Energy Saving Can Kill: Evidence from the Fukushima Nuclear Accident

Guojun HE, Takano TANAKA

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HKUST Institute for Emering Market Studies
The Hong Kong University of Science and Technology
Clear Water Bay, Kowloon, Hong Kong
T: +852 3469 2215 E: iems@ust.hk W: iems.ust.hk

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Abstract

Following the Fukushima nuclear accident, Japan gradually shut down all its nuclear power plants, causing a country-wide power shortage. In response, the government launched large-scale campaigns that aimed to reduce summer electricity consumption by as much as 15% in some regions. Because electricity use plays a key role in mitigating climate impacts, such policies could potentially damage the population's health. Exploiting the different electricity- saving targets set by different regions, we show that the reduction in electricity consumption indeed increased heat-related mortality, particularly during extremely hot days. This unintended consequence suggests that there exists a trade-off between climate adaptation and energy saving.

Keywords: Electricity Saving, Climate Change Adaptation, Fukushima Accident, Extreme Weather

JEL: Q48; Q54; O12; I1

Author's contact information

Guojun He

Division of Social Science, Division of Environment and Sustainability, and Department of Economics,
The Hong Kong University of Science and Technology,
Clear Water Bay, Kowloon,
Hong Kong.
E: gjhe@ust.hk

Takanao Tanaka
Division of Social Science,
The Hong Kong University of Science and Technology,
Clear Water Bay, Kowloon,
Hong Kong.
E: takanao_tanaka@hotmail.co.jp

I. Introduction

Understanding the consequences of climate change is of tremendous scientific and policy relevance. Decades of research have generated important insights on how human society should respond to potential climate damages.[1] Among these damages, excess mortality caused by extreme weather is considered as the most devastating consequence: it is estimated the mortality cost alone could account for about 70% of the total damages in the U.S. by the end of the 21st century (e.g. Hsiang et al., 2017).

Facing such threats, one line of literature has devoted much attention to finding effective ways to mitigate climate damages. In particular, there is evidence that, when exposed to extremely hot temperature, people tend to stay indoors (e.g. Zivin and Neidell, 2014), use more air conditioning (e.g. Barreca et al., 2016; Davis and Gertler, 2015), consume more electricity (e.g. Auffhammer et al., 2018; Deschenes and Greenstone, 2011), and migrate to more pleasant environments (e.g. Deschenes and Moretti, 2009; Bohra-Mishra et al., 2014). The power of these adaptive measures is impressive. In the U.S., the chance of dying on extremely hot days has fallen by 75% over the past half-century and this remarkable decline can be almost entirely attributed to the diffusion of residential air conditioning (Barreca et al., 2016). In India, people in rural areas, who cannot easily adapt to hot temperature due to financial constraints, face a mortality risk that is more than 10 times that of urban dwellers (Burgess et al., 2017). As a result, identifying effective

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[1] See Auffhammer (2018), Carleton and Hsiang (2016), Dell et al. (2014) and IPCC (2014) for recent reviews.

adaptive measures to promote health is recognized as a global research priority for the 21st century (WHO, 2009; NIEHS, 2010).

In a separate line of literature, researchers focus on how to reduce greenhouse gas (GHG) emissions associated with generation and consumption of energy, which will benefit the climate in the long run. In particular, many countries adopt aggressive policies encouraging households to reduce energy consumption, as the residential sector alone accounts for 13% of the world energy consumption (transportation uses excluded).[2] Not surprisingly, such policies are often recognized as a "win-win" opportunity, in which they not only help people save money but also reduce the negative externality of energy use (see Alcott and Greenstone (2012) for a recent review). Governments around the world thus provide costly support to promote energy saving (e.g. Reiss and White, 2008; Alcott and Rogers, 2014; Ito, 2015; Costa and Gerard, 2018; and Ito et al., 2018). From 2007 to 2012, the U.S. government alone spent around $25 billion in subsidies for energy saving programs.[3]

A dilemma immediately emerges from these two lines of literature: if energy consumption is so critical for people to mitigate climate damages, would policies aiming to reduce people's energy consumption have any negative consequences? This paper sheds light on this issue by investigating a large-scale energy saving campaign in Japan and highlights the grand trade-off between climate adaptation and energy saving.

Our empirical strategy exploits the dramatic changes in Japan's energy policies caused by the Fukushima Daiichi nuclear disaster. Following the epic magnitude-

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[2] Source: International Energy Outlook (2016): https://www.eia.gov/outlooks/ieo/pdf/buildings.pdf.

[3] Source: U.S. Energy Information (2018): Electric Power Annual 2017.

9.0 Tōhoku earthquake on 11 March 2011, a 13-to-15-meter (43 to 49 ft)-high tsunami struck the nuclear power plant in Fukushima and eventually led to a meltdown of the nuclear reactors. A massive quantity of radioactive substances leaked from the reactors and within days the accident raised country-wide concerns about nuclear safety. The government therefore decided to stop the operation of *all* nuclear power plants, which resulted in a severe countrywide electricity shortage. To address the challenge, the central government launched ambitious electricity-saving programs, with the aim of reducing the demand for electricity consumption within a short period of time. Large campaigns were initiated to encourage people to reduce electricity consumption, aiming to reduce summer electricity usage by as much as 15% in some prefectures. The government paid particular attention to reducing the usage of air conditioning, because it is the largest contributor to residential electricity consumption in Japan. For example, it was recommended to set the air conditioner at 28°C on hot days, and people were encouraged to substitute fans for air conditioning if possible. Electricity prices were also raised to further discourage demand. Arguably, these measures could significantly limit people's adaptive opportunities and make them more vulnerable to extreme weather shocks.

Analyzing the plausibly exogenous variation in electricity-saving targets set by different regions after the Fukushima accident, we explore how electricity saving affects heat-related mortality and how it reshapes the temperature-mortality relationship. Applying a two-way fixed effects model, we document three important findings. First, we show that a higher electricity saving target caused more people to die from heat strokes. The total number of excess heat-related deaths caused by a 10 percentage point change in the electricity saving target is estimated to be around 1.57 per 1,000,000 people (about 3.3%) during each summer. Almost all the extra deaths caused by electricity saving occurred on very hot days (mean daily temperature above 27.5 °C), suggesting that electricity saving restricts people's capacity to mitigate heat damage. Second, we show that the effect is likely to be driven by households' behavioral changes: people use less air conditioning (AC) and buy more non-AC cooling appliances (such as fans), as recommended by the central government during the energy saving campaign. Finally, our heterogeneity analyses reveal that formerly well-adapted areas are disproportionately affected by the electricity saving policy: while people in hotter and richer areas are less likely to die when exposed to extreme heat, they also suffered most from the electricity saving policy, probably because they were discouraged from using the air conditioners they already owned. A back-of-envelop calculation reveals that the energy saving campaign could lead to 800 ~ 836 additional heat-related deaths during the period of 2011–2015. These findings highlight the critical role of electricity consumption in mitigating heat damages.

This study contributes to the literature in three important ways. First, our study provides some of the first quasi-experimental evidence on the role of energy consumption in mitigating climate impact. Previously, a key limitation in the literature is that adaptation (i.e. use of air conditioner or electricity consumption) is often discussed as a mechanism to explain temperature-mortality heterogeneity and there lacks exogenous variation in the adaptive measures in most studies.[4]

[4] Existing evidence often estimates the benefits of adaptation by measuring the sensitivity of economic outcomes to climate factors. For example, if the probability of people dying on extremely hot days in one area is larger than in another area, the difference is regarded as the benefit of adaptation. This approach is used by Barreca et al. (2016) and Margarita (2018) on mortality, Lobell et al. (2010) for agricultural output, Hsiang and Narita (2012) for hurricanes, and Dell et al. (2012) for income.

Since people's avoidance and adaptive behaviors are fundamentally endogenous, failure to account for such selection in adaptation precludes one from drawing credible causal inferences on the impacts of adaptation.[5] In our empirical set-up, because the Fukushima accident and the subsequent electricity-saving policies were totally unexpected, and the degree of the savings largely depends on a region's former-reliance on nuclear power, they exogenously changed people's adaptive opportunities. This unique setting allows us to credibly estimate the impact of electricity saving on the temperature-mortality relationship, which helps identify the causal impact of adaptation on mortality.

Second, our findings contribute to the literature on the consequences of the Fukushima accident. The catastrophic experience of Fukushima generated far-reaching consequences for nuclear policies around the world. Many countries, such as Germany, Italy and Switzerland, made a sharp U-turn on nuclear development immediately after the accident and determined to rely less on nuclear power.[6] Existing evidence on the Fukushima accident often focuses on the direct consequences of the disaster on the damaged areas, such as its impacts on local land prices (e.g. Kawaguchi and Yukutake, 2016) and health outcomes and subjective well-being of the locally affected population (e.g. Rehdanz et al., 2015; Hasegawa et al., 2016). This study highlights an unexpected consequence of the

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[5] For instance, rich and educated people tend to act more aggressively to mitigate climate damage, because they are better informed about the potential harm and have more resources. At the same time, these people also tend to have healthier life styles, better nutrition, and high-quality medical services. The observed correlation between mitigation behaviors and health outcomes thus may overstate the true effect of climate adaptation. Alternatively, if the adaptation decision is driven by latent health vulnerabilities to extreme weather and the more sensitive population adapts more aggressively, the effect of adaptation can be understated.

[6] For example, Germany shut down its eight oldest nuclear power plants within three months after the accident.

Fukushima accident and reveals that the elimination of nuclear power affected population health in the whole country.

Third, we speak to the climate change literature by investigating how hot weather affects mortality in Japan. Previously, most studies have focused on how extreme temperature affects mortality in the U.S. (e.g. Barreca et al., 2016; Deschênes and Moretti, 2009; Deschênes and Greenstone, 2011; Heutel, Miller and Molitor, 2017), while a few studies have investigated other countries (e.g., Burgess et al., 2017 for India, and cross-countries analyses in Gasparrini et al. 2015; Carleton et al., 2018; and Geruso and Spears, 2018). We add the case of Japan to this literature and show that a one-day increase in extremely hot days (>27.5 °C) will lead to a 0.07 per 1,000,000 people (about 1.5%) increase in heat-related mortality. The heat impact is greater in cooler and poorer areas.

