Abstract

Climate change and global warming have significant implications for people worldwide, necessitating an understanding of how extreme weather conditions affect individuals. This study investigates the relationship between individual affective well-being and extreme temperatures, using data from the American Time Use Survey's Well-Being Module for multiple years. The analysis focuses on daily variations in weather conditions er g a

This study makes three contributions to the literature. First, it contributes to the well-being literature by examining how day-to-day weather conditions impact individual self-reported well-being (Connolly, 2013; Frijters et al., 2020). While previous studies have looked at how weather conditions affect overall life evaluations or instant feelings, there is, as yet, no conclusive evidence. This study is the first to use nationally representative time use diary data from the US. Second, most existing research focuses on cognitive measures of well-being, such as life satisfaction or self-rated health, but this study examines six different affective measures of instant feelings. Third, the study goes beyond examining the relationship between weather and well-being and aims to understand the potential mechanisms behind these effects. Additional analyses are conducted to explore the effects of extreme temperatures on sleep quality measures and the geographical distribution of the population in the US.

The rest of the paper is organized as follows. Section 2 provides a literature review on the relationship between weather conditions and subjective well-being in the US. Section 3 presents data and the construction of the variables used in the paper, together with certain descriptive statistics. Section 4 introduces the econometric strategy. Section 5 shows the empirical findings of the paper and Section 6 concludes.

2. Literature review

Recent research has focused on the relationship between weather conditions and health outcomes, particularly in terms of well-being. Despite these efforts, there are still gaps in the literature, particularly in the context of the United States where the existing evidence is mixed. Studies exploring the relationship between cognitive and affective measures of well-being and weather conditions include the works of researchers such as Connolly (2013), Lucas and Lawless (2013), Noelke et al. (2016), and Frijters et al. (2020).[1]

In Connolly's (2013) study, data from the Princeton Affect and Time Survey (PATS) is used to examine the relationship between weather conditions and well-being[2], finding

of feelings experienced during different activities, specifically for the three randomly

4. Econometric strategy

To examine the relationship between weather conditions and well-being, we employ ordinary least squares (OLS) regression models while considering the sampling weights provided by the ATUS. Clustered standard errors by individual are adjusted in order to account for correlation within individuals, as the data contains multiple observations from each respondent. For binary dependent variables, such as the U-index, we estimate linear probability models, while for continuous dependent variables like happiness, meaningfulness, sadness, stress, tiredness, pain, and net affect, we use OLS models.

To address the differences in the fraction of time spent on eligible activities and the probability of selecting an eligible activity in the module, we apply activity-level weights. These weights help account for various aspects of the ATUS sample design and data collection process, including the oversampling of certain demographic groups and weekends, nonresponse rates, and the requirement that activities should be at least 5 minutes in duration. By using activity weights, we can appropriately adjust and compensate for these important aspects. It is worth noting that subjective well-being questions are asked for three activities specifically, which is why activity weights are utilized in our analysis.[6]

The decision to use the OLS estimator in our analysis is based on its simplicity and ease of interpreting results. Coefficients in the linear model can be directly interpreted as marginal effects, providing a quantitative understanding of the relationship between variables. In contrast, ordered models, such as ordered logit or probit models, do not allow for direct quantitative interpretation of coefficients. Prior research has demonstrated that the cardinal models (OLS regressions) and ordinal models (ordered latent response models) yield very similar results, at least qualitatively. Studies by Ferrer-i-Carbonell and Frijters (2004) and Rasciute et al. (2023) have supported this finding. Therefore, considering the similarity in results between cardinal and ordinal models, we choose to adopt a cardinal interpretation of individual responses, even though the survey provides ordinal measures of affective well-being.

[6] Note that our unit of analysis is activity, rather than individual. Thus, we cluster the standard errors on the person because the data contains multiple observations from each respondent (i.e., 3 episodes are from the same respondent).

Specifically, we estimate the following linear regression, separately by gender:

$$, = 0 + , + , + , + + + + , \quad (1)$$

In all models, subscript denotes individuals, denotes county of residence,

are typically asleep during minimum temperature occurrences (Graff Zivin and Neidell, 2014; Krüger and Neugart, 2018). Additionally, maximum temperatures are highly correlated with average and minimum temperatures in our sample, with correlation coefficients of 0.981 and 0.918, respectively, and statistically significant at the 99% confidence level. Consequently, the parameter represents the impact of an additional day within a specific temperature range on each instantaneous feeling outcome variable, relative to the impact of a day within the 70-80ºF range.

