[QUANTIFYING THE NON-LINEAR IMPACT OF EXTREME TEMPERATURES ON POWER GENERATION EFFICIENCY]

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Overview

The electricity generation sector contributes to climate change while at the same time being exposed to physical and financial risks due to climate change-related extreme weather. Thermal power plants, in particular, are vulnerable to abnormal air or water temperature as the turbine cycle of power generation requires an external source of water and air for cooling (Linnerud et al., 2011; Zamulda et al., 2013; Jalgom et al., 2014). Several studies have tried to estimate the effect of external temperatures on power generation. Some examined macro indicators such as electricity market price (Boogert and Dupont, 2005; McDermott and Nilsen, 2014), whereas others estimated the efficiency loss from high temperatures. However, their approaches are limited to either a time series analysis of one example unit (Şen et al., 2018) or empirical research based on a linear impact model (Herny and Praston, 2016; Coffel and Mankin, 2021).

This paper quantifies the impact of extreme air temperatures on power generation efficiency based on a large panel dataset consisting of 1,742 thermal power plants covering the period between January 2008 and December 2020. Also importantly, our model explicitly represents the possible nonlinear response of power generation efficiency to extreme temperatures, acknowledging that linear models can underestimate the physical impact of extreme weather and associated business risks. We expect that a precise estimation of climate impacts on physical assets like the one undertaken here would be a prerequisite for assessing climate-related financial risks faced by enterprises such as electric utilities.

Methods

Our study extends the semi-parametric panel fixed effect model proposed by Schlenker and Roberts (2009) to the U.S. power sector context. The model specifies a flexible nonlinear relationship between the temperature exposure of individual regions and the efficiency of power generation units in those regions, taking step functions, polynomial bases, and natural cubic spline approaches. In addition, individual fixed effects control for time-independent plant unit-specific heterogeneity in plant operation patterns. Moreover, extra explanatory variables, including time-varying, plant unit-specific capacity factors, and individual plant ages, are selected to control other sources of efficiency loss.

The study draws on historical weather information from PRISM Climate Data and plant-level data from the U.S. Energy Information Administration (EIA). These two datasets are merged at the county and year-month levels to quantify the main variables. As a measure of county-level exposure to extreme temperatures, we employ the monthly distribution of temperatures for each county rather than the monthly average or min-max values. The open-source R codes for generating the distribution are provided by Ortiz-Bobea (2021). In addition, for power generation efficiency, we use ‘heat rate,’ which is the amount of energy input in MMBtu required to produce one kWh of the net generation.

Results

The preliminary results indicate that exposure to moderate air temperature does not have a statistically significant impact on the heat rate of electricity generation. However, exposure to temperature over a certain threshold has the effect of increasing the heat rate. For example, with natural cubic spline bases with six degrees of freedom, one additional day of exposure to 35 ºC bin lowers the generation efficiency on average by a half percent (Figure 1). Although the exact marginal effects vary with the specification of the function and degrees of freedom of the bases, the existence of the impact and the nonlinearity pattern remain robust. On top of that, the study additionally estimated the effects in separate climate regions to consider the possible regional differences of the power plants constructed to adapt to the specific climates. However, the results are generally similar to those that cover the entire contiguous U.S.

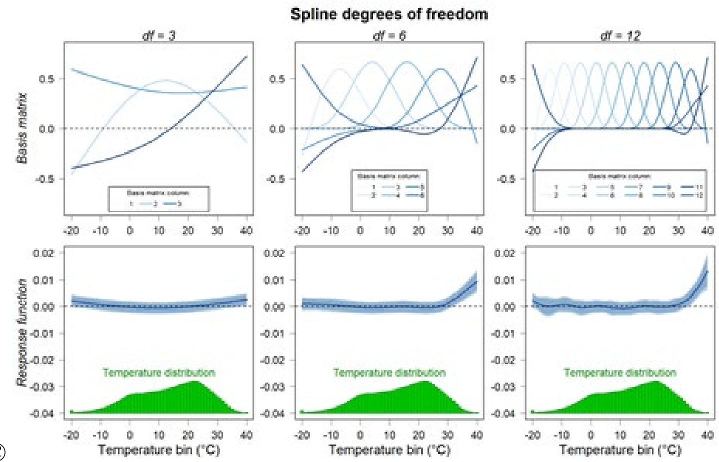

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Figure 1. Nonlinear effect of air temperature on monthly heat rate of thermal power plant generators in the U.S.

Conclusions

Our preliminary results suggest that increasing periods with high temperatures can deteriorate the profitability of power plant owners as more energy should be supplied to generate the same amount of electricity. Of course, other critical factors, such as electricity price and system demand, can also explain profitability. Our study contributes to the literature on the assessment of climate-related physical risk, revealing one specific direct channel by which climate change can negatively influence business operations, that is, the impact of extreme temperatures on the efficiency of thermoelectric power generation.

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