Finally, in terms of policy implications, our findings contribute to the discussion on how to design better energy saving programs. We want to emphasize that different approaches to encourage people to save energy may have different welfare implications. As shown in this study, policies that directly restrict people's adaptive opportunities can make people less resilient to climate shocks. It is possible that many other programs, which share similar features to Japan's, can also incur significant health costs; such programs could include dynamic pricing (e.g. Faruqui and Sergici 2010; Wolak, 2011), energy conservation subsidy (e.g. Reiss and White, 2008; Ito, 2015), nudging (e.g. Allcott and Rogers, 2014), and moral suasion (e.g. Reiss and White, 2008; Costa and Gerado, 2018; Ito et al., 2018). In comparison, policies that allow people to enjoy the same level of utility/functionality at a lower cost, notably energy efficiency programs, may bring about additional health benefits. Existing studies on energy-efficiency programs often find that they cannot achieve the expected level of savings, because people tend to use electronic appliances more intensively when they become more energy-efficient (e.g. Davis et al. 2014). Our findings imply that this higher-than-expected electricity consumption can be beneficial to people's health and that previous literature might have thus understated energy-efficiency programs' overall benefits (e.g. Dubin et al., 1986; Davis et al., 2014, Levinson, 2016; Allcott and Greenstone, 2017; Fowlie et al. 2018).

We are aware of one concurrent study that adopts a similar (in spirit) approach to investigate the relationship between energy use and population health. In Chirakijia et al. (2019), the authors find a fascinating relationship: lower energy prices due to shale gas expansion in the U.S. saved people's lives during the winter. While Chirakijia et al. (2019) is motivated by a different line of research, their findings are essentially telling the same story as ours: more (less) energy consumption expands (limits) people's ability to mitigate climate damage.

The rest of this paper is structured as follows. Section II provides the background of the Fukushima accident and the electricity saving campaigns in Japan. Section III describes our data and provides the summary statistics of the key variables. Section IV discusses the empirical strategy. Section V reports our findings and explores the channels. Section VI concludes.

II. Background

The Fukushima nuclear accident is recognized as one of the worst catastrophes in the civil use of nuclear power in history. It is rated Grade 7 on the International Nuclear and Radiological Event Scale, which is the maximum value used to assess nuclear accidents. Prior to Fukushima, only the Chernobyl disaster was rated as a level 7 accident.[7]

On March 11, 2011, the Great East Japan Earthquake, the strongest earthquake in Japan's history since the modern measurement of earthquakes has been employed, triggered a gigantic tsunami that subsequently struck the Fukushima Nuclear Power Plants. This disabled the power supply used for cooling the nuclear reactors and resulted in the meltdown of the cores of several reactors. Within a couple of days, immense quantities of radioactive substances were released into the environment, raising nationwide concerns about nuclear safety.

After the accident, the Japanese government ordered urgent shutdowns of nuclear reactors located in all areas with high risks of earthquakes. Within the next several months, the government also gradually suspended the operations of other reactors located in low-risk locations, as the public became more concerned about nuclear safety. Eventually, by May 2012, all nuclear reactors were taken off the grid. Figure 1 illustrates the sharp reduction in the utilization rate of nuclear power plants after the Fukushima accident.

Because Japan had relied heavily on nuclear power (about 30% before the accident), the shutdowns of the nuclear power plants caused a nationwide electricity shortage. The electricity shortage was particularly serious during the summer, as the peak use of air conditioning imposed significant challenges to the stability of the grid. Thus, to avoid costly power blackouts, from July to September, the government set ambitious electricity-saving targets for different regions and initiated large campaigns to encourage people to reduce electricity consumption. Because the reliance on nuclear power and the timing of the shutdowns differed

7 Source: https://www-ns.iaea.org/downloads/iec/ines_flyer.pdf

across regions, the electricity saving target also varied across regions and over time.[8] For instance, in the Tokyo region, where the Fukushima power plant supplied electricity, the government set a saving target of 15% in 2011. By contrast, in the Okinawa islands, no saving target was set because they do not use nuclear power. Figure 2 illustrates the summer electricity saving targets across different regions from 2011 to 2014.[9]

A large part of the electricity-saving campaign was devoted to encouraging people to reduce air conditioner usage, since air conditioning accounted for nearly 50% of residential electricity consumption.[10] For example, it was suggested by the government that households should use electric fans instead of air conditioners if possible and should set the air conditioner at 28°C if such equipment had to be used. These measures were requested from 9:00 am to 8:00 pm from Monday to Friday.

In addition to asking households to reduce air conditioner usage, the government also provided guidelines to restrict the use of other electronic appliances. For example, people were asked to set their refrigerators to "medium" rather than "high" and to turn off the lights during the daytime. Even for electronic toilet seat covers, the government suggested households set them on "energy-

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[8] The electricity market in Japan is divided into 10 regions. A single power company has a near-monopoly on the provision of electricity in each region.

[9] There are a few prefectures in which two different power companies supply the electricity. In those cases, two different regional saving targets were announced within the same prefecture. For example, in Shizuoka prefecture, about one-third of the electricity was supplied by Tokyo Electric Power Co. and the remaining two-thirds by Chubu Electric Power Co. In such cases, we assign the saving target adopted by the power company with the larger market share to the prefecture. The results are similar when we use the weighted average saving targets.

[10] Agency for Natural Resource and Energy, Ministry of Economy, Trade and Industry (2011): http://www.kantei.go.jp/jp/singi/electricity_supply/0513_electricity_supply_02_08.pdf

saving" mode, which was expected to reduce about only 1% of households' electricity consumption. Appendix B shows a government advertising poster for the electricity saving campaign, with a detailed action list for households.

Although none of the above measures was mandatory, the campaign was indeed effective. For example, according to Tanaka and Ida (2013), in the Tokyo area in 2011, where the government set a saving target of 15%, 95.2% of survey respondents were aware of the power conservation campaign, which resulted in remarkable changes in their behaviors: 71.0% set a higher temperature when using air conditioners, 45.4% changed their refrigerator setting, and 81.0% reduced their standby power consumption. Fujimi et al. (2016) also finds that Japanese people were very responsive to these campaigns: the average setting of air conditioners increased from 24.1℃ to 26.4℃ in the Tokyo and Tohoku areas during the first summer after the Fukushima accident. In Appendix C, we run a simple regression with the actual electricity consumption as the dependent variable and the energy saving targets as the independent variable, conditional on region and year fixed effects. We find that a 10 percentage point increase in energy saving targets corresponds to a decline in total electricity consumption per capita by around 7.4–11.2%, confirming the electricity consumption was reduced more in regions with higher saving targets.

The electricity saving campaign was a nationwide and collective effort. Schools, restaurants, grocery stores, and firms were all involved. The central government directly released guidelines to these parties and asked local governments to simultaneously raise public awareness. Moreover, the power companies were required to provide real time information on their demand and supply capacity and to issue warnings when there was a risk of a blackout.

In addition, increases in electricity prices also motivated people to consume less electricity. After shutting down the nuclear reactors, the power companies faced severe financial difficulties because they had to re-utilize old thermal plants to generate electricity; these plants are more costly than nuclear power. To relieve the financial stress, eight out of ten power companies raised electricity prices, by about 4% to 19% in our study period.[11]

The electricity saving campaigns following the Fukushima accident are in fact a bundle of treatments that include both pecuniary and non-pecuniary incentives. Figure 3 describes the trends in total electricity consumption in the summer. We observe that electricity consumption was increasing every year before 2011; however, starting in 2011, the trend was broken and electricity consumption started to decrease. In Figure 4, we further plot the percentage changes in summertime electricity consumption between 2010 and 2015 against the annual electricity saving targets for different regions in Japan. We observe a strong correlation between the saving target and change in actual electricity consumption. In regions with high saving targets, the total electricity consumption in the summer was brought down by more than 20% in just five years.

In this paper, we try to avoid debating on whether the increased mortality is caused by higher electricity price or by people "voluntarily" saving more electricity. The reason is that we actually find both contribute to the reduction in actual electricity consumption. In a separate study, we show that the significant drop in

[11] Electricity pricing is based on three components: the demand charge, energy charge, and Renewable Energy Power Promotion Surcharge (REPPS). The energy charge is automatically adjusted by reflecting mainly fuel prices and exchange rates. REPPS is also automatically adjusted based on the regulated prices and the amount of renewable energy provided. Only the demand charge is based on the consumption level. After the Fukushima accident, an increase in the demand charge for eight power companies was approved by the Ministry of Economy, Trade, and Industry.

electricity consumption after the Fukushima accident cannot be fully explained by electricity price changes, suggesting that the moral suasion/nudging also played an important role.[12] In addition, we also find that including electricity price as a control variable does not really absorb the effects of saving targets on heat-related mortality, as discussed in Appendix D.

It is noteworthy to mention that hospitals and clinics were excused from many of the electricity saving actions.[13] To avoid degrading healthcare quality, healthcare facilities were allowed to set their own saving targets. Relatedly, to avoid the worst scenario, in which the electricity demand would exceed the supply and trigger a blackout of the entire grid, the government planned to intentionally disconnect certain districts when the blackout risk was high. Health facilities were exempted from such planning so that electricity supply for them was always guaranteed. Hence, healthcare quality was unlikely to be affected (which is consistent with our empirical findings) due to the electricity saving campaign. This is important to our identification strategy because it rules out changes in healthcare as a cause of mortality.

These dramatic changes offer a rare opportunity to investigate climate adaptation. Because the Fukushima accident was unexpected, and because the resulting plant shutdowns varied from place to place for reasons unrelated to local climate or the local population's heat sensitivity, the situation creates plausibly exogenous

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[12] We first estimate the price elasticity of electricity consumption using the pre-accident data and predict the counterfactual electricity consumption after the accident based on the estimated elasticity. We then attribute the difference between the predicted consumption and actual consumption to moral suasion and observe that more than 60% of the observed reduction in electricity consumption cannot be explained by price changes. These results are available upon request and will be summarized in a separate study from the authors.

[13] Source: http://www.kantei.go.jp/jp/singi/electricity_supply/20120518/taisaku.pdf

variations in the electricity saving targets. Exploiting this unique setting, we try to answer the following questions. First, does electricity saving cause health damages, as measured by heat-related mortality? Second, if electricity saving indeed leads to heat-related deaths, is it because the policy limits people's ability (or strongly discourages their willingness) to mitigate the heat damage? Third, can we rule out alternative explanations that may confound our interpretations? Below, we use systematic data to address these questions and explore the channels through which electricity saving damages population health.

