Uncertainty in Time Use Allocation due to Weather Shocks

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Overview

- Intergovernmental Panel on Climate Change (IPCC) report in August 2021: some of the worsening impacts of climate change (e.g. rising sea levels) are already irreversible for the next millennia (United Nations 2021).
- In the US —from the Caldor Fire in California to the deadly remnants of Hurricane Ida in Louisiana, New York and New Jersey (Joselow 2021).
- Extreme heat has now become the US' leading weather-related cause of death (Joselow 2021).

Overview

- Excessively high (or low) temperature can cause discomfort, stress and fatigue that can impair a person's ability to do one's task depending on the degree to which the individual is exposed to these elements.
- This implies that weather may play a significant role in affecting an individual's decision regarding their use of time.
- The potential impacts of weather phenomenon on marginal productivity of labor and marginal utility of leisure can result in individuals changing their behavior affecting how they allocate their time.

Research Question

1. How do weather shocks (e.g. changes in temperature) impact an individual's time allocation?
2. Do weather shocks cause substitutability between indoor and outdoor leisure activities, and leisure and work activities?

Literature Review - Empirical

Empirical analyses on the impact of weather on time use allocation:

- Connolly (2008) - provides intertemporal labor supply analyses using exogenous variations in daily rainfall
- Hamermesh, Myers, and Pocock (2008) - investigates how various cues that include daylight and time zones, can affect the timing and coordination of economic activities in US and Australia
- Graff Zivin and Neidell (2014) - estimates the impacts of temperature on time allocation by exploiting the exogenous variation in temperature over time in the US
- Huang et al. (2020) - examines the long-term effects of climate change on rural residents' individual-level labor allocation in rural China

Literature Review - Theoretical

A Theory of the Allocation of Time by Becker (1965)

$$Max \;\; U(x_1, ..., x_m; T_1, .., T_m) \tag{1}$$

subject to:

$$\sum_{1}^{m} p_i x_i = V + T_w \overline{w} \tag{2}$$

$$\sum_{1}^{m} T_i = T_c = T - T_w \tag{3}$$

where x_i are market goods with price p_i, V is non-labor income, T_w hours spent at work, $\overline{w}$ are the earnings per unit of T_w, T_c are hours spent on consumption, and T is the total time available for an individual to do their activities.

Main Contribution

- Build a theoretical framework that modifies the Becker (1965) model by introducing uncertainty in the use of time due to exogenous weather shocks.
- Explicitly test substitutability of indoor-outdoor leisure, and leisure-work using real-world data

Definition of Terms

As in the Becker (1965) model, households are both producing units and utility maximizers.

$$Z_j = \begin{cases} Z_o = f_o(x_o, T_o) & \text{for outdoor leisure activities} \\ Z_i = f_i(x_i, T_i) & \text{for indoor leisure activities} \end{cases} \quad (4)$$

where:
$\boldsymbol{Z_o}$ and $\boldsymbol{Z_i}$ are the vector of commodities associated with outdoor and indoor leisure activities,
$\boldsymbol{x_o}$ and $\boldsymbol{x_i}$ are the vector of market goods associated to outdoor and indoor leisure activities
$\boldsymbol{T_o}$ and $\boldsymbol{T_i}$ are vector of time inputs used in producing commodity $\boldsymbol{Z_o}$ and $\boldsymbol{Z_i}$, respectively, via the production functions $\boldsymbol{f_o}$ and $\boldsymbol{f_i}$.

Illustration

If Z_o refers to hiking, x_o refers to the input of physical goods such as tents, hiking gear, food and the like, and t_o refers to the time the individual allocates for the hike.

Intuitively, the higher the production inputs in terms of market goods and time, the more Z_j is produced. That is,

$$\frac{\partial Z_j}{\partial x_j} > 0 \quad and \quad \frac{\partial Z_j}{\partial t_j} > 0 \tag{5}$$

where $j \in \{o \equiv outdoor, i \equiv indoor\}$.

