The Thirst for Power: The Impacts of Water Availability on Electricity Generation in China

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Economic development under restricted resource availability has become a complex challenge for both developing and well-established economies. The availability of resources, like water, has been drastically affected by global warming with increased frequency in droughts and heat waves, which lowers agriculture production and disrupts international trade. More damagingly, electricity supply becomes unreliable due to increased water temperature and reduced water availability, as water is both directly used for power generation in hydropower plants, and indirectly for cooling in thermal and nuclear generation. Firm productivity has been significantly limited by the increased electricity scarcity. To maintain a sustainable resource supply and mitigate the impact of water shortage on economic development, it is therefore important to understand how utility firms respond to the change in water availability and unpacks the underlying mechanisms of power outage.

Although the correlation between frequent droughts and persistent electricity shortages is well known, it remains unclear as to how and why electricity shortages are related to drought. Relevant studies on this relationship are scant, especially for developing countries, possibly because meteorological data on water shortage and temperature at the power plant level are not readily available. In this study, we match a plant-level panel of electricity generation information with a fine-scale monthly meteorological dataset on electricity generation, installed capacity, and water-use characteristics, relevant social economic factors of individual plants, and climatic information for plant locations for the period from 2007 to 2014. We use Palmer Drought Severity Index (PDSI) as a proxy for water scarcity. In addition, we employ two alternative proxies for water scarcity: the Standardized Precipitation Evapotranspiration Index (SPEI) for the relative long-term and precipitation (P) for the short term. We show that based on fuel type, coal and nuclear are called upon to substitute for the forgone hydropower when water availability declines.

We find that a one-standard-deviation decrease in water availability causes an approximate 205 GWh decline in hydro power generation, a 145 GWh increase in nuclear generation, and a 28 GWh increase in coal generation. To minimum the estimation biases stemming from omitted variables, we also control for time invariant firm fixed effects, year-of-sample fixed effects, power grid region by year, and fuel type by year fixed effects in all our estimations. The results are robust for alternative measures of the water scarcity index. We also rule out factors that may confound our results on the technology substitution, such as newly constructed generators and regular generator maintenance.

To support our findings, we further construct quarterly average water scarcity as an alternative measure. The finding is consistent with that of using annual data. We also find that water scarcity may result in electricity shortages in the second and third quarters of a year in particular due to a technology shift. Moreover, we analyse the effects of the characteristics of water withdrawal mechanisms for generators. Specifically, we focus on the water sources the plants rely on and the technology that the plants have installed to cool generators. We identify that technology selection in

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China's electricity sector is likely to move from relatively water-intensive generation technologies towards less water-intensive technologies. Our result is consistent with prior studies. By examining the spatial effects of water scarcity on technology substitution across grids, we find that water scarcity-induced electricity shortages cannot be alleviated by supply from other grids via inter-grid transmission, which may suggest that the inefficiency of the power grid dispatch and transmission system is another reason for the frequent power shortages that occurred in the early 2010s in China.

In addition, we address the environmental consequences of the technology selected for electricity generation induced by water scarcity. Our results suggest that the rising use of coal for electricity is associated with an increase in CO_2 emissions. The results imply a hidden increase in carbon emission up to 32000 tons of each thermal power plant per year, resulting in an additional cost of 0.18 million USD. We also note that a change from moderate drought to extreme drought would sharply intensify CO_2 emissions.

Overall, this paper provides the very first quantitative investigation of the impact of water scarcity on electricity generation in a developing country. Its contributions can be summarized in three directions. Firstly, it contributes to an understanding of technology selection with restricted resource input in the process of transition towards greener economy. Secondly, the paper contributes to the understanding of how the government responses to climate shock. In this paper, the efficacy of government response to drought is measured by looking into the decisions related to electricity generation technology substitution. Thirdly, this paper identifies the underlying mechanisms for the severe electricity shortages in China in the early 2000s by linking water scarcity with electricity generation technologies.