III. Data and Summary Statistics

A. Data Sources

1. Electricity Saving Target Data

We collect region-specific electricity saving targets from 2011 to 2015 from the Electricity Supply-Demand Verification Subcommittee which determines the energy saving targets in each season.[14] The Ministry of Economy, Trade and Industry (METI) was responsible for advocating, promoting and implementing the campaigns.[15] The targets were calculated based on the deviation between expected demand and supply. The government tried to ensure sufficient backup capacity to avoid power blackouts. While other factors could affect the saving target (e.g. weather, regional electricity demand forecast, and the electricity generating capacity

14 Website: http://www.kantei.go.jp/jp/singi/electricity_supply/

15. For example, METI manages "Setsuden.go.jp (Setsuden means energy saving)" and targets and related guidelines are published on this website from 2013.
(https://www.enecho.meti.go.jp/category/electricity_and_gas/setsuden/index.html)

of other power plants), the primary determinant of the saving target was a region's dependence on nuclear power before the accident. For example, the Kansai area, where nuclear power had generated 51% of its electricity, faced a saving target of 10% on average, while the Chubu area, where nuclear power had generated 9.44%, faced a target of about 3.4%.[16]

Note that there is a concern that households or firms could purchase electricity from neighboring regions, which might affect our identification strategy. In practice, however, this is rare. As noted above, each of the 10 main power companies nearly monopolizes the provision of electricity in its own region. According to METI (2017), in 2015, less than 5% of electricity was purchased from the PPS (Power Producer and Supplier), i.e., purchased outside the 10 companies.[17] Therefore, the majority of the residents and firms didn't purchase electricity from other power companies.

2. Heat-Related Mortality Data

We construct annual prefecture-level heat-related mortality from the Vital Statistics of the Ministry of Health, Labour, and Welfare (MHLW) between 1999 and 2015. Cause-specific deaths are based on the International Statistical Classification of Diseases, 10th Revision, 2013 (ICD 10) classification, in which heat-related deaths are defined by "exposure to excessive natural heat" in code X30. Population data are collected from the Statistical Observations of Prefectures from the Ministry of Internal Affairs and Communications (MIAC)

16 Estimated by authors using data from Agency for Natural Resources and Energy. https://www.enecho.meti.go.jp/statistics/electric_power/ep002/

17 METI (2017): https://www.enecho.meti.go.jp/about/special/tokushu/denryokugaskaikaku/denryokujiyuka.html

3. Heat-Related Ambulance Transports

We use heat-related ambulance transports as an alternative measure of population health. The data are provided by the National Institute for Environmental Studies and are available at the district level from 2004 to 2015. We have information on the number of ambulance transports in 215 districts from 20 main cities across Japan, which cover over 35 million people (about 30% of the entire Japanese population).

4. Climate Damage Mitigation Measures

We collect three different variables on climate mitigation measures that are likely be affected by the energy saving policy. These three variables are Google search rate for terms including "energy savings (*Setsuden* in Japanese)", AC penetration rate, and spending on other cooling appliances (such as fans).

The keyword search for "energy saving" is collected from Google Trend. It represents the intensity of online search of a keyword in a prefecture during a specific period of time. To compare the search indices across different prefectures and periods, we normalize the search indices from 0 to 100, with 100 representing the maximum number during our study period and other numbers representing the proportion of the maximum. For example, in Tokyo prefecture, the google search index is 0.4 in 2010 and 90.0 in 2011, suggesting that the search intensity is as much as 0.4% and 90.0% of the highest search rate in our dataset. We aggregate Google search index from May to September including two months before the hottest season since the campaign was announced before the summer. The Google Trend Data are only available from 2004.

We collect data on the air conditioner penetration rate and spending on other cooling appliances from the Family Income and Expenditure Survey. The survey is conducted by the Ministry of Internal Affairs and Communications (MIAC) and the data include detailed information about household income, expenditure and ownership of different facilities and appliances. Non-single households from all regions in Japan are randomly chosen to answer the questionnaires. The survey collects data on households' spending on different appliances at the monthly level, and we use data from May to September to construct people's purchases of cooling appliances. We include data two months before the campaign since households might buy cooling appliances before the hottest season. For air conditioner penetration, the survey only collects such data every five years. The government publishes the aggregated summary statistics for the capital cities online.

5. Weather Data

The weather data are obtained from the Meteorological Agency. The micro weather information is collected by the Automated Meteorological Data Acquisition System, which consists of 1,300 real-time weather stations covering all of Japan. We collect data on temperature and precipitation from all the weather stations and calculate the prefectural temperature and precipitation by aggregating the station-level data. We use the inverse of the distance from the population center as the weights in aggregating the station-level data so that the closer stations are given larger weight. The weights are inversely proportional to squared distance.[18]

B. Summary Statistics and Balance Checks

We exclude three prefectures (Iwate, Miyagi and Fukushima) from our main analyses because these regions were damaged by the earthquake and tsunami and

18 We also try a different weighting method to aggregate the station-level weather data. Instead of using the squared inverse distances as weights, we use the inverse distances as weights. We find similar results.

may not be readily comparable to other prefectures. The reason is that survivors in these prefectures might be different from people in other prefectures, in terms of age structure, mental and physical health status, and access to medical resources.[19] According to the Emergency Disaster Countermeasures Headquarters of National Police Agency of Japan (2019), more than 95% of the total number of deaths and missing people were from Iwate, Miyagi and Fukushima.[20]

Table 1 reports the summary statistics of the key variables. Column (1) shows the means and standard deviations from 1999 to 2015. The mean of per capita monthly electricity consumption during summer is about 1,794 kwh. On average, 4.67 per 1,000,000 people died of heat-related illness each summer, while 217 people per 1,000,000 were transported by ambulance due to heat-related illness. In terms of air conditioning usage, the mean penetration rate is 88.5%. There were an average of 27.9 "hot" days per summer (mean daily temperature 25.0 ~ 27.5℃) and 26.7 very hot days (mean daily temperature higher than 27.5℃).

Columns (2) and (3) summarize the means and standard deviations of key variables before the Fukushima accident (2006-2010) and afterward (2011-2015). Column (4) reports percentage changes in the key variables between those periods. Results in Panel A show that, on average, electricity consumption dropped by 8.8% after the Fukushima accident. In contrast, in Panel B, we see large increase in heat-related mortality and ambulance transportation (11% and 93%) over the same period. Panel C shows that people are significantly more likely to search terms including "energy savings" after the nuclear accident. We also observe a modest increase in the AC penetration rate (2.0%), and a relatively larger increase in the

19 The results including the three prefectures are presented in one of the robustness checks.

20 Source: https://www.npa.go.jp/news/other/earthquake2011/pdf/higaijokyo_e.pdf

purchase of non-AC cooling appliances (28%). These trends are consistent with the governments' efforts providing massive information for energy savings and encouraging households to rely more on electric fans rather than AC during the electricity saving campaigns. Finally, Panel D reveals that the number of hot days slighted increased over the years, but the difference is not very large.

Our identification relies on the assumption that the saving targets are plausibly exogenous. To test this, in Column (6), we estimate the correlations between average saving targets *after* the accident and the key variables *before* the accident. The results show that none of the coefficients is statistically significant at the 5% level. The results indicate that the targets are unlikely to be correlated with the pre-accident heat-related mortality rate or with the main factors affecting the mortality rate.

IV. Empirical Strategy

We examine the impact of the electricity saving policy and temperature on health outcomes using the following model:

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where ౿□க denotes the heat-related mortality rate in prefecture *i* in summer *t*.[21]

ӧӧӧݐӧӧᏕ□க is the electricity saving target in prefecture *i* in summer *t*.

ӧӧӧᵩ□க□ denotes the number of days in prefecture *i* in summer *t* that fall into the *k*-th temperature bins. ӧ□க denotes a vector of control variables including the log mean

[21] We use the annual heat-related mortality rate as the dependent variable since we do not have monthly data. According to the Vital Statistics of Japan, 91.3% of heat-related deaths occurred from July to September over the period from 2007 to 2015.

monthly precipitation, log mean monthly wind speed, log prefectural GDP per capita, and population share of four age groups: 0–4, 5–19, 20–64 and 65+. ȶஞ is a time effect common to all prefectures in summer *t*, and ˥□ is a time-invariant effect unique to each prefecture *i*.

We define three temperature bins: below 25℃, 25℃ ~ 27.5℃, and above 27.5℃. The below ~25℃ bin serves as the baseline group and is omitted in the regression, thus the coefficients of 25℃~27.5℃ and 27.5℃+ bins measure the health risks of higher temperature relative to the baseline temperature.[22] The heat effect is identified by temperature variations within prefecture. Intuitively, it is estimated by the deviation in the heat-related mortality rate between an average summer in a given prefecture and a hotter-than-average summer in the same prefecture, conditional on the set of fixed effects and controls. Since whether a prefecture will have several hotter or cooler days in a summer (relative to the average) is largely unpredictable and likely independent from other covariates, the estimates of ȸ□ can be interpreted as a causal relationship.

The coefficient ȶ୕ estimates the impact of electricity saving target on heat-related mortality. Recall that the electricity saving campaign is a bundle of treatments including both pecuniary and nonpecuniary incentives. Thus, we think that the intensity of the campaigns can be best measured by the electricity saving targets rather than by any single treatment such as electricity prices or the prevalence of media messages. While it is of interest to study which policies are more effective in changing electricity consumption behaviors, such an investigation is beyond the scope of this study. Moreover, using the saving targets as the policy

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[22] We also estimated the baseline specification using different temperature bins (below 20℃ is omitted). We find very similar results.

measure has two additional merits. First, they were directly set by the central government, so arguably they are exogenous to local communities, while local enforcement tends to be highly heterogeneous and difficult to measure. Second, by focusing on a comprehensive measure, we can generate intuitive interpretations on the estimates and calculate policy-relevant counterfactuals.

Equation (1) estimates the overall effect of electricity-saving targets on heat-related mortality rates. To test whether the effect is indeed driven by restricting people's capacity to mitigate the climate damage, we estimate the following equation:

$$Y \; [illegible] \qquad (2)$$

where $\sum$ [illegible] indicate the interactions between the temperature bins and the electricity saving target. The interactions tell us whether the saving target can amplify the heat damage when the number of hot days changes. Again, we omit the below 25℃ bin, so the estimated temperature effect is relative to the below 25℃ group.

We conjecture that the coefficients of the interaction terms will be positive for high temperature bins. That is, the impact of saving electricity on population health will be even greater if a summer is hotter than the average. Because both the temperature distribution and the electricity saving targets are arguably exogenous, the coefficient γ [illegible] has a causal interpretation and captures how the electricity saving target shifts the temperature-mortality relationship.

