Mitigation or a Vicious Circle? An Empirical Analysis of Abnormal Temperature Effects on Residential Electricity Consumption

University of Nevada, Reno

Gi-Eu Lee[1]; Scott Loveridge[2]; Loretta Singletary[1]; Kimberly Rollins[1]

[1]University of Nevada, Reno; [2]Michigan State University

MICHIGAN STATE UNIVERSITY

Abstract

We use data from the past decade to estimate effects of abnormal temperatures on residential electricity use and find that historically hot years lead to less electricity use and CO_2 emissions.

We define 2 types of abnormalities: seasonal (unpleasant) and unseasonable (pleasant). Our results show that in an extremely hot year (e.g. 2012) response to unseasonable abnormalities dominated to reduce annual electricity use, while response to seasonal abnormalities occurring in "normal" years lead to an overall increase in annual electricity use.

Introduction

Much of the literature on climate change impact on energy consumption suggests that more energy will be used to adapt to increased occurrences of unpleasant temperatures (e.g., Auffhammer and Aroonruengsawat, 2011; Deschênes and Greenstone, 2011). Yet, Egan and Mullin (2016) show that the majority of the Americans currently live in places where the weather is more pleasant than decades ago. This demographic detail would be consistent with less electricity consumption over time as an outcome of climate change.

In recent decades, residential electricity consumption dropped as annual temperatures reached historical highs (2006 and 2012; Fig. 1). Although this simple statistic corresponds with Egan and Mullin (2016), other factors such as economic status and population would also contribute to this phenomena.

Our study empirically identifies impacts of abnormal air temperature on residential electricity consumption in the past decade, controlling for other factors. We find that in an extremely hot year, an unseasonable abnormality (e.g. spring or winter warm spells) is more dominant than a seasonal abnormality (e.g. extreme summer heat). But a seasonable abnormality is more influential in the long run as it occurs more often than an unseasonable abnormality.