Model Assumptions

- Weather is considered an exogenous shock whose actual realization is only known at the same day of the activity.
- Weather does not affect wages and the demand for labor, and does not put any additional constraint on the time allocated for work as adopted in Connolly (2008).
- $$\frac{\partial U(Z_o, Z_i)}{\partial Z_o} > 0 \quad and \quad \frac{\partial^2 U(Z_o, Z_i)}{\partial Z_o^2} < 0 \quad if \quad \mu \leq \overline{\mu} \tag{6}$$
  $$\frac{\partial U(Z_o, Z_i)}{\partial Z_o} < 0 \quad and \quad \frac{\partial^2 U(Z_o, Z_i)}{\partial Z_o^2} < 0 \quad if \quad \mu > \overline{\mu} \tag{7}$$
  $$\frac{\partial U(Z_o, Z_i)}{\partial Z_i} > 0 \quad and \quad \frac{\partial^2 U(Z_o, Z_i)}{\partial Z_i^2} < 0 \tag{8}$$

Introducing Uncertainty

$$\max_{z_o, z_i} \quad U = \delta U(Z_o) + (1 - \delta) U(Z_i) \tag{9}$$

subject to:

$$I \equiv p_o x_o + p_i x_i = V + wT_w \quad (\textit{income constraint}) \tag{10}$$

$$T_o + T_i = T - T_w \quad (\textit{time constraint}) \tag{11}$$

$$\left.\begin{aligned} x_j &\equiv b_j Z_j \\ T_j &\equiv t_j Z_j \end{aligned}\right\} \textit{(production functions)} \tag{12}$$

$$\delta \equiv f(\mu), \quad \textit{where} \;\; f'(\mu) < 0 \tag{13}$$

Introducing Uncertainty

The constrained maximization set-up is then:

$$\mathcal{L} = \delta U(Z_o) + (1-\delta)U(Z_i) + \lambda\{w[T - t_i z_i - t_o z_o] + V - P_i b_i z_i - P_o b_o z_o\} \quad (14)$$

Taking the first order conditions will give:

$$\frac{\partial \mathcal{L}}{\partial Z_o} = \delta \frac{\partial U}{\partial Z_o} - \lambda[w t_o + p_o b_o] = 0 \quad (15)$$

$$\frac{\partial \mathcal{L}}{\partial Z_i} = (1-\delta) \frac{\partial U}{\partial Z_i} - \lambda[w t_i + p_i b_i] = 0 \quad (16)$$

▸ back

Indoor-Outdoor Leisure Substitution

The idea here is to investigate the changes in the intensive margin of leisure decomposed in terms of the time allocated for indoor and outdoor leisure activities.

$$|MRS_{z_o,z_i}| = \frac{\frac{\partial U(Z_o,Z_i)}{\partial Z_o}}{\frac{\partial U(Z_o,Z_i)}{\partial Z_i}} = \frac{1-\delta}{\delta}\left(\frac{wt_o + p_o b_o}{wt_i + p_i b_i}\right) \tag{17}$$

where substitution is prompted when $\mu > \overline{\mu}$ due to the disutility illustrated in equation (4).

Recall that $\delta \equiv f(\mu)$ and $f'(\mu) < 0$.

$$|MRS_{z_o,z_i}| = \frac{\frac{\partial U(Z_o,Z_i)}{\partial Z_o}}{\frac{\partial U(Z_o,Z_i)}{\partial Z_i}} = \frac{1-f(\mu)}{f(\mu)}\left(\frac{wt_o + p_o b_o}{wt_i + p_i b_i}\right) \tag{18}$$

Indoor-Outdoor Leisure Substitution

Proposition 1: A higher probability of bad weather increases the substitutability of outdoor activities for indoor activities.

Comparative Statics

$$\frac{\partial MRS_{z_o,z_i}}{\partial \mu} = \frac{f(\mu)(-f'(\mu)) - [(1-f(\mu))f'(\mu)]}{(f(\mu))^2} \frac{wt_o + p_o b_o}{wt_i + p_i b_i} \tag{19}$$

where

$$\frac{\partial MRS_{z_o,z_i}}{\partial \mu} = \frac{\overbrace{f(\mu)(-f'(\mu))}^{(+)} \overbrace{-[(1-f(\mu))f'(\mu)]}^{(+)}}{\underbrace{(1-f(\mu))^2}_{(+)}} \frac{\overbrace{wt_o + p_o b_o}^{(+)}}{\underbrace{wt_i + p_i b_i}_{(+)}}$$

as $f'(\mu) < 0$, making equation (19) positive.