We cluster standard errors at the prefecture level to allow arbitrary correlation over time within the same prefecture. All the regressions are weighted by population in 2010, so that prefectures with larger population are given greater weight. Intuitively, these weights help to estimate the impact of the policy on an average person instead of on an average prefecture.[23]

V. Results

A. Main Results

We report our main findings in Table 2. Columns (1) and (2) summarize the results from estimating Equation (1). We find that the electricity saving target increases the heat-related mortality rate and this effect is statistically significant at the 5% level. A 10 percentage point increase in the saving target is associated with a 1.57~1.64 per 1,000,000 (about 33.6~35.1%) increase in the heat-related mortality rate. Given that the average saving target during the policy period is around 8.1%, the policy could have increased the number of heat-related deaths by 25~30% each summer. For temperature, we find that extreme heat (temperature over 27.5℃) causes more people to die and this effect is statistically significant at 5 or 10%. Compared with the baseline group (temperature below 25℃), one additional day in the hottest temperature bin (over 27.5℃) can lead to a 0.07 per 1,000,000 (about 1.5%) increase in the heat-related mortality rate. On average, a prefecture has about 26.7 very hot days in summer, which would raise heat-related mortality by roughly 40%. Relatively mild temperature (25~27.5℃), however, does not have a meaningful effect on heat-related mortality. These results imply that hot weather has a nonlinear impact on human health and the marginal damage becomes larger when the temperature is higher.

[23] We alternatively use population in the first (1999) and last (2015) year of our sample period rather than population in 2010 as weights. We find similar results.

Comparing Column (1) with Column (2), we see that the estimated coefficient of the electricity saving target is remarkably robust to the inclusion of a rich set of time-varying control variables. This finding implies that the saving target is indeed exogenously set and is not correlated with local weather or socio-economic conditions. Given that temperature variations are also presumably exogenous, both estimates have causal interpretations.

Columns (3) and (4) of Table 2 report the results from estimating Equation (2). Several interesting patterns emerge. First, when the temperature is low, the saving target alone does not have any statistically significant effect on heat-related mortality (i.e. the coefficient of "Saving Target"). Second, high temperature causes more people to die (the coefficient of "Number of days above 27.5℃"), which is consistent with the results in Columns (1) and (2). Third, electricity saving amplifies the heat damage: the interaction between "saving target" and "high temperature" (number above 27.5 ℃) is positive and statistically significant in both regressions. The size of the effect is also economically meaningful: if we put 26.7 days above 27.5℃ into the equation, which represents the average, the estimated coefficient of the interaction term will be 1.60 ~ 1.87 (0.06 ~ 0.07 * 26.7 from Column (3) and (4)), which is nearly identical to the policy effect (1.64 from column (1)). In other words, almost the entire policy effect can be attributed to excess heat-related deaths on extreme hot days, revealing that electricity saving kills people primarily because people cannot mitigate the heat damage through using sufficient electricity.

To visualize the health damages of the electricity saving policy, we estimate the predicted excess mortality by fitting the observed temperature distribution in each prefecture over the period from 2011 to 2015 into the equation. Figure 5 plots the predicted health damage based on two different scenarios: one without an electricity saving target and one with a 10% saving target. The difference between these two scenarios measures the policy effect. Specifically, the y-axis reports the change in the heat-related mortality rate (per 1,000,000) in a specific prefecture, compared to the case of the same prefecture always having a daily mean temperature below 25℃ during the summer. The x-axis ranks all the prefectures in Japan from low to high based on the number of very hot days (over 27.5℃) in summer. We observe that the electricity saving policy amplifies the heat damage in most prefectures and the effect becomes even larger in prefectures with more very hot days.

Applying our estimates to all the prefectures in Japan, we can calculate the number of additional deaths caused by the energy saving campaign. Roughly speaking, 150 ~ 179 additional deaths could be caused by the energy saving campaign each summer from 2011 to 2015 respectively. Summing these numbers up, the energy saving campaign could have caused more than 800 ~ 836 additional heat-related deaths.[24]

B. Channels

In this section, we examine the channels through which the electricity saving policy affects heat-related mortality and try to rule out alternative explanations.

The first alternative explanation is that the excess deaths caused by electricity saving during the extremely hot days can be driven by a deterioration in healthcare quality. Specifically, if higher saving targets somehow jeopardized the quality of

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[24] The mean saving target is about 8.0% in a typical summer. To calculate the number of additional heat-related deaths caused by the policy, we multiply this number by the estimated coefficient in Table 2 and then times the total population of Japan (127 million).

medical services, more people would die. This observed effect in our regression may not be driven by people becoming more vulnerable, but by fewer people being saved.

Conceptually, we think this is highly unlikely, as the healthcare facilities are exempted from many electricity saving actions. Nevertheless, to address this concern, in Columns (1) to (3) of Table 3, we examine how the electricity saving policy affects the number of heat-related ambulance transports and the number of two types of healthcare providers; doctors and nurses.

We first look at the ambulance usage as an alternative outcome. People are transported by the ambulances only when they call for help and when the hospital responds to the emergency. Thus, an increase in heat-related ambulance usage would not only suggest that more people are suffering from exposure to heat, but also would imply that hospitals have the capacity to do the job.[25] The result in Column (1) shows that the electricity saving policy indeed increased the number of heat-related ambulance transports. A 10% rise in the saving target can lead to a 24.2 (per 1,000,000) rise in heat-related ambulance use. This finding is consistent with our argument that the electricity saving policy makes people more vulnerable to heat shocks.[26] The results further suggest that hospital emergency departments can respond to the emergency calls even in high saving targets areas.

In Column (2) and (3), we examine whether the electricity saving policy affects health care conditions. We focus on the number of doctors per capita and the number of nurses per capita. We find that these indicators for healthcare quality were not affected by the electricity saving target. Thus, there is no suggestive

[25] In Japan, ambulance use is common because ambulance transportation is free of charge.

[26] If we further interact the temperature bins with the saving target, we find similar results: electricity saving increased heat-related ambulance use during the very hot days.

evidence that the health care conditions deteriorated after the electricity saving policy was implemented.

In Columns (4) to (6), we investigate adaptive behaviors, which shed light on the channels through which electricity saving damages human health. We have data on Google search index for "energy saving" in Japanese, air conditioner (AC) penetration and the purchases of non-AC cooling appliances. Because the central government provided intensive information during the energy saving campaign, we expect the google search rate for "energy savings" could be increased. Furthermore, as the campaigns repeatedly encouraged households to substitute ACs by other cooling appliances (such as fans), we expect that air conditioner penetration could have been reduced and the purchase of non-AC cooling appliances could have been increased. Results in Columns (4) and (6) confirm our conjecture and show that a 10 percentage point increase in the electricity saving target increases the search for "energy saving" on Google by around 33.6%, reduces air conditioner penetration by around 14.7% and increases purchases of non-AC cooling appliances by around 13.0%. As air conditioning plays a key role in mitigating climate impact (e.g., Burgess et al., 2016, Heutel et al., 2017), these results suggest that reducing air conditioner use is a likely channel through which electricity saving increases heat-related mortality rate.

In Columns (7) and (8), we investigate how the saving target affects two basic socio-economic variables: per capita GDP and demographic structure. Our first concern is that if the electricity saving policy negatively affects the economy, it can also lead to undesirable health consequences. In Column (7), we find that the saving target does not affect per capita GDP. The second concern is about the age structure of the population. Because old people are particularly vulnerable to heat shocks, they may have the incentive to migrate across regions to mitigate the climate damage. In Column (8), however, we find that electricity saving does not affect the share of old people (above 65 years old) in the population.

C. Heterogeneous Effects

In this section, we investigate the heterogeneous impacts of electricity saving on the heat-related mortality rate across different subsamples. We first examine heterogeneity based on number of days with extreme heat (over 27.5℃). Existing studies reveal that there is large heterogeneity in adverse heat effects across different locations. For example, areas facing extreme heat more frequently have smaller heat damages, presumably because they are well adapted to the climate and have succeeded in diminishing its risk, for instance by purchasing air conditioners (Barreca et al., 2016; Portnykh, 2017; and Carleton et al., 2018). We find consistent results for the temperature-health relationship in Panel A, showing that areas with more extreme weather have much smaller temperature effects, by more than 5 times. One more hot day (above 27.5℃) can lead to a 0.16 (per 1,000,000) increase in the heat-related mortality rate in cooler areas (Column (1)), contrasting to a 0.03 change in warmer areas (Column (3)). Turning from the impact of hot days to the impact of electricity saving, we find the opposite pattern. Electricity saving has a smaller effect on heat-related deaths (0.51 in Column (1)) in areas with less exposure to extreme heat. In sharp contrast, in areas experiencing extreme heat more frequently, the electricity saving target has a statistically significant impact on heat-related mortality by more than 4 times (2.31 in column (2)). These results imply that the health cost of electricity saving is primarily driven by the warmer areas, possibly by discouraging the use of existing air conditioners.

Next, we examine income heterogeneity. Existing evidence suggests that the climate-health relationship can be moderated by income levels (e.g. Carleton et al., 2018, Burgess et al., 2017, Hsiang and Narita, 2012) because higher income loosens households' budget constraint and helps people adopt defensive behaviors. Panel B reports our findings. Column (1) shows that, in low-income areas, extreme heat (above 27.5℃) has a significant impact on heat-related mortality, while Column (3) reveals that the effect is smaller and statistically non-significant in high-income area. The electricity saving policy, however, has the opposite effect. Richer regions suffer more from electricity saving than poor regions, as measured by heat-related mortality. A plausible explanation is that wealthier regions, like warmer regions, had a relatively large number of air conditioners, but were discouraged from using them by the saving targets.

To summarize, climate damage tends to be smaller in richer and warmer regions. Our interpretation is that people in these regions can better adapt to climate shocks. When an electricity saving policy is implemented, however, richer and warmer regions will be more severely affected and experience larger health damages, since electricity saving reduces their ability to mitigate the climate damage.

D. Additional Checks

In this section, we conduct a variety of placebo tests and robustness checks, which together lend additional credibility to our findings.

Our main results are that electricity saving increases heat-related deaths and the effect is driven by excess deaths during extremely hot days. Our explanation is that electricity saving limits people's adaptive opportunities and thus amplifies the heat damage. We argue that the observed effect cannot be explained by other channels, such as changes in medical and socio-economic conditions.

To further rule out such possibilities, we conduct placebo tests using other causes of death. We focus on outcomes that are unlikely to be affected by extremely hot weather and adaptive technologies: infectious diseases, congenital malformations and accidents. Table 5 summarizes the results. As expected, hot temperature does not affect any of these cause-specific deaths (except for accidents). Similarly, we cannot find a statistically significant impact of electricity saving on any of these outcomes.