To account for time-specific fixed effects, we incorporate year dummies ( ) indicating the year in which the survey was conducted. These dummies help control for unobserved factors specific to a particular year, such as survey issues and macroeconomic conditions. The reference year is 2010. Additionally, the variable represents month dummies to capture any seasonal patterns in subjective well-being (with December serving as the reference month category). To account for regional heterogeneity and address any unobserved characteristics at the state level, we include US state of residence fixed effects denoted as . These fixed effects control for permanent (time-invariant) state characteristics that may simultaneously influence daily maximum temperature and subjective well-being, such as latitude, longitude, elevation, and other factors. The error term is described by , representing the standard errors.

5. Results

Tables 2 and 3 present the OLS estimates that examine the relationship between daily maximum temperature and individual instant well-being, including happiness, meaningfulness, sadness, stress, tiredness, pain, net affect, and the U-index. The analysis takes into account demographic, household, episode, time, and state characteristics. The results are reported separately for males and females to explore any gender-specific differences and exposure to maximum temperatures.[7]

Our estimates reveal notable gender differences, indicating that males may be more sensitive to extreme maximum temperatures. Specifically, we find that days with

[7] .50 Tc -0.005 .98 -0 0287-

include this variable in the main specification because it is not available for the 2010 survey year.

We conduct a simple placebo or falsification test in Tables B5 and B6. In these tables, we re-estimate the main specification using weather data from the year prior to the survey day, instead of the same day. The remaining specification remains unchanged. The results from this placebo test do not yield similar findings to those presented in Tables 2 and 3, suggesting that the relationship between temperature and well-being is not spurious.

Additionally, as a further placebo test, Tables B7 and B8 present estimates using maximum temperature information from a randomly selected county on the diary day. This serves as a test to determine if the specific county's temperature has a causal impact on well-being. (Further details on additional placebo tests are available upon request).

Potential mechanisms

We delve into the potential mechanisms underlying our main well-being estimates, as presented in Tables 2 and 3. Our findings suggest that males exhibit heightened sensitivity to extreme temperatures, resulting in increased fatigue and stress, as well as reduced levels of happiness and meaningfulness. We focus our analysis on two potential factors: sleeping time and quality, as well as the population's location.

First, sleeping time and quality may play a crucial role in understanding the relationship between temperature and well-being. Extreme temperatures can disrupt sleep patterns, leading to inadequate sleep duration and poor sleep quality. Such disturbances]TJ( )TjEMC /P <

2013, and 2021, which includes the Well-Being Modules. The focus is on the United States, given the availability of data and the country's broad coverage. By utilizing data from four entire years, this study provides more robust estimates compared to prior research that often focused on specific seasons, which can introduce bias.

The empirical analysis covers a sample of 17,499 individuals, with over 69,000 pooled observations, contributing to the existing literature on the health impacts of climate change from both subjective well-being and gender perspectives. Notably, the finding that males appear to be more sensitive to temperature is a novel result and suggests that global climate change could have negative affective well-being consequences for males. This contrasts with prior research by Connolly (2013), which indicated that women were more affected by daily temperature, based on data from the summer of 2006.

The study also explores potential mechanisms and finds that higher temperatures are negatively associated with sleep quality in males. Additionally, the analysis reveals that warmer states have, on average, a lower proportion of males over the past four decades (1980-2021). These findings contrast with Frijters et al. (2020) and contribute to an understanding of the relationship between daily temperatures and subjective well-being, even after accounting for various well-being determinants, episode characteristics, and weather variables.

