ADAPTATION OF MARKET-BASED DEMAND RESPONSE MITIGATES WELFARE LOSS AGAINST EXTREME WEATHER EVENTS

Boyan Zhang, School of Applied Economics, Renmin University of China, +86 13752681361, zhangboyan@ruc.edu.cn
Hao Chen, School of Applied Economics, Renmin University of China, +86 15510721059, chenhao01@ruc.edu.cn
Zhanming Chen, School of Applied Economics, Renmin University of China, +86 13810000157, chenzhanming@ruc.edu.cn

Overview

The frequency and intensity of extreme weather events are increasing, threatening the power supply reliability. Various existing research focused on the impacts of extreme weather on electricity supply and demand. However, research on strategies and policy design for adapting to extreme weather shocks on power system remains limited. As the importance of demand-side flexibility becomes increasingly evident, market-based interruptible load contract (ILC) provides a potential solution for mitigating power security shocks.

To evaluate the role of ILCs under extreme weather, this paper first generates extreme weather scenarios based on hourly meteorological data from the past 65 years. Then, we develop a welfare maximization model from the perspective of a power system operator, and employ the model to evaluate the reliability impacts of extreme weather and the optimal design of ILC. Finally, the social value of optimal ILCs is quantified by comparing the improvements in social welfare between counterfactual scenarios with and without these contracts.

This paper makes two potential contributions to the existing literature. First, it extends the literature on market design in the context of climate change and extreme weather adaptation. We emphasize the crucial role of market-based mechanisms in addressing extreme weather shocks and quantify the welfare effects of related policies. Second, in terms of modeling, this paper integrates traditional power system modeling with economic methods, enabling a precise depiction of power system operational constraints and economic analysis.

Methods

- **Weather scenario construction**

This paper collects hourly temperature data from the past 65 years and uses the Finkelstein-Schafer (FS) statistical method to derive temperature curves for a typical meteorological year (TMY), extreme hot year (EHY), and extreme cold year (ECY). Following the approach in Perera et al. (2020), this paper identifies the two most extreme temperature scenarios, EHY and ECY, at the hourly level, to analyze the operational reliability and economic impacts of the power system under boundary conditions.

- **Welfare maximization model**

We model the problem of a power system opeartor who makes various decisions to maximize the expected welfare. Our framework build on Gowrisankaran et al. (2016) and He et al. (2016) to both explore the electricity market design and reflect the operational constraints on power system.

We assume that both the power generation and demand is affected by the climate factors such as temperature. Considering different weather scenarios, the system operator first choose a ILC price, then the customers who decide to sign up the contract must curtail electricity demand to secure the power system when there is potential electricity shortage and receive the monetary compensation.

Results

- **Impact of extreme weather on the power system**

Impact of extreme weather on demand: Under the EHY scenario, the average demand is significantly higher than the typical year's load. During summer, power demand under the EHY scenario is noticeably increased due to cooling demand. The load curve under the ECY scenario is flatter than that under the EHY scenario.

Impact of extreme weather on system reliability: The risk of power deficit is highest under the EHY scenario, primarily due to the significant increase in summer power demand caused by high temperatures, as well as the reduced efficiency of power plants.

- **Optimal ILC price under different weather scenarios**

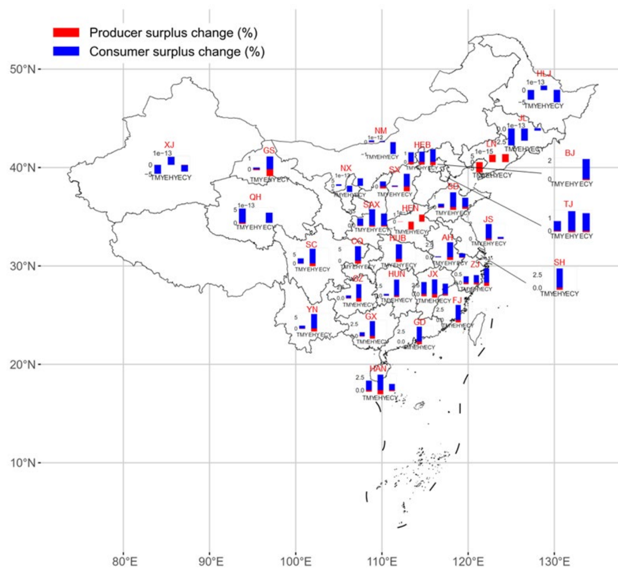
The relationship between social welfare and the setting of ILC price: In different weather scenarios, as the ILC price increases, there is an inverted U-shaped relationship between the ILC price and social welfare.

Regional heterogeneity of the optimal ILC price: Due to the varying economic value of electricity consumption, optimal ILC prices are generally higher in coastal provinces than in inland regions. The ILC prices in provinces with a small share of imported electricity or a high proportion of hydroelectric power are higher.

- **Welfare effects of ILC**

Overall effect: The welfare improvement of ILC is significant under the EHY scenario, while the welfare improvement is relatively smaller under the ECY scenario.

Welfare decomposition: Regarding consumer surplus, ILC reduces the welfare loss caused by power shortages, resulting in an overall increase in consumer surplus. However, suppliers may experience a loss in sales profits due to load curtailment, leading to a decrease in producer surplus.



Conclusions

This paper constructs a welfare maximization model to quantitatively assess the mechanism design and welfare effects of ILC under extreme weather conditions. We find that the optimal ILC pricing is not only influenced by the economic value of electricity per unit but also by the local power generation mix. Moreover, an inverted U-shaped relationship between the ILC price and social welfare reflects the trade-off that electricity market operators face between outage risks and welfare losses. Although the welfare impacts of ILC on producers and consumers are directionally different, the overall social welfare improvement is generally positive. The results of this study highlight the value of electricity market mechanisms in addressing extreme weather shocks.

References

Gowrisankaran, G., Reynolds, S.S., Samano, M., 2016. Intermittency and the value of renewable energy. Journal of Political Economy 124, 1187-1234.

He, G., Avrin, A.-P., Nelson, J.H., Johnston, J., Mileva, A., Tian, J., Kammen, D.M., 2016. SWITCH-China: a systems approach to decarbonizing China's power system. Environmental science & technology 50, 5467-5473.

Perera, A., Nik, V.M., Chen, D., Scartezzini, J.-L., Hong, T., 2020. Quantifying the impacts of climate change and extreme climate events on energy systems. Nature Energy 5, 150-159.