Table 6 checks the robustness of our main findings in several different ways. First, we examine whether the results are sensitive to slight revisions of the electricity saving targets. Recall that the saving targets were calculated based on the deviation between expected supply and demand for electricity and the government announced these saving targets for different regions before the summer electricity saving campaigns. At the same time, however, the electricity shortage raised heated debates on whether the government should re-utilize some nuclear power plants. In July 2012, during the national campaign period, the Oi Nuclear Reactors located in Kansai region were re-started, after being approved by the central government. The increased supply capacity resulted in a reduction in the saving target in Kansai and nearby areas and the government thus slightly revised the saving targets in these areas.[27] Using the revised electricity saving targets as the explanatory variable, we re-estimate Equations (1) and (2).[28] As reported in Panel A of Table 6, the new

[27] Source: https://www.bbc.com/news/world-asia-18662892

[28] For the explanatory variable, we take the mean saving target in each region during the campaign. For example, if the target is revised on August 1st, we use 31 days (before revision, July 1st to 31st) and 61 days (after revision, August 1st to September 30th) to obtain a weighted average.

estimates become slightly smaller but are still quantitatively similar to the baseline estimates, suggesting that modification of the saving targets have negligible impacts on our findings.

Panel B uses a wider exposure window to estimate the policy impact. An electricity saving campaign could somehow affect behavior even when it's not in effect. On the one hand, households' behaviors might have been changed before the campaign was initiated, as they were well aware of the electricity shortage. On the other hand, people's energy saving habits might persist after the campaign. In Panel B, we construct an alternative temperature variable, which counts the number of days in different temperature bins from June to October, including one month before and after the summer, as the primary explanatory variables. The findings remain the same.

In Panel C, we control for lagged effects of temperature and electricity saving policy. One minor concern is that the effects of heat and energy saving may be cumulative over time. To alleviate such concerns, we estimate the main specifications with additional controls for lagged variables on temperature bins, saving target and interaction between temperature and saving target in previous year. We find that adding these controls does not affect our estimation.

Panel D reports the results after controlling air pollution measures. Since many power companies have re-utilized old thermal power plants to generate electricity after the nuclear power is politically less acceptable, there is a concern that thermal power plants may deteriorate air quality, which further affects the population health. Note that we focus on heat-related mortality, so such concern is conceptually not quite relevant. That being said, we further look into this issue by including air pollutants into the regression. We find that our main results remain similar when air pollutants are controlled.[29]

Other robustness checks are summarized in Panels E to G. In Panel E, we use a slightly different temperature bin (< 20℃) as the reference group. In Panel F, instead of controlling precipitation using a linear function, we construct precipitation bins to control for relative amount of summer precipitation (such as unusually high or low precipitation) given the same prefecture to capture the potential non-linear effect of rainfall on temperature and health. In Panel G, we use all the prefectures for the estimation, including the three prefectures seriously damaged by the earthquake. In all these robustness checks, we find similar results.

Finally, in Table 7, we use two alternative outcome measures – the logarithm of heat-related mortality rate, and the logarithm of the number of heat-related deaths – and find quantitatively similar results. These results imply that our baseline findings are not driven by outliers in the sample or by changes in the population over the years.

VI. Conclusion

Energy consumption plays a central role in mitigating climate damage. Therefore, energy-saving policies that limit people's adaptation opportunities may cause significant health damages. Such damages will be amplified, particularly when

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[29] In Appendix E, we also test whether electricity savings lead to worse air quality. The findings do not support the argument that air quality deteriorated after re-utilizing the thermal power plants. The reason can be that all the thermal power plants in Japan have to install scrubbers to remove the pollutants and the country has very stringent environmental regulation in general

energy saving is interacted with extreme weather, as people depend critically on energy consumption to avoid the extreme exposure.

This paper provides an empirical investigation on how energy saving affects population health using data from Japan. We exploit the electricity saving targets in different regions following the Fukushima accident and show that electricity saving significantly increased heat-mortality rates. This effect can be entirely attributable to excess deaths on extremely hot days. We also find that electricity saving discourages people from using air conditioners and encourages people to buy non-AC cooling appliances. The negative impact of electricity saving is particularly large in rich and warmer regions, which had higher AC penetration before the disaster but made less use of their AC afterward because of the electricity saving target.

Our findings highlight the non-negligible cost of energy saving, which is largely neglected in climate discussions and policy implementation. We believe what is captured in this study is just a small portion of the overall cost of energy saving, as the same logic can also be applied to other scenarios (such as winter heating and cold-related deaths). Future research is needed to better understand how to balance the trade-off between climate adaptation and energy saving.

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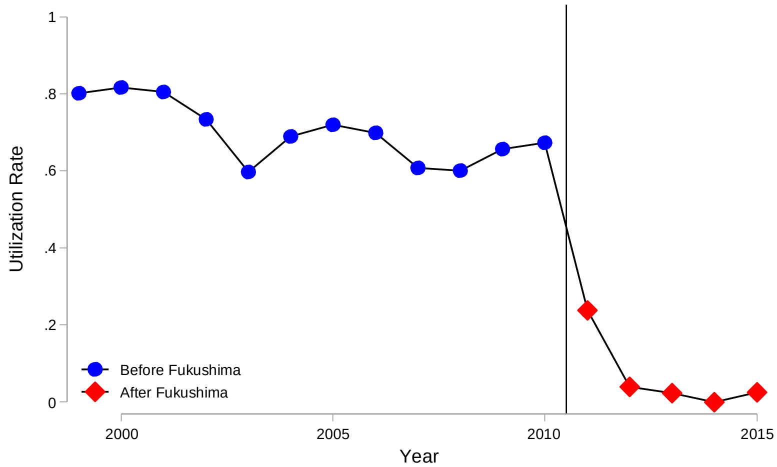
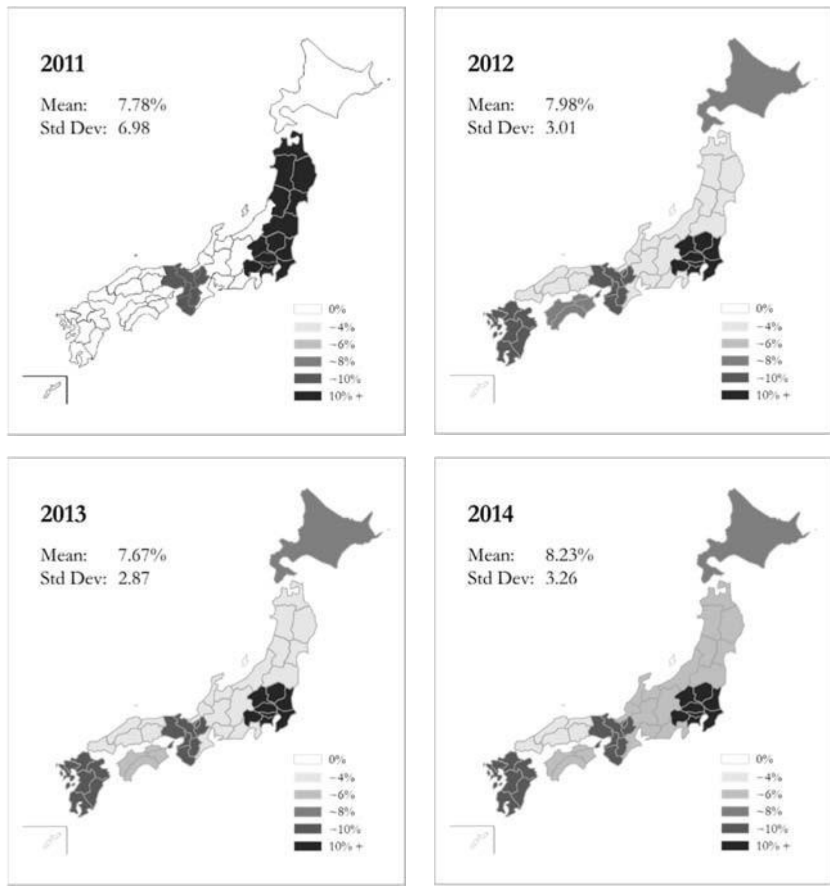
Figure 1. Nuclear Power Utilization Rate



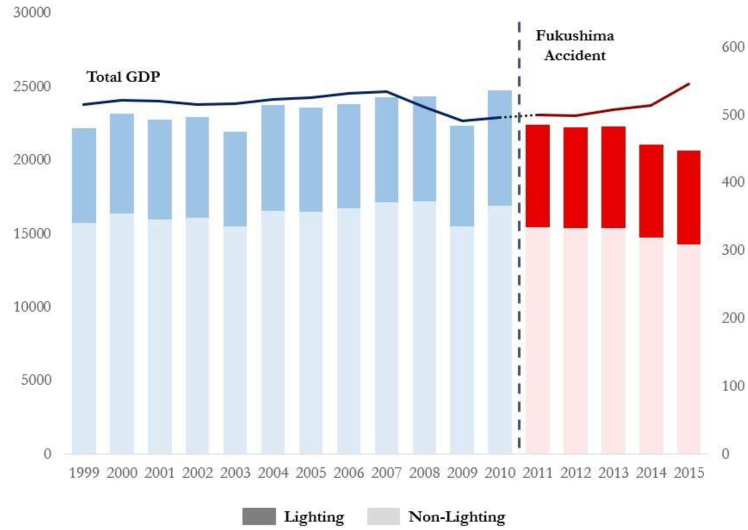
Notes: This figure shows the utilization rate of nuclear reactors in Japan. The vertical dashed line represents the timing of the Fukushima accident. The blue circles represent utilization rate before the accident while the red squares represent utilization after the accident.
Source: Federation of Electric Power Companies of Japan (FEPC, 2018)
https://www.fepc.or.jp/library/data/infobase/pdf/08_d.pdf

Figure 2. Electricity Saving Targets in Different Years



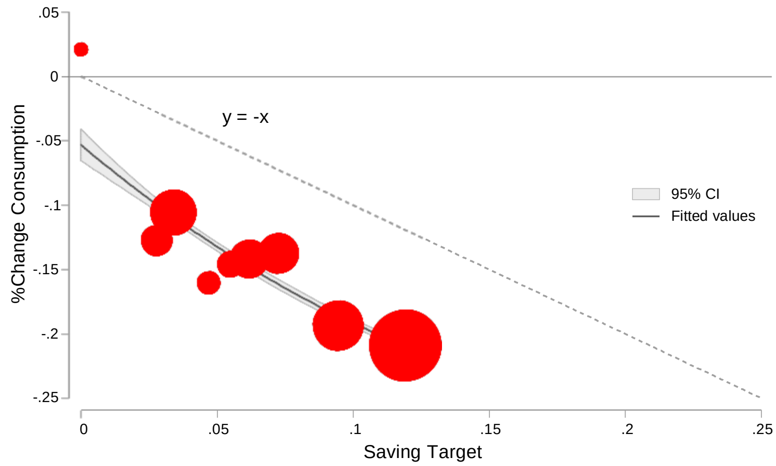
Notes: This figure shows saving targets over the time period from 2011 to 2014. In 2011, only three regions had electricity saving targets. In 2012, almost all areas in Japan had saving targets, and this trend continued until 2015. The mean and standard deviation are weighted by the population in each year.

