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Electricity-market price and nuclear power plant shutdown: Evidence from California

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HIGHLIGHTS

- Japan's disaster led to calls for shutting down existing nuclear plants.
- We perform a regression analysis of California's real-time electricity-market prices.
- We estimate that the San Onofre plant shutdown has raised the market prices by \$6/MWH to \$9/MWH.
- The price increases could be offset by demand reduction and renewable generation increase.

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ABSTRACT

Japan's Fukushima nuclear disaster, triggered by the March 11, 2011 earthquake, has led to calls for shutting down existing nuclear plants. To maintain resource adequacy for a grid's reliable operation, one option is to expand conventional generation, whose marginal unit is typically fueled by natural-gas. Two timely and relevant questions thus arise for a deregulated wholesale electricity market: (1) what is the likely price increase due to a nuclear plant shutdown? and (2) what can be done to mitigate the price increase? To answer these questions, we perform a regression analysis of a large sample of hourly real-time electricity-market price data from the California Independent System Operator (CAISO) for the 33-month sample period of April 2010–December 2012. Our analysis indicates that the 2013 shutdown of the state's San Onofre plant raised the CAISO real-time hourly market prices by \$6/MWH to \$9/MWH, and that the price increases could have been offset by a combination of demand reduction, increasing solar generation, and increasing wind generation.

1. Introduction

The Tohuku earthquake and its ensuing tsunami hit Japan on March 11, 2011, precipitating the Fukushima nuclear disaster. Three years later, Japan has yet to contain the disaster's long-lasting damages: heavily contaminated water from the nuclear plant continues leaking into the soil and sea (Hirokawa et al., 2013; Kubota and Obayashi, 2013; Takenaka and Topham, 2013).

The Fukushima disaster has sparked intensive research interest into Japan's electricity resource mix. This research has yielded diverse findings with differing policy implications. To wit, Hong et al. (2013) apply multi-criteria decision making to show that a nuclear-free pathway may not best meet the long-term goals of emissions reduction, energy sustainability, and reasonable costs. The life-cycle analysis of Pereira et al. (2013), however, suggests that Japan, from an economic, environmental and supply-security perspective, should increase the share of renewable energy in its generation mix. Though echoed by Nesheiwat and Cross (2013), this suggestion differs from the recommendation of Vivoda (2012) and Hayashi and Hughes (2013), which is to maintain the role of nuclear power in Japan's electricity future.

The Fukushima disaster's policy impact is international and significant. A case in point