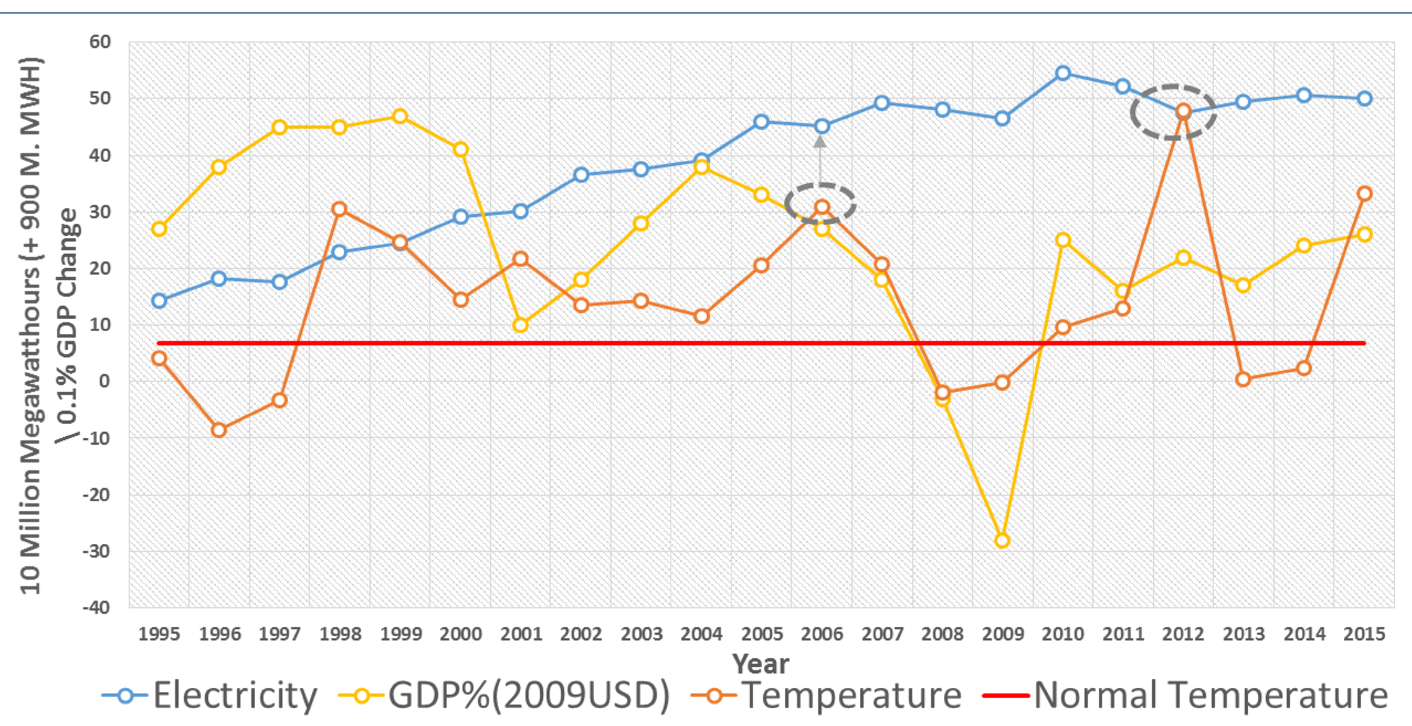

Figure 1. Residential Electricity Consumption, GDP, and Temperature

Data and Methods

DATA: We use 1999 – 2014 residential electricity data from U.S. Energy Information Administration by state (s), year (y), and month (m), including electricity sold (E), electricity price (P), and number of consumers (C). Temperature data are from National Oceanic and Atmospheric Administration's QCLCD and nClimDiv Dataset. Economic data are from the U.S. Bureau of Economic Analysis.

IDENTIFICATION STRATEGY and EMPIRICAL MODEL: In addition to temperature (T), we include abnormal temperature to capture the effects of an abnormality. An abnormality is identified in two ways: 1) temperature departure (D) from the normal level defined by NOAA (Model (1)); 2) Days of hot (HD) and cold (CD) departure by 1.645 standard deviation (Model (2)). Model (2) separates cold and hot abnormalities and excludes normal variation of temperature from the abnormality. A fixed effects model with robust variance is used to relax assumptions about ϵ_s and serial correlation (Wooldridge, 2010).

(1) $E_{sym} = \alpha + \beta_1 T_{sym} + \beta_2 D_{sym} + \beta_3 T_{sym} D_{sym} + \beta_4 P_{sym} + \beta_5 C_{sym} + \beta_6 GDP_{sy} + \beta_7 year + \epsilon_s + \varepsilon_{sym}$

(2) $E_{sym} = \alpha + \beta_1 T_{sym} + \beta_2 HD_{sym} + \beta_3 T_{sym} HD_{sym} + \beta_4 CD_{sym} + \beta_5 T_{sym} CD_{sym} + \beta_6 P_{sym} + \beta_7 C_{sym} + \beta_8 GDP_{sy} + \beta_9 year + \epsilon_s + \varepsilon_{sym}$

Similar to Deschênes and Greenstone (2011), monthly effects are approximated by mean value of abnormalities (averaged across states) times marginal effects.

Results

Model (1) results suggest negative marginal effects of an abnormality during cold months and positive effects during hot months (p-values < 0.1). Model (2) isolates the effects due to hot extremes and cold extremes. We report results of Model (2) from 2011 – 2013 as they are representative years. While marginal effects of hot extremes plot an inverse U-shape across months (see Fig. 2), marginal effects of cold extremes plot a U-shape.

The monthly marginal effects suggest that, while more cold extreme days in winter and more hot extreme days in summer both increased electricity consumption, more days of unseasonable abnormality decreased consumption. Measured at mean, unseasonable abnormality dominated the annual effect of abnormality in the U.S. in 2012 (see Table 1). Monthly unseasonable abnormality influenced electricity use by 6.9% (March) while the seasonal abnormality influenced use by 7.4% (July). In 2011 and 2013, seasonable abnormalities were more influential. As a result of U.S. household electricity consumption change, greenhouse gas emissions due to electricity generation reduced in 2012 but increased in 2011 and 2013.