Figure 3. Trend in Japan's Electricity Consumption in Summer and GDP



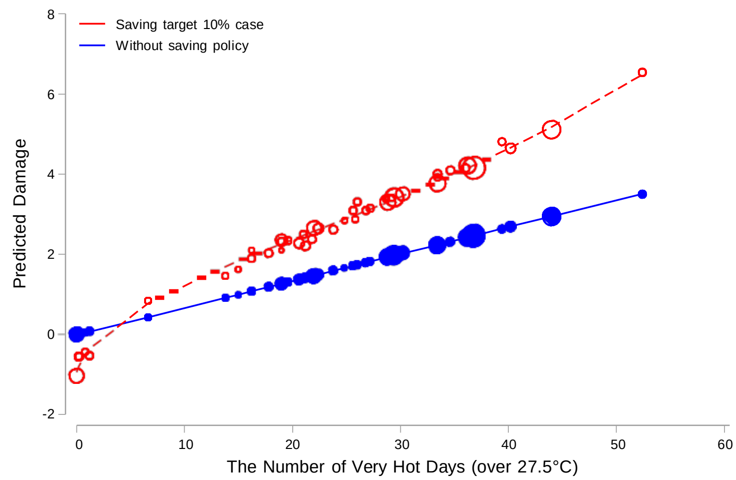
Notes: This chart shows the electricity consumption (million kwh) from July and September by lighting and non-lighting. Lighting is generally consumed by households, small offices, shops, and street lights. Non-lighting is generally consumed by the industrial and commercial sectors. The lines represent GDP (trillion yen). The Fukushima accident happened on March 11, 2011.

Figure 4. Electricity Saving Targets and Changes in Actual Consumption



Notes: This figure shows the relationship between average saving target and % change in electricity consumption in all 10 regions in Japan. The size of each circle represents population in each region. The downward line is where the saving target and % change in electricity consumption are equal. If a circle is located above this line, the region saves less electricity than the target.

Figure 5. Predicted Damage of Electricity Saving Policy



Notes: By using mean temperature distribution in each prefecture from 2011 to 2015, when the saving policy was in effect, we calculate the predicted damage. The red circles predict the heat related mortality rate when the saving policy with a 10% saving target was in effect, while the blue circles estimate the damage without the saving policy. The size of the circle represents the size of the population. We calculate damage based on column (4), showing the main results in Table 2.

TABLE 1— SUMMARY STATISTICS OF THE KEY VARIABLES AND BALANCE CHECKS

	Summary Statistics				Balance Checks
	Entire Sample (1)	2006-2010 (2)	2011-2015 (3)	% Change (4)	Saving Target (per 10pps) (5)
Panel A. Energy Saving Policy					
Monthly Electricity Consumption per capita	1,794	1,873	1,708	-8.8%	-152
(summer, kwh)	(204)	(189)	(200)		(105)
Panel B. Health Outcomes					
Heat-Related Mortality Rate	4.67	5.96	6.63	11%	0.26
(per 1,000,000)	(4.11)	(5.25)	(3.46)		(1.36)
Heat-Related Ambulance Use	217	161	310	93%	-18.0
(per 1,000,000)	(162)	(142)	(150)		(16.0)
Panel C. Adaptation Technology					
Google Search Rate "Energy Saving"	8.23	0.95	18.4	1838%	-0.45
(Index)	(19.1)	(1.00)	(26.3)		(0.27)
Air Conditioner Penetration	88.5	89.1	90.9	2.0%	10.9
(%)	(18.1)	(17.8)	(15.4)		(7.72)
# of purchases of non-AC Cooling Appliances	13.3	12.0	15.3	28%	-1.89*
(per 100 household)	(4.96)	(3.97)	(5.88)		(1.12)
Panel D. Weather					
# of days below 25℃	37.4	38.1	38.2	0.3%	-4.51
(in summer)	(19.5)	(20)	(18.5)		(7.71)
# of days from 25℃ to 27.5℃	27.9	26.9	26.4	-1.9%	2.77
(in summer)	(10.6)	(9.79)	(10.2)		(3.24)
# of days exceeding 27.5℃	26.7	27.0	27.4	1.5%	1.74
(in summer)	(15.5)	(17.2)	(14.2)		(5.93)
Monthly Precipitation	187	177	199	12%	-19.9
(mm)	(68.2)	(59.8)	(73.1)		(14.3)
Mean Monthly Wind Speed	2.14	2.06	2.21	7.3%	-0.15
(m/s)	(0.581)	(0.546)	(0.545)		(0.34)

Notes: Columns (1) to (3) report the means and standard deviations of the key variables using different samples. Column (4) reports percentage differences between (2) and (3) for the key variables. In Column (5), we test how these variables before the Fukushima accident are correlated with the electricity saving targets announced after Fukushima accident. Each cell represents a separate regression in which the average energy saving target is the explanatory variable and the dependent variable is each key variable. We use data between 2008 and 2010, and year dummies are included in each regression. Robust standard errors are reported below the coefficients. * significant at 10% ** significant at 5%. *** significant at 1%.

TABLE 2— TEMPERATURE, ELECTRICITY SAVING TARGET AND HEAT-RELATED MORTALITY

	Heat-Related Mortality Rate (per 1,000,000)			
	(1)	(2)	(3)	(4)
Saving Target (per 10 pps)	1.64**	1.57**	-1.60	-1.04
	(0.69)	(0.59)	(1.08)	(1.23)
# of days between 25℃ ~ 27.5℃		-0.00	-0.01	-0.00
		(0.04)	(0.03)	(0.03)
# of days above 27.5℃		0.07**	0.06*	0.07**
		(0.03)	(0.03)	(0.03)
# of days between 25℃ ~ 27.5℃ * Saving Target (per 10 pps)			0.03	0.03
			(0.03)	(0.02)
# of days above 27.5℃ * Saving Target (per 10 pps)			0.07**	0.06*
			(0.03)	(0.03)
Log (Monthly Precipitation)		0.57	0.52	0.50
		(0.37)	(0.35)	(0.35)
Prefecture FE	Y	Y	Y	Y
Year FE	Y	Y	Y	Y
Controls	N	Y	N	Y
Obs.	748	748	748	748
R-Squared	0.66	0.69	0.68	0.69

Notes: The omitted group is # of days below 25℃. Controls include log wind speed, log prefectural GDP per capita, and population shares of age groups 0 to 4, 5 to 19 and over age 65. Three prefectures that were heavily damaged by the earthquake are excluded from the regressions. All regressions are weighted by population in 2010. Standard errors are clustered at the prefecture level and reported below the coefficients.
* significant at 10% ** significant at 5%. *** significant at 1%.

TABLE 3— CHANNELS THROUGH WHICH ELECTRICITY SAVING COULD LEAD TO MORE HEAT-RELATED DEATHS

	Health Status & Healthcare Quality			Behaviors for Adaptation			Socio-economic Characteristics	
	Heat-Related Ambulance Use (per 1,000,000)	Log (# doctors per capita)	Log (# nurses per capita)	Log (Google Search Rate "Energy Saving")	Log (AC Penetration)	Log (# Purchase of non-AC Cooling Appliances)	Log (Prefectural GDP per capita)	Share of Age 65+
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Saving Target (per 10 pps)	24.197***	0.014	-0.004	0.336***	-0.147*	0.130**	0.013	0.004
	(8.699)	(0.011)	(0.015)	(0.083)	(0.077)	(0.051)	(0.012)	(0.004)
# of days between 25℃ ~ 27.5℃	-0.468	0.000	0.000	-0.004	0.003	-0.001	0.000	0.000
	(0.496)	(0.000)	(0.000)	(0.004)	(0.003)	(0.003)	(0.000)	(0.000)
# of days above 27.5℃	3.073***	0.000	-0.000	-0.002	0.002	0.001	0.001*	0.000
	(0.597)	(0.000)	(0.000)	(0.004)	(0.002)	(0.003)	(0.000)	(0.000)
Prefecture FE	Y	Y	Y	Y	Y	Y	Y	Y
Year FE	Y	Y	Y	Y	Y	Y	Y	Y
Controls	Y	Y	Y	Y	Y	Y	Y	Y
Obs.	2,689	352	352	528	176	704	748	748
R-Squared	0.71	0.95	0.99	0.89	0.40	0.27	0.49	0.97

Notes: In column (4) and (6), we use data from May to September, including two months before the summer campaign since household may change behaviors before the hottest season. The omitted group is # of days below 25℃. Controls include log monthly precipitation, log wind speed, log prefectural GDP per capita, population shares of age groups 0 to 4, 5 to 19 and over age 65. Three prefectures that were heavily damaged by the earthquake are excluded from the regressions. All regressions are weighted by population in 2010. Standard errors are clustered at the prefecture level and reported below the coefficients. * significant at 10% ** significant at 5%. *** significant at 1%.

TABLE 4— HETEROGENEOUS EFFECTS OF SAVING TARGET ON HEAT-RELATED MORTALITY

	Heat-Related Mortality Rate (per 1,000,000)			
	Low		High	
	(1)	(2)	(3)	(4)
Panel A. The number of days above 27.5℃ (Low < Median; High > Median)				
Saving Target (per 10 pps)	0.51	-1.13	2.31**	-2.82
	(0.60)	(1.35)	(0.87)	(3.43)
# of days between 25℃ ~ 27.5℃	0.02	0.02	-0.02	-0.01
	(0.04)	(0.04)	(0.06)	(0.05)
# of days above 27.5℃	0.16***	0.16***	0.03	0.03
	(0.03)	(0.04)	(0.05)	(0.05)
# of days between 25℃ ~ 27.5℃ * Saving Target (per 10 pps)		0.05		0.04
		(0.03)		(0.06)
# of days above 27.5℃ * Saving Target (per 10 pps)		0.01		0.11*
		(0.04)		(0.06)
Obs.	374	374	374	374
R-Square	0.67	0.67	0.72	0.73
Panel B. GDP per capita (Low < Median; High > Median)				
Saving Target (per 10 pps)	1.14	-0.16	1.75*	-2.67
	(0.73)	(1.35)	(0.88)	(1.70)
# of days between 25℃ ~ 27.5℃	0.01	0.01	-0.03	-0.02
	(0.04)	(0.04)	(0.04)	(0.04)
# of days above 27.5℃	0.11***	0.11***	0.01	0.01
	(0.02)	(0.02)	(0.05)	(0.04)
# of days between 25℃ ~ 27.5℃ * Saving Target (per 10 pps)		0.05		0.03
		(0.03)		(0.05)
# of days above 27.5℃ * Saving Target (per 10 pps)		-0.01		0.11***
		(0.03)		(0.03)
Obs.	374	374	374	374
R-Square	0.62	0.62	0.74	0.75
Prefecture FE	Y	Y	Y	Y
Year FE	Y	Y	Y	Y
Controls	Y	Y	Y	Y

Notes: Subsamples are based on the number of days above 27.5℃ and prefectural GDP per capita from 2010, before the Fukushima accident. The omitted group is # of days below 25℃. Controls include log monthly precipitation, log wind speed, log prefectural GDP per capita, and population shares of age groups 0 to 4, 5 to 19 and over age 65. Three prefectures that were heavily damaged by the earthquake are excluded from the regressions. All regressions are weighted by population in 2010. Standard errors are clustered at the prefecture level and reported below the coefficients. * significant at 10% ** significant at 5%. *** significant at 1%.