Comparing the estimates with other determinants of affective well-

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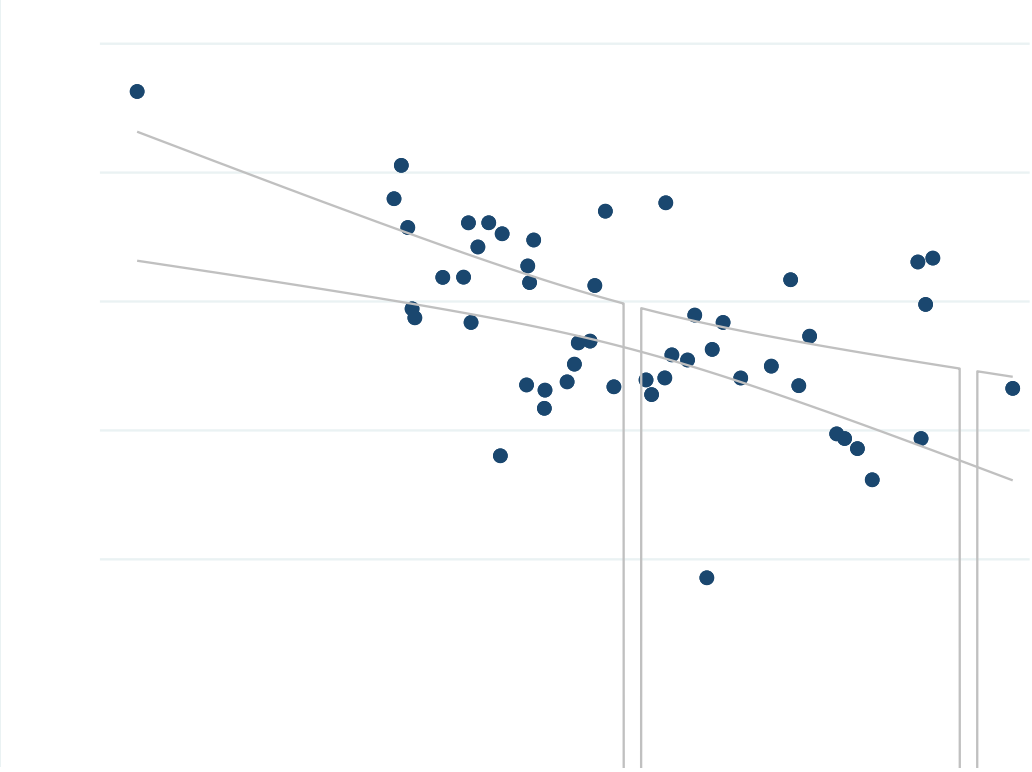
Figure 1. Scatter plot of sex ratio vs. maximum temperature, state averages during 1980-2021



Notes: Author's own elaboration. Each circle represents the average sex ratio and maximum temperature in a state during 1980-2021. The red line trend describes the relation between sex ratio and maximum temperature in these states, whereas the grey lines represent the associated 95% confidence intervals.

Table 2. Relationship between maximum temperature and instant feelings, males

	Happy	Meaningful	Sad	Stress	Tired	Pain	Net affect	U-index

Constant	-0.916***	-1.658***	-0.272	-0.782***	0.651***	-0.409**	-1.012***	0.107*
	(0.186)	(0.187)	(0.197)	(0.200)	(0.201)	(0.183)	(0.197)	(0.061)
Activity categories	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Month F.E.	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year F.E.	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
State F.E.	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Number of episodes	30,861	30,861						

R-squared	0.084	0.097	0.077	0.075	0.074	0.084

Notes: Clustered standard errors at the state level are given in parentheses. Data come from the 2003-2019 and 2021 ATUS in Columns (1-3), and from the 2010, 2012, 2013 and 2021 ATUS WB-Module in Columns (4-6). Estimation method for specifications is OLS. Omitted category is maximum temperature in the 70s. Estimates are weighted using sampling demographic weights at the individual level. All models control for month, year and state fixed effects, but not shown for brevity. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

APPENDIX A. VARIABLES DESCRIPTION

Table A1. Description of socio-demographics set from ATUS WB-Module

Variable name	Definition and measurements
1) Male	Coded from gender, 1 if male. Value 0 otherwise
2) Age	Coded from age, measured in years
3) Native citizen	Coded from citizen, 1 if citizen equal to "Native, born in United States". Value 0 otherwise
4) Primary education	Coded from educ, 1 if educ equal to "Less than 1st grade", "1st, 2nd, 3rd, or 4th grade", "5th or 6th grade", "7th or 8th grade", "9th grade", "10th grade", "11th grade", "12th grade, no diploma". Value 0 otherwise
5) Secondary education	Coded from educ, 1 if educ equal to "High school graduate – GED", "High school graduate – diploma". Value 0 otherwise
6) University education	Coded from educ, 1 if educ equal to "Some college but no degree", "Associate degree – occupational vocational", "Associate degree –

21) Holiday	Coded from holiday, 1 if holiday equal to yes. Value 0 otherwise

Source: Author's own elaboration

Table A2. Classification of time use categories, ATUS WB-Module 2010, 2012, 2013, 2021