Leisure-Work Substitution

Suppose $W \equiv V + wT$ is the maximum potential income of individuals if all time is allocated on work, and if the forgone earnings for higher leisure to increase utility is denoted by a loss function L, then formally:

$$L(Z_o, Z_i) \equiv W - I(Z_o, Z_i) \tag{20}$$

where I is the equivalent forgone work activities to translate to an additional utility. In other words, the less leisure chosen, the less forgone labor income.

Using the income constraint in equation (7), equation (20) can be rewritten as:

$$P_o b_o z_o + P_i b_i z_i + L(Z_o, Z_i) \equiv W \tag{21}$$

However, since the forgone income is identical to the total time spent on consumption in lieu of working, the loss function simplifies to:

$$L(Z_o, Z_i) = w(T_w) = w(T - T_o - T_i) \tag{22}$$

and hence equation (20) will just reduce to the constraint in equation (11).

Leisure-Work Substitution

Therefore, the substitutability between leisure and work due to weather shocks will be captured indirectly by the model, through the impact of μ, the probability of bad weather, on Z_o and Z_i and eventually the impact of Z_o and Z_i on the loss function $L(Z_o, Z_i)$. More formally,

$$\frac{\partial L(Z_o, Z_i)}{\partial Z_o} > 0 \quad \textit{and} \quad \frac{\partial L(Z_o, Z_i)}{\partial Z_i} > 0 \tag{23}$$

Leisure-Work Substitution

Proposition 2: A higher probability of bad weather inclines individuals to substitute leisure for work activities.

Comparative Statics

$$\frac{\partial MU_{z_o}}{\partial \mu} = -\left[\frac{\overbrace{-\lambda(wt_o + p_o b_o) f'(\mu)}^{(+)}}{(f(\mu))^2}\right] < 0 \quad \text{if} \quad \mu > \overline{\mu} \tag{24}$$

by equation (11).

$$\frac{\partial MU_{z_i}}{\partial \mu} = \frac{\overbrace{-\lambda(wt_i + p_i b_i)\overbrace{(-f'(\mu))}^{(+)}}^{(-)}}{(1 - f(\mu))^2} < 0 \tag{25}$$

Leisure-Work Substitution

Mechanism

$$\text{Higher } \mu \Rightarrow \textit{lower} \;\; \text{MU}_{z_o} \; (MU_{z_i}) \Rightarrow \textit{lower} \;\; \text{z}_o \; (z_i) \Rightarrow \textit{lower} \;\; \text{L}(\text{Z}_o, Z_i)$$

In other words, this indirectly implies that less work activities are forgone due to bad weather.

Data

- I use an individual-level data from the American Time Use Survey (ATUS) from Hofferth et al. (2020) and extract the observations from the dates that are covered by the analysis period (February to April 2016) based on my empirical strategy.
- Each respondent completes a 24-hour time diary for a preassigned date for a specific month detailing the type of the activity, the time allocated and the location for each activity.
- The ATUS data is linked with the Current Population Survey using the unique ID of the respondents as the merging variable to retrieve the individual's characteristics such as their age, sex, presence of disability, marital status, race, ethnicity, veteran status, and educational attainment.

Data

- I group individual activities by three main categories: work, indoor leisure, and outdoor leisure.
- To calculate the time allocated for work, I sum the total number of minutes of the activities that are done in the individual's workplace.
- For indoor and outdoor definition, I use the categorization of activities by the Bureau of Labor Statistics that is already indicated in the ATUS data merged with the CPS (Hofferth et al. 2020).
- I merge the ATUS-CPS data with the time-series weather data from the National Oceanic and Atmospheric Administration for the daily temperature data.