TABLE 5— PLACEBO TEST

	Infectious Diseases				
	All	Tuberculosis	Viral Hepatitis	Congenital Malformations	Accident
	(1)	(2)	(3)	(4)	(5)
Mean	43.4	4.2	9.6	4.2	51.5
S.D	(9.33)	(1.6)	(3.03)	(1.38)	(14.9)
Saving Target (per 10 pps)	0.00	-0.21	0.03	-0.07	1.41
	(0.94)	(0.29)	(0.43)	(0.22)	(1.00)
# of days between 25℃ ~ 27.5℃	-0.05	-0.02	-0.00	0.00	0.01
	(0.05)	(0.01)	(0.02)	(0.01)	(0.05)
# of days above 27.5℃	-0.01	-0.02*	-0.01	0.01	0.09**
	(0.05)	(0.01)	(0.01)	(0.01)	(0.04)
Prefecture FE	Y	Y	Y	Y	Y
Year FE	Y	Y	Y	Y	Y
Controls	Y	Y	Y	Y	Y
Obs.	748	748	748	748	748
R-Squared	0.52	0.11	0.13	0.12	0.28

Notes: The cause-specific mortality rate is adjusted to per 1,000,000. Data on cause-specific mortality is collected from July to September. In column (5), accidents mainly include deaths from traffic, falling, drowning and choking. The omitted group is # of days below 25℃. Controls include log monthly precipitation, log wind speed, log prefectural GDP per capita, and population shares of age groups 0 to 4, 5 to 19 and over age 65. Three prefectures that were heavily damaged by the earthquake are excluded from the regressions. All regressions are weighted by population in 2010. Standard errors are clustered at the prefecture level and reported below the coefficients. * significant at 10% ** significant at 5%. *** significant at 1%.

TABLE 6— ROBUSTNESS CHECK: ALTERNATIVE SPECIFICATIONS

	Impact on Heat Related Mortality Rate (per 1,000,000)				
	Saving Target (10 pps)	# of days between 25~27.5℃ * Saving Target (10 pps)	# of days over 27.5℃ * Saving Target (10 pps)	Obs.	R^2
A. Using Saving Target After Revision	1.37**			748	0.69
	(0.56)				
	-1.16	0.02	0.06*	748	0.69
	(1.21)	(0.02)	(0.03)		
B. Different Temperature Window	1.60***			748	0.69
	(0.58)				
	-1.02	0.03	0.05*	748	0.69
	(1.37)	(0.02)	(0.03)		
C. Controlling for Lagged Effects	1.55**			704	0.69
	(0.58)				
	-0.68	0.02	0.05*	704	0.69
	(1.33)	(0.03)	(0.03)		
D. Controlling for Air Pollution and Ozon	1.61***			745	0.70
	(0.55)				
	-1.07	0.03	0.06*	745	0.71
	(1.21)	(0.02)	(0.03)		
E. Using < 20℃ Bin as the Reference Group	1.57**			748	0.69
	(0.59)				
	-2.93	0.04	0.08*	748	0.69
	(2.55)	(0.03)	(0.04)		
F. Controlling for non-linear Precipitation	1.58**			748	0.69
	(0.61)				
	-0.90	0.03	0.06*	748	0.69
	(1.27)	(0.02)	(0.03)		
G. Using all samples	1.45**			799	0.68
	(0.58)				
	-0.90	0.03	0.06*	799	0.69
	(1.03)	(0.02)	(0.03)		

Notes: All regressions include prefecture fixed-effects, year fixed-effects and the set of controls. Controls include # of days between 25℃ ~ 27.5℃, # of days above 27.5℃, log monthly precipitation, log wind speed, log prefectural GDP per capita, and population shares of age groups 0 to 4, 5 to 19 and over age 65. Three prefectures that were heavily damaged by the earthquake are excluded from the regressions. Panel B uses temperature from June to October while our main specification uses temperature from July to September. Panel C include variables lagged on the saving target, numbers of days in each temperature bins and their interaction with saving target. Panel D adds logarithm of three air pollutants; SPM (Suspended Particulate Matter), NOx and SO2, and a specific kind of ozone; Ox (photochemical oxidant). Panel E adds the number of days between 20℃~25℃ and its interaction with saving target. Panel E adds four different precipitation bins indicating the relative amount of precipitation given the same prefecture instead of log monthly precipitation. For all model, standard errors are clustered at the prefecture level and reported below the coefficients. * significant at 10% ** significant at 5%. *** significant at 1%.

TABLE 7— ROBUSTNESS CHECK: USING ALTERNATIVE OUTCOMES FOR HEAT-RELATED DEATHS

	Log (Heat-Related Mortality Rate)		Log (Heat-Related Deaths)	
	(1)	(2)	(3)	(4)
Saving Target (10 pps)	0.246**	0.028	0.274**	0.045
	(0.115)	(0.226)	(0.120)	(0.229)
# of days between 25℃ ~ 27.5℃	-0.004	-0.003	-0.004	-0.003
	(0.006)	(0.006)	(0.006)	(0.006)
# of days above 27.5℃	0.016***	0.015***	0.016***	0.015***
	(0.005)	(0.005)	(0.005)	(0.005)
# of days between 25℃ ~ 27.5℃ * Saving Target (10 pps)		-0.001		-0.001
		(0.005)		(0.005)
# of days above 27.5℃ * Saving Target (10 pps)		0.007*		0.008*
		(0.004)		(0.004)
Prefecture FE	Y	Y	Y	Y
Year FE	Y	Y	Y	Y
Controls	Y	Y	Y	Y
Obs.	728	728	728	728
R-Squared	0.69	0.69	0.69	0.70

Notes: The omitted group is # of days below 25℃. Controls include log monthly precipitation, log wind speed, log prefectural GDP per capita, and population shares of age groups 0 to 4, 5 to 19 and over age 65. Three prefectures that were heavily damaged by the earthquake are excluded from the regressions. All regressions are weighted by population in 2010. Standard errors are clustered at the prefecture level and reported below the coefficients. * significant at 10% ** significant at 5%. *** significant at 1%.

Energy Saving Can Kill: Evidence from Fukushima Nuclear Accident

APPENDIX

Appendix A. Data Sources

1. Electricity Consumption and Electricity Prices

Electricity consumption data are collected from the Federation of Electric Power Companies of Japan (FEPC). The FEPC reports regional-level monthly electricity consumption. We construct regional-level panel data on electricity consumption in the summer (from July to September) from 1999 to 2015.

The regional-level average price is calculated by dividing the total electricity sales by the total consumption in each region. Data on total sales are obtained from quarterly report of each power companies. When quarterly data are not available, we use semi-annual or annual level data to calculate the average price.

2. Cause Specific Deaths

Cause-specific deaths data are collected from the Vital Statistics reported by the Ministry of Health, Labour, and Welfare (MHLW). We conduct placebo tests using several causes that are arguably not related to energy consumption: infectious diseases (tuberculous and viral hepatitis), congenital malformations and accident. We count all the cause-specific deaths appearing from July to September, during which the electricity saving policy was implemented.

The classification of the cause-specific deaths follows the International Statistical Classification of Diseases, 10th Revision (ICD 10, 2013). Infectious diseases correspond to codes A00 ~ B99, tuberculous to A15 ~ A19, viral hepatitis to B15 ~ B19, congenital malformations to Q00 ~ Q99 and accident to V00 ~ V99 and

W00 ~ W84. Accidents mainly include those from traffic, falling, drowning and choking.

3. Prefectural Socio-Economic Conditions

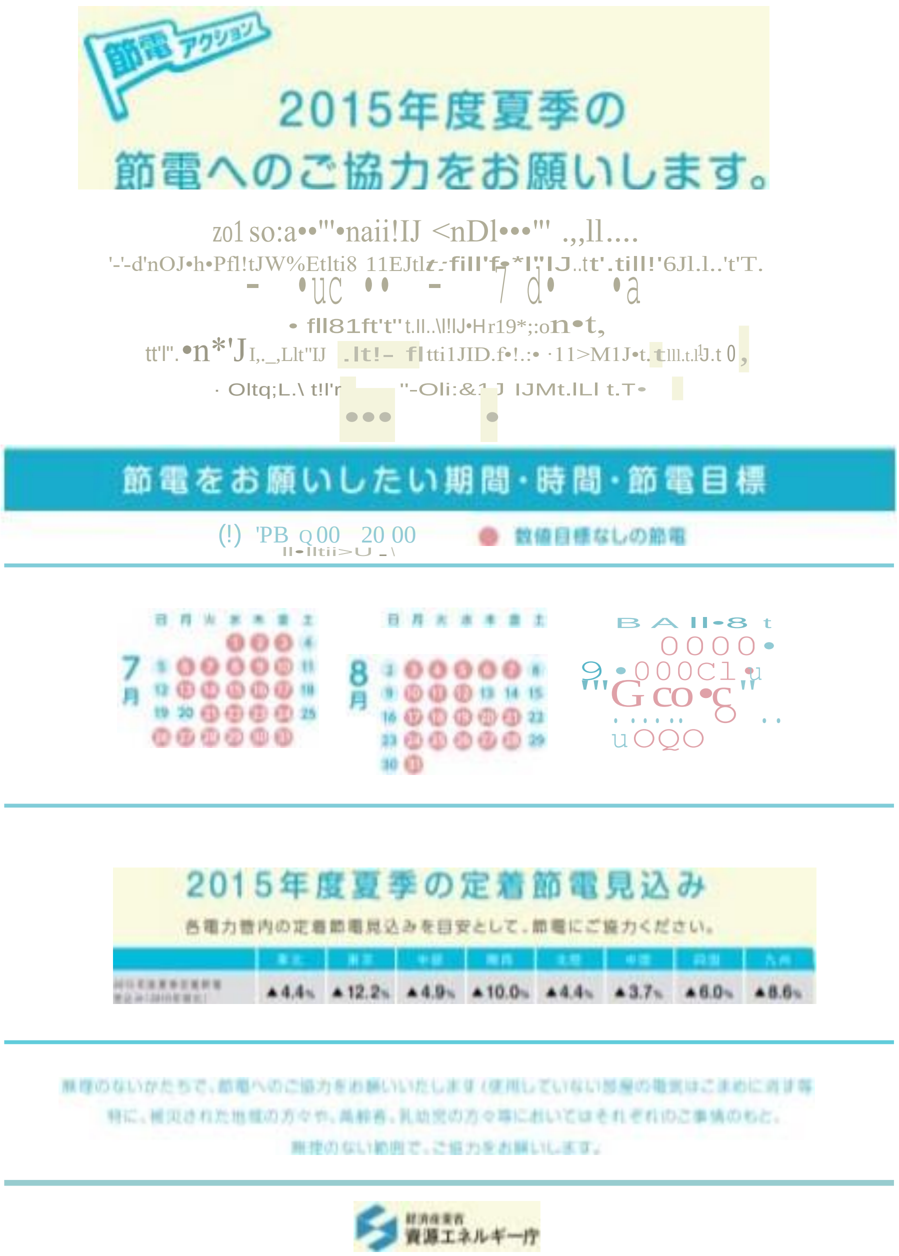
Population data are collected from the Ministry of Internal Affairs and Communications. Prefectural GDP data is collected from the Cabinet Office, and other socio-economic data from the Statistical Observations of Prefectures reported by Ministry of Internal Affairs and Communications (MIAC). The number of doctors and nurses are surveyed once every two years.