Time use categories	Time use activity codes
Personal care	Health-related self care; Self care, n.e.c.; Using health and care services outside the home; Using in-home health and care services; Waiting associated with medical services; Using medical services, n.e.c.; Using personal care services; Waiting associated with personal care services; Eating and drinking; Waiting associated with eating and drinking; Providing care; Telephone calls to or from professional or personal care services providers; Travel related to personal care; Travel related to using personal care services; Travel related to using professional and personal care services, n.e.c.; Travel related to eating and drinking
Cooking	Food and drink preparation
Shopping	Grocery shopping; Purchasing gas; Purchasing food (not groceries); Shopping, except groceries, food, and gas; Waiting associated with shopping; Comparison shopping; Travel related to grocery shopping; Travel related to purchasing food (not groceries) (2005+); Travel re (;)0.5 ( )0.52l--t-1.2 (C (a)4.9 (r5

	services; Using clothing repair and cleaning services; Using home maintenance, repair, decoration, or construction services; Waiting associated with home maintenance, repair, decoration, or construction; Using pet services; Waiting associated with pet services; Using lawn and garden services; Using vehicle maintenance or repair services; Using vehicle maintenance and repair services, n.e.c.; Using police and fire services; Using social services; Obtaining licenses and paying fines, fees, or taxes; Using government services, n.e.c.; Security procedures related to government services or civic obligations; Telephone calls to or from salespeople; Telephone calls to or from household services providers; Telephone calls to or from government officials; Travel related to housework; Travel related to food and drink preparation, clean-up, and presentation; Travel related to interior maintenance, repair, and decoration; Travel related to exterior maintenance, repair, and decoration; Travel related to lawn, garden, and houseplant care; Travel related to care for animals and pets; Travel related to vehicle care and maintenance; Travel related to appliance, tool, and toy set-up, repair, and maintenance; Travel related to household management; Travel related to caring for household adults; Travel related to helping household adults; Travel related to caring for and helping non-household children; Travel related to caring for non-household adults; Travel related to helping non-household adults; Travel related to using financial services and banking; Travel related to using legal services; Travel related to using medical services; Travel related to using personal care services; Travel related to using real estate services; Travel related to using veterinary services; Travel related to using household services; Travel related to using home maintenance, repair, decoration, or construction services; Travel related to using pet services (not veterinary care); Travel related to using lawn and garden services; Travel related to using vehicle maintenance and repair services; Travel related to using government services; Travel related to civic obligations and participation
Childcare	

	Waiting associated with relaxing/leisure; Socializing, relaxing and leisure, n.e.c.; Watching baseball; Watching basketball; Watching dancing; Watching equestrian sports; Watching football; Watching hockey; Watching racquet sports; Watching soccer; Watching water sports; Telephone calls (except hotline counselling); Administrative and support activities, n.e.c.; Food preparation, presentation, clean-up; Collecting and delivering clothing and other goods; Indoor and outdoor maintenance, repair, and clean-up; Indoor and outdoor maintenance, building, and clean-up activities, n.e.c.; Performing; Public health services; Telephone calls to/from family members; Phone calls to/from friends, neighbors, or acquaintances; Telephone calls (to or from), n.e.c.; Waiting associated with telephone calls; Travel related to socializing and communicating; Travel related to attending or hosting social events; Travel related to socializing, relaxing, leisure, n.e.c.; Travel related to phone calls
Sports	Doing aerobics; Playing baseball; Playing basketball; Biking; Playing billiards; Boating; Bowling; Climbing, spelunking, caving; Dancing; Participating in equestrian sports; Fishing; Playing football; Golfing; Hiking; Playing hockey; Hunting; Participating in martial arts; Playing racquet sports; Rollerblading; Running; Skiing, ice skating, snowboarding; Playing

APPENDIX B. ROBUSTNESS CHECKS

Table B1. Regression results, relationship between daily weather conditions and instant feelings, males (143

	Happy	Meaningful	Sad	Stress	Tired	Pain	Net affect	U-index
	(1)	(2)	(3)					

	(0.043)	(0.042)	(0.047)	(0.047)	(0.045)	(0.042)	(0.044)	(0.012)
Secondary education	-0.138**	-0.013	-0.129*	-0.041	-0.004	-0.059	-0.021	0.024
	(0.058)	(0.058)	(0.072)	(0.066)	(0.062)	(0.059)	(0.063)	(0.016)
University education	-0.199***	-0.026	-0.040	0.111*	0.112*	-0.077	-0.117**	0.037**
	(0.054)	(0.053)	(0.073)	(0.064)	(0.059)	(0.056)	(0.057)	(0.015)
Employed	0.117**	0.054	-0.134***	-0.062	0.125***	-0.210***	0.112***	-0.003
	(0.047)	(0.043)	(0.050)	(0.045)	(0.042)	(0.042)	(0.043)	(0.012)
Married or cohabiting	0.097**	0.047	-0.020	0.004	0.024	0.032	0.050	-0.010
	(0.040)	(0.040)	(0.041)	(0.045)	(0.040)	(0.042)	(0.041)	(0.013)
Number of household members	0.022	0.019	0.027	-0.006	0.013	0.015	0.009	0.003
	(0.018)	(0.019)	(0.021)	(0.020)	(0.019)	(0.019)	(0.018)	(0.006)

