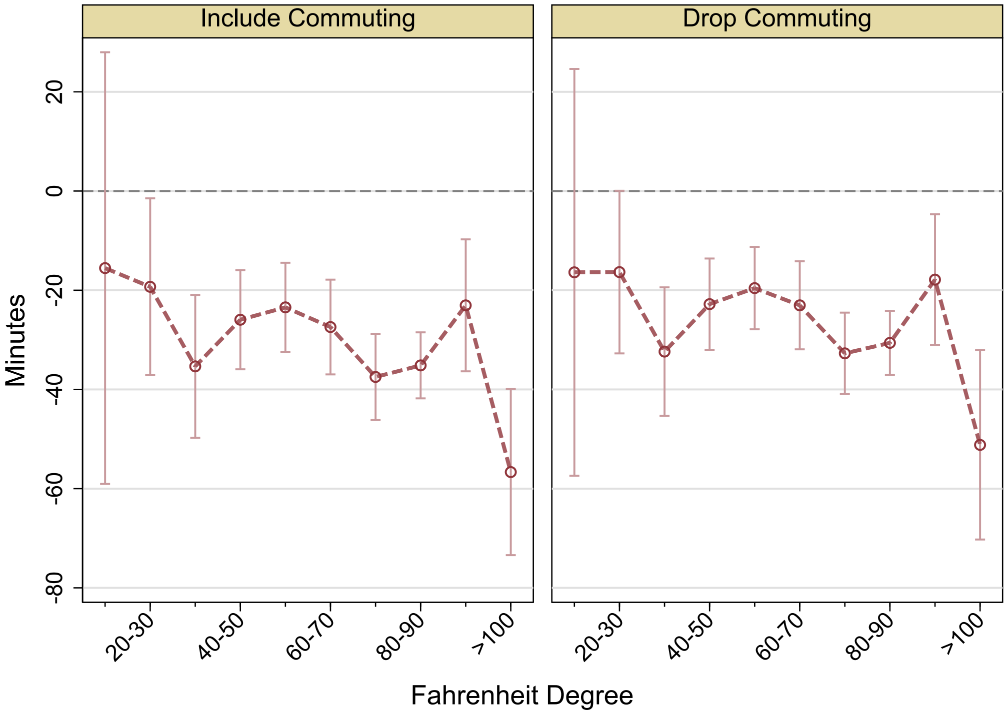

Figure A14: Effect of Temperature on Time Allocation between Males and Females Working Indoors

Table A1: Categories of Activities

Category	Activity	ATUS Code
Work	Working	050100
	Work-related activities	0502XX
	Travel related to work	1805XX
Leisure	Eating and drinking	11XXXX
	Socializing, relaxing, and leisure	12XXXX
	Sports, exercise, and recreation	13XXXX
	Shopping, except groceries, food and gas	070104
	Telephone calls to/from family members	160101
	Telephone calls to/from friends, neighbors, or acquaintances	160102
	Travel related to shopping (except grocery shopping)	180782
	Travel related to eating and drinking	1811XX
	Travel related to socializing, relaxing, and leisure	1812XX
	Travel related to sports, exercise, and recreation	1813XX
Housework	Household activities	02XXXX
	Caring for and helping household members	03XXXX
	Caring for and helping nonhousehold members	04XXXX
	Household services	09XXXX
	Grocery shopping	070101
	Telephone calls to/from education services providers	160103
	Telephone calls to/from household services providers	160106
	Telephone calls to/from paid child or adult care providers	160107
	Travel related to grocery shopping	180701
	Travel related to household activities	180280
	Travel related to caring for and helping household members	1803XX
	Travel related to caring for and helping nonhousehold members	1804XX
	Travel related to using household services	1809XX

Table A2: Sample Distribution.