4. Air Pollution Data

Air pollution are obtained from National Institute for Environmental Studies. The concentrations of Suspended Particulate Matter ($PM_{7\sim8,}$), NOx, and SO2 and Ox (Photochemical Oxidants) are collected from around 1,900 monitoring stations covering the entire Japan. We calculate the prefectural air pollution by averaging the readings from all the monitoring stations within a prefecture.

Appendix B. ElectricityS:Mng Policy and Electricity Consumption

Poster for ElectricityS:Mng Campaign in Summer 2015: Page 1



Sources: https://www.enecho.meti.go.jp/category/electricity_and_gas/setsuden/

Poster for Electricity Saving Campaign in Summer 2015: Page 2

Sources: https://www.enecho.meti.go.jp/category/electricity_and_gas/setsuden/

Translation: page 1

We Appreciate Your Cooperation in the Electricity Saving Campaign in Summer 2015

It is expected that, in summer in 2015, we need to reserve 3% of the power capacity (the minimum requirement) to ensure stable and safe electricity supply, with the assumption that some of the old thermal power plants will be utilized.
However, there is a risk that unforeseen problems with the power plants may jeopardize the electricity supply. The government and power companies will make the best efforts to strengthen the power supply capabilities.
Given such, we appreciate your cooperation in saving electricity.
* Meanwhile please take care of the risks of heat stroke

Period, Time and Goals for the Electricity Savings

Time	**9:00 ~ 20:00 on week days**
Period	**July, August, and September**
Goals	There is **no mandatory** electricity saving goal

Expected Electricity Savings Targets

We appreciate if you refer to this guide and respond accordingly.

It would be appreciated if you can cooperate and save electricity. However, please manage the degree of electricity saving and take care of yourself.
In particular, the elderly, children, and those living in areas that suffered from the earthquake should be cautious.

Ministry of Economy, Trade, and Industry

Agency for Natural Resource and Energy

For Households

We would really appreciate it if you refer to **the expected percentage of electricity savings in each region** and try to reduce your electricity consumption. The following action plan is provided for your reference.

Electricity Saving Menu and Expected Saving Percentages

Air Conditioner	1	Set temperature at 28℃	10%
	2	Block sunlight with curtain	10%
	3	Turn off the air conditioner and use fans if possible	50%
Refrigerator	4	Change temperature setting from "strong" to "middle." Close the door of the refrigerator as soon as possible. Try not to put too many foods in the refrigerator.	2%
Light	5	Turn off the light when it's unnecessary	5%
TV	6	Set the TV at "energy saving mode" and lower the brightness of its display. Turn off the TV when it's not used	2%
Electric Toilets	7	Set the toilets at "energy saving mode"	1%
	8	Unplug the toilet when it's not used	
Rice Cooker	9	Cook a large volume of rice at once in the morning and keep it in the refrigerator for the rest of the day	2%
Standby Power	10	Turn off and unplug home appliances when they are not used.	2%

Meanwhile, please avoid using home appliances consuming a lot of electricity during the daytime (**from 13:00 to 16:00**), such as electric kettle, electric griddle, toaster, dishwasher and washing/drying machine.

Appendix C. The Effects of Saving Targets on Electricity Consumption

Our main analyses focus on the reduced-form impact of electricity saving targets on heat-related health outcomes. We show that restrictions on adaptive opportunities are the main driver of the impact. In this appendix, we show that the saving targets indeed reduced electricity consumption. We do not have monthly (or summer) electricity consumption data at the prefecture level, so this analysis is based on region-level data. This is also the reason that we focus on the reduced-form results in the paper, rather than adopting a more fancy instrumental variable framework.

Appendix Table 1 summarizes our findings. Columns (1) and (3) show that the impact of electricity saving targets on total electricity consumption is large and statistically significant. A 10 percentage point change in the saving target is associated with decline in actual consumption per capita by around 9.2 ~ 11.2%. This finding suggests that the nationwide electricity saving campaign was very effective, in that households and firms reduced their electricity consumption by nearly as much as what was requested. Column (4) adds regional-level average electricity price as a control.[32] The results show that even after accounting for electricity price, saving targets have a significant impact on the consumption. A 10 percentage point change in the saving leads to a 7.5% drop in actual per capita

[32] In Japan, the electricity price is determined by three components: the demand charge, energy charge, and Renewable Energy Power Promotion Surcharge (REPPS). Energy charge is automatically adjusted by reflecting mainly fuel prices and exchange rate. REPPS is also automatically adjusted based on the regulated prices and amount of the provision of the renewable energy. Only the demand charge is based on the consumption level. After Fukushima Accident, any rise in the demand charge in eight power companies need to be approved by Ministry of Economy, Trade, and Industry.

electricity consumption. This also implies that the sharp decline in electricity consumption in summer cannot be fully explained by the price changes.

As a side note, we also find that an increase in the number of very hot days is associated with higher electricity consumption. This is not surprising, as households and firms need to use more electricity during hot days.

APPENDIX TABLE 1— THE IMPACT OF SAVING TARGETS ON ELECTRICITY CONSUMPTION

	Log (Electricity Consumption per capita)			
	(1)	(2)	(3)	(4)
Saving Target (per 10 pps)	-0.112***	-0.111***	-0.092***	-0.074***
	(0.026)	(0.022)	(0.014)	(0.014)
Log (Average Price)				-0.400***
				(0.087)
# of days between 25℃ ~ 27.5℃		0.018	0.016**	0.009*
		(0.012)	(0.006)	(0.004)
# of days above 27.5℃		0.057**	0.042***	0.024***
		(0.023)	(0.012)	(0.007)
Log (Monthly Precipitation)		0.010	0.009	-0.013
		(0.017)	(0.009)	(0.012)
Prefecture FE	Y	Y	Y	Y
Year FE	Y	Y	Y	Y
Controls	N	N	Y	Y
Obs.	170	170	170	170
R-Squared	0.73	0.76	0.76	0.9

Notes: The omitted group is # of days below 25℃. Controls include, log prefectural GDP per capita, population shares of age groups 0 to 4, 5 to 19 and over age 65. We use monthly average temperature and precipitation since daily average temperature is likely to be very different within the same region. All regressions are weighted by population in 2010. Standard errors are clustered at the prefecture level and reported below the coefficients. * significant at 10% ** significant at 5%. *** significant at 1%.

Appendix D. Results After Accounting for Price Change

APPENDIX TABLE 2— ADDITIONAL CHECKS CONTROLLING FOR PRICE CHANGES

	Heat-Related Mortality Rate (per 1,000,000)			
	(1)	(2)	(3)	(4)
Saving Target (per 10 pps)	1.570**		1.626***	-0.988
	(0.593)		(0.550)	(1.131)
Ln (Average Price)		1.752	-1.052	-0.443
		(4.437)	(4.116)	(4.172)
# of days between 25℃ ~ 27.5℃ * Saving Target (per 10 pps)				0.026
				(0.024)
# of days above 27.5℃ * Saving Target (per 10 pps)				0.058*
				(0.033)
Prefecture FE	Y	Y	Y	Y
Year FE	Y	Y	Y	Y
Controls	Y	Y	Y	Y
Obs.	748	748	748	748
R-Squared	0.69	0.68	0.69	0.69

Notes: The omitted group is # of days below 25℃. Controls include # of days between 25℃ ~ 27.5℃, # of days above 27.5℃, log monthly precipitation, log wind speed, log prefectural GDP per capita, and population shares of age groups 0 to 4, 5 to 19 and over age 65. Three prefectures that were heavily damaged by the earthquake are excluded from the regressions. All regressions are weighted by population in 2010. Standard errors are clustered at the prefecture level and reported below the coefficients. * significant at 10% ** significant at 5%. *** significant at 1%

Appendix E. Channels

APPENDIX TABLE 3— THE IMPACT OF SAVING TARGETS ON ELECTRICITY CONSUMPTION

	Log (SPM)	Log (SO2)	Log (NOx)	Log (Ox)
	(1)	(2)	(3)	(4)
Saving Target (per 10 pps)	-0.036	0.012	-0.006	-0.030
	(0.027)	(0.076)	(0.020)	(0.023)
# of days between 25℃ ~ 27.5℃	0.001*	-0.003	-0.002***	0.002**
	(0.001)	(0.003)	(0.001)	(0.001)
# of days above 27.5℃	0.000	-0.003	-0.003***	0.002***
	(0.001)	(0.003)	(0.001)	(0.001)
Region FE	Y	Y	Y	Y
Year FE	Y	Y	Y	Y
Controls	Y	Y	Y	Y
Obs.	748	745	748	748
R-Squared	0.81	0.67	0.95	0.63

Notes: The omitted group is # of days below 25℃. Controls include log monthly precipitation, log wind speed, log prefectural GDP per capita, population shares of age groups 0 to 4, 5 to 19 and over age 65. Three prefectures that were heavily damaged by the earthquake are excluded from the regressions. All regressions are weighted by population in 2010. Standard errors are clustered at the prefecture level and reported below the coefficients. * significant at 10% ** significant at 5%. *** significant at 1%.