Table B3. Regression results, relationship between maximum temperature and instant feelings (controlling for life satisfaction), males

	Happy	Meaningful	Sad	Stress	Tired	Pain	Net affect	U-indeeW

Life satisfaction (*z*-score)	0.299***	0.194***	-0.219***	-0.253***	-0.134***	-0.144***	0.347***	-0.059***
	(0.021)	(0.021)	(0.023)	(0.022)	(0.019)	(0.020)	(0.022)	(0.006)
Constant	0.067	-0.808***	-0.189	-0.697***	0.688*	0.421	-0.420	0.186*
	(0.221)	(0.273)	(0.222)	(0.253)	(0.360)	(0.362)	(0.260)	(0.106)
Activity categories	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Month F.E.	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year F.E.	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
State F.E.	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Number of episodes	21,259	21,259	21,259	21,259	21,259	21,259	21,259	21,259
Number of individuals	5,470	5,470	5,470	5,470	5,470	5,470	5,470	5,470
R-squared	0.206	0.177	0.120	0.226	0.083	0.169	0.266	0.114

Notes: Clustered standard errors at the individual level are given in parentheses. Data come from the 2012, 2013 and 2021 ATUS WB-Module. Estimation method for specifications is OLS. Dependent variables in columns (1-

Table B4

Life satisfaction (*z*-score)	0.288***	0.172***	-0.210***	-0.258***	-0.166***	-0.173***	0.346***	-0.069***
	(0.018)	(0.018)	(0.020)	(0.020)	(0.019)	(0.020)	(0.020)	(0.007)
Constant	-1.034***	-1.448***	0.217	0.167	0.918**	0.382	-1.396***	0.705***
	(0.361)	(0.215)	(0.291)	(0.463)	(0.418)	(0.353)	(0.356)	(0.134)
Activity categories	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Month F.E.	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year F.E.	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
State F.E.	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Number of episodes	26,326	26,326	26,326	26,326	26,326	26,326	26,326	26,326
Number of individuals	6,695	6,695	6,695	6,695	6,695	6,695	6,695	6,695
R-squared	0.202	0.190	0.130	0.222	0.116	0.213	0.276	0.133

Notes: Clustered standard errors at the individual level are given in parentheses. Data come from the 2012, 2013 and 2021 ATUS WB-

Table B5. Placebo test, maximum temperature from one year before, males

	Happy	Meaningful	Sad	Stress	Tired	Pain	Net affect	U-index
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Under 50s (								

Constant	-0.998***	-1.679***	-0.132	-0.733***	0.680***	-0.370*	-1.099***	0.128**
	(0.186)	(0.188)	(0.201)	(0.202)	(0.203)	(0.192)	(0.203)	(0.061)

Table B7. Placebo test, maximum temperature from a random county, males

	Happy	Meaningful	Sad	Stress	Tired	Pain	Net affect	U-index
	(1)	(2)	(3)	(4)				

Table B8. Placebo test, maximum temperature from a random county, females

	Happy	Meaningful	Sad	Stress	Tired	Pain	Net affect	U-index
	(1)	(2)	(3)	(4)	(5)	(6)		

Constant	-1.079***	-1.357***	0.333	-0.010	0.649*	0.243	-1.265***	0.602***
	(0.334)	(0.191)	(0.251)	(0.461)	(0.392)	(0.284)	(0.349)	(0.135)
Activity categories	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Month F.E.	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year F.E.	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
State F.E.	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Number of episodes	37,917	37,917	37,917	37,917	37,917	37,917	37,917	37,917
Number of individuals	9,502							

APPENDIX C: ADDITIONAL ANALYSES

Table C1. Cognitive well-being measures

General health status

Notes: Clustered standard errors at the state level are given in parentheses. Data come from the 2010, 2012, 2013 and 2021 ATUS WB-Module. Estimation method for specifications is OLS. Omitted category is maximum temperature in the 70s. Estimates are weighted using sampling demographic weights at the individual level. All models control for month, year and state fixed effects, but not shown for brevity. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.