Regionally, historically cooler states (e.g. New England) had stronger unseasonable marginal effect (UME) and weaker seasonal marginal effects (SME) (see Fig. 2), which resulted in less electricity use (see Table 3). Historically warmer states (e.g. West South Central region) had impacts similar to the literature due to weaker SME but stronger UME. Extreme temperature effects on annual electricity use in West North Central states are less certain as both UME and SME are large. Table 3 shows large annual decrease in electricity use in 2012 in New England states, but an increase in South West Central states.

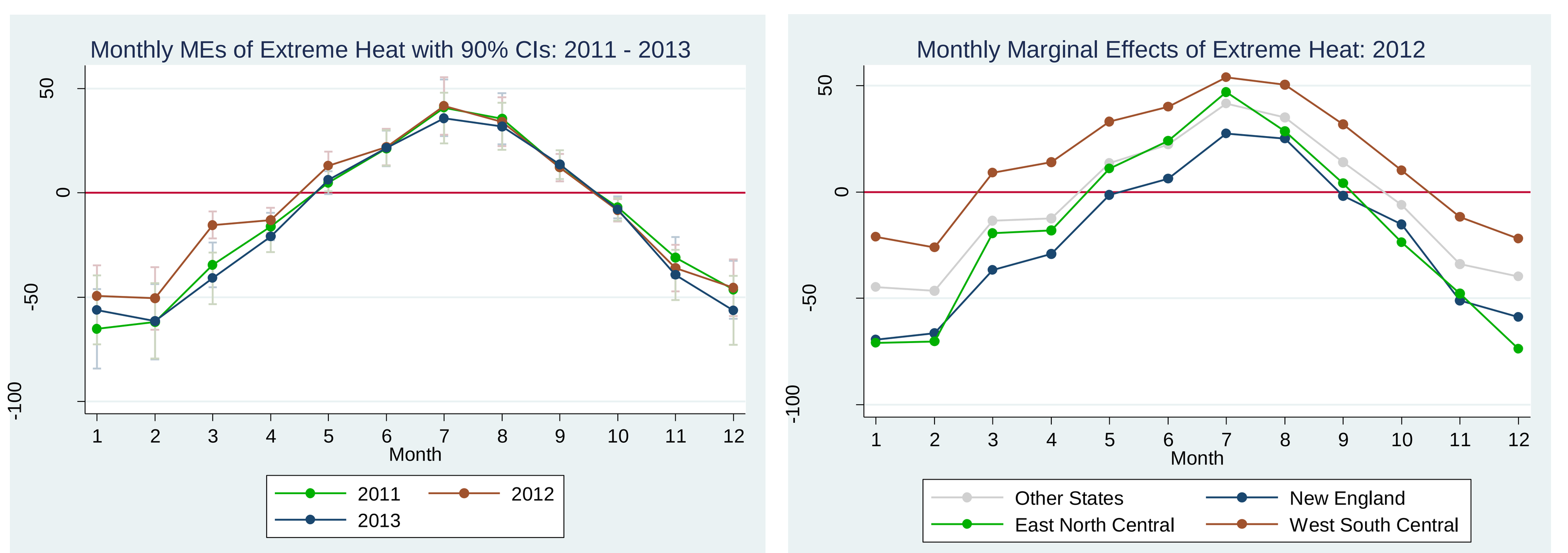

Figure 2. Marginal Effects of Extreme Heat: 2011-2013 US Continent (Left) and 2012 Representative Regions (Right)

Table 1. Effects of Extreme Temperature on Monthly Electricity Use (%): 2011 – 2013 US Continent