	Mean (include work time 0)			Mean (drop work time 0)		
	Male	Female	p (Difference)	Male	Female	p (Difference)
			A. By Job Characteristics			
Self-employed workers	0.12	0.08	0.00	0.14	0.09	0.00
Outdoor workers	0.19	0.04	0.00	0.18	0.04	0.00
			B. By Family Characteristics			
Marital status						
Married	0.59	0.49	0.00	0.60	0.48	0.00
Unmarried but Cohabitants	0.04	0.04	0.80	0.04	0.04	0.94
Single and Others	0.37	0.47	0.00	0.36	0.48	0.00
Parenthood status						
If there are children<18	0.45	0.47	0.00	0.46	0.47	0.05
Number of own children<18	0.85	0.83	0.01	0.87	0.82	0.00
			C. By Individual Characteristics			
Educational attainment						
High school and below	0.32	0.27	0.00	0.30	0.26	0.00
Some college	0.26	0.30	0.00	0.26	0.29	0.00
College graduate and above	0.42	0.43	0.16	0.44	0.45	0.01
Race						
Non-Hispanic White	0.66	0.64	0.00	0.67	0.64	0.00
All others	0.34	0.36	0.00	0.33	0.36	0.00
Age						
Young (15-30)	0.19	0.20	0.00	0.18	0.20	0.00
Prime age (31-50)	0.55	0.53	0.00	0.56	0.53	0.00
Old (51-65)	0.25	0.26	0.00	0.26	0.27	0.01
Family income bins	6.59	6.21	0.00	6.63	6.27	0.00

Table A3: Effects of Maximum Temperature on the Work Time of Males

VARIABLES: Work Time	(1)	(2)	(3)	(4)	(5)	(6)
Max Temp (≤20)	-31.959*	-32.813*	-32.326*	-38.031*	-36.806*	-37.234*
	(16.620)	(16.972)	(19.174)	(20.844)	(18.693)	(18.657)
Max Temp (20-30)	-26.614***	-27.405***	-25.948***	-26.251***	-28.846***	-28.846***
	(8.692)	(8.780)	(8.728)	(9.276)	(8.980)	(8.918)
Max Temp (30-40)	-13.107*	-13.818*	-15.029*	-16.621*	-15.958*	-16.196*
	(7.172)	(7.458)	(8.028)	(8.808)	(8.311)	(8.337)
Max Temp (40-50)	-10.770+	-11.352*	-10.720*	-12.578*	-9.780+	-9.670+
	(6.698)	(6.562)	(6.321)	(7.102)	(6.158)	(6.127)
Max Temp (50-60)	-9.703+	-10.028+	-10.195+	-10.606+	-9.361+	-9.391+
	(6.232)	(6.246)	(6.210)	(6.621)	(6.065)	(6.052)
Max Temp (60-70)	-5.296	-5.401	-4.763	-5.900	-4.515	-4.699
	(4.181)	(4.215)	(4.134)	(4.626)	(4.152)	(4.107)
Max Temp (80-90)	-2.445	-2.390	-2.408	-0.766	-2.666	-2.564
	(3.837)	(3.840)	(3.665)	(4.349)	(3.616)	(3.613)
Max Temp (90-100)	-14.662**	-14.602**	-14.051**	-13.535**	-15.006***	-14.675**
	(5.796)	(5.828)	(5.545)	(5.738)	(5.514)	(5.533)
Max Temp (>100)	-12.920+	-12.626+	-11.475	-2.149	-14.920*	-14.667*
	(8.311)	(8.385)	(8.031)	(9.685)	(8.353)	(8.233)
Observations	70,389	70,389	70,389	64,214	70,389	70,389
R-squared	0.403	0.403	0.418	0.420	0.419	0.420
Year FE	×	×	×	×	×	×
Month FE	×	×	×	×	×	×
County FE	×	×	×	×	×	×
State-Season FE	×	×	×	×	×	×
Daylight		×	×	×	×	×
Industry-Month FE			×	×	×	×
Occupation-Month FE			×	×	×	×
Snowfall and Snow Depth				×		
Year-Month FE					×	×
State Linear Trend						×

Robust standard errors in parentheses.
*** p<0.01, ** p<0.05, * p<0.10, + p<0.15