Data - Outdoor Activities

Table 1: Outdoor Activities based on ATUS-CPS data

ATUS Variable	Outdoor Activities Definition
bls_educ_class	Educational activities: Attending class
bls_educ_travel	Educational activities: Travel related to education
bls_food_travel	Eating and drinking: Travel related to eating and drinking
bls_hhact_exter	Household activities: Exterior maintenance
bls_hhact_lawn	Household activities: Lawn and garden care
bls_hhact_travel	Household activities: Travel related to household activities
bls_hhact_vehic	Household activities: Vehicles
bls_leis	Leisure and Sports
bls_pcare_travel	Personal care: Travel related to personal care
bls_purch	Purchasing goods and services
bls_social	Organizational, civic, and religious activities

Data - Indoor Activities

Table 2: Indoor Activities based on ATUS-CPS data

ATUS Variable	Indoor Activities Definition
bls_carehh	Caring for and helping household members
bls_comm	Telephone calls, mail, and e-mail
bls_educ_hwork	Educational activities: Homework and research
bls_food_food	Eat and drinking: Eating and drinking
bls_hhact_food	Household activities: Food preparation and cleanup
bls_hhact_hhmgmt	Household activities: Household management
bls_hhac_hwork	Household activities: House work
bls_hhact_inter	Household activites: Interior maintenance
bls_hhact_pet	Household activities: Animals and pets
bls_hhact_tool	Household activities: Appliances, tools, and toys
bls_pcare_act	Personal care: Personal activities
bls_pcare_groom	Personal care: Grooming
bls_pcare_health	Personal care: Health-related self-care
bls_pcare_sleep	Personal care: Travel related to personal care

Data - Summary Statistics

	Mean
Maximum Temperature (tmax) in $^{\circ}F$	61.34
Outdoor Time Use Proportion (outdoorprop)	0.28
Indoor Time Use Proportion (indoorprop)	0.56
Work Time Use Proportion (workprop)	0.15
Daylight Savings Time (DST)	0.60
Oregon	0.43
Age	47.36
Female	0.51
Presence of disability	0.15
Married	0.54
Veteran Status	0.07
Born in the U.S.	0.84
White	0.88
Hispanic	0.19
With at least college degree	0.32
Observations	115

Means weighted by final basic weights.

Empirical Strategy

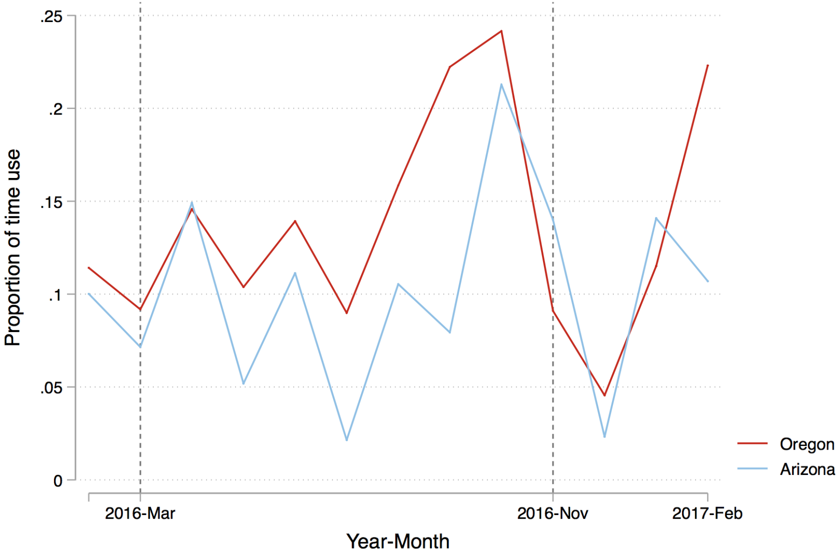
I use a difference-in-differences framework to test my theoretical model.

$$activity_{its} = \alpha_j temp_{its} + \beta_j Oregon_{is} + \delta_j DST_{it} + \chi_j (temp_{its} \cdot Oregon_{is} \cdot DST_{it}) + \gamma_j X_{its} + \theta_t + \varepsilon_{its} \quad (26)$$

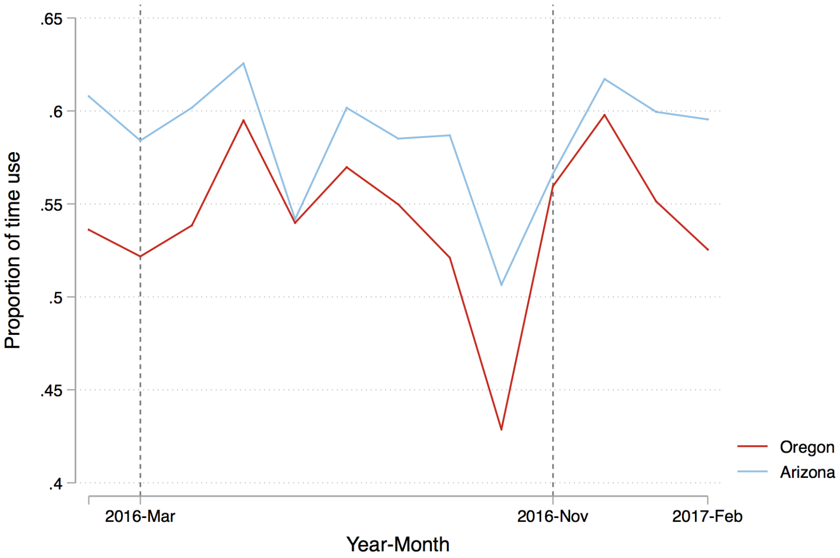
Oregon is the treatment group, and Arizona is the control group.

> "If you give workers daylight, when they leave their jobs, they are much more apt to stop and shop on their way home." - Michael Downing

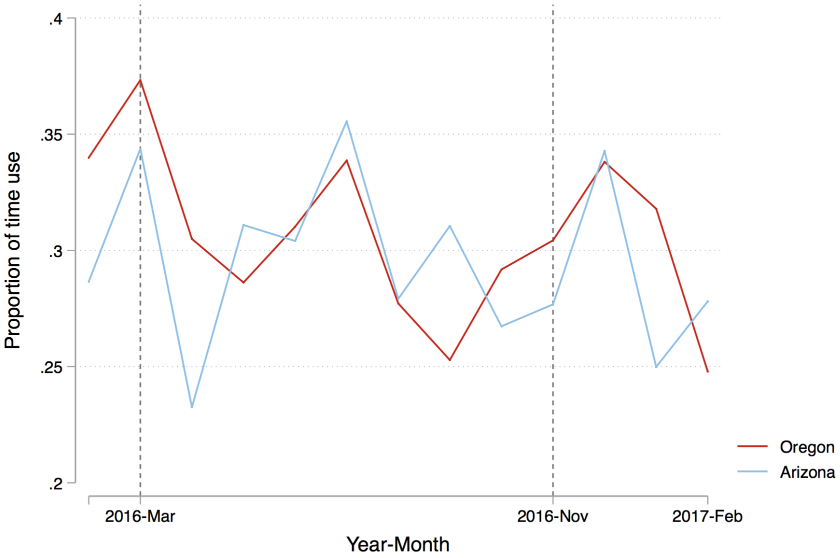
Parallel Trends - Outdoor Activities



Parallel Trends - Indoor Activities



Parallel Trends - Work



Empirical Results - OLS

	(1) outdoorprop	(2) indoorprop	(3) workprop
Maximum Temperature (tmax)	-0.004	-0.004*	0.008**
	(0.003)	(0.002)	(0.003)
Daylight Savings Time (DST)	-0.119	0.169**	-0.064
	(0.096)	(0.080)	(0.100)
Oregon	-0.019	-0.114**	0.152*
	(0.090)	(0.054)	(0.088)
tmax_dst_OR	0.001	0.001	-0.002
	(0.002)	(0.001)	(0.002)
Observations	115	115	115

Robust standard errors in parentheses.

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

Conclusion

- A higher probability of bad weather increases the substitutability of outdoor activities for indoor activities.
- A higher probability of bad weather inclines individuals to substitute leisure for work activities.
- Estimates suggest that improving weather (i.e. warmer temperature from extreme cold weather) causes individuals to increase leisure activities and decrease work activities.

Future Work

- Offer discussions on policy implications
- Add element of time to transform the model to a dynamic environment that will allow for expectations on weather, capture the intertemporal substitution effects on time use between activities
- Use different dataset

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