Unit: %; °F

	2011				2012				2013			
Month	Hot Effect	Cold Effect	Net	T. Dep.	Hot Effect	Cold Effect	Net	T. Dep.	Hot Effect	Cold Effect	Net	T. Dep.
1	-1.04	1.06	0.02	-2.09	-4.30	0.13	-4.17	4.32	-5.77	1.74	-4.03	0.45
2	-4.90	2.61	-2.29	-2.36	-3.20	0.27	-2.93	2.11	-0.44	0.51	0.07	-0.63
3	-2.58	0.34	-2.23	-0.05	***-6.87***	0.22	-6.65	7.29	-1.36	1.84	0.48	-2.21
4	-2.45	0.20	-2.25	0.20	-2.17	0.20	-1.96	2.92	-1.56	1.23	-0.33	-2.08
5	0.55	0.28	0.83	-1.67	2.41	-0.01	2.40	2.65	0.70	0.20	0.91	0.05
6	2.89	-0.06	2.83	0.81	2.94	-0.11	2.83	1.53	1.81	-0.03	1.78	1.38
7	6.18	-0.04	6.15	2.18	***7.41***	-0.25	7.17	2.81	3.34	-0.60	2.75	0.25
8	3.56	-0.01	3.56	2.26	2.36	-0.23	2.12	1.06	2.06	-0.49	1.57	0.25
9	1.14	-0.05	1.09	0.90	0.54	-0.01	0.53	1.12	1.28	-0.02	1.25	1.77
10	-0.57	0.42	-0.15	0.94	-0.70	0.57	-0.12	-0.26	-0.53	0.22	-0.31	-0.71
11	-4.06	0.49	-3.57	1.01	-2.17	0.75	-1.42	1.27	-1.81	2.45	0.64	-1.13
12	-3.93	0.28	-3.65	2.18	-5.15	0.07	-5.08	2.70	-4.38	2.47	-1.91	-2.16
Annual	-0.04	0.45	0.41	0.36	-0.33	0.10	-0.24	2.46	-0.50	0.75	0.25	-0.39

Table 2. 2012 Effects of Extreme Temperature on Monthly Electricity Use (%): Representative Regions

Unit: %; °F

	New England				West North Central				West South Central			
Month	Hot Effect	Cold Effect	Net	T. Dep.	Hot Effect	Cold Effect	Net	T. Dep.	Hot Effect	Cold Effect	Net	T. Dep.
1	-17.01	0.00	-17.01	4.63	-12.91	0.00	-12.91	8.10	-2.42	0.00	-2.42	6.55
2	-16.84	0.00	-16.84	5.10	-0.69	0.37	-0.32	3.93	-1.90	0.54	-1.37	1.13
3	-62.06	0.00	-62.06	9.37	-23.14	0.00	-23.14	15.31	2.57	0.01	2.57	8.08
4	-20.95	0.00	-20.95	3.17	-5.67	0.00	-5.67	4.26	2.11	0.00	2.11	4.00
5	-0.71	0.00	-0.71	2.37	6.22	-0.01	6.20	4.64	5.57	0.00	5.57	3.98
6	2.98	0.11	3.09	-0.67	7.08	-0.17	6.90	4.49	6.01	-0.10	5.91	3.30
7	6.19	-0.16	6.03	2.73	22.64	0.00	22.64	7.26	6.56	-0.25	6.31	2.95
8	4.52	0.00	4.52	2.92	3.76	-0.49	3.28	2.06	3.28	-0.44	2.84	1.33
9	0.00	0.00	0.00	0.45	0.45	0.04	0.49	2.91	2.06	-0.14	1.92	1.25
10	-7.27	0.72	-6.54	2.22	-2.82	3.19	0.37	-2.19	0.60	0.02	0.62	-1.33
11	-1.44	5.70	4.26	-1.77	-9.41	0.00	-9.41	3.56	-0.41	0.12	-0.29	3.30
12	-6.99	0.00	-6.99	3.17	-10.14	0.00	-10.14	2.79	-2.65	0.15	-2.50	4.88
Annual	-9.29	0.47	-8.82	2.82	-0.90	0.17	-0.73	4.77	2.21	-0.05	2.16	3.30

Conclusions

Our results suggest that, after controlling for other factors, extreme temperatures contributed significantly to changes in residential electricity use in the U.S.

Response to an unseasonable abnormality, as defined here, dominates the annual decrease of the electricity use in an extreme hot year, with the impacts varying across regions of the U.S. In other years, annual residential electricity use increased due to dominant seasonal abnormality.

Contact

Gi-Eu Lee, Ph.D., NSF Post-Doctoral Research Fellow
Department of Economics, University of Nevada, Reno
Email: gieul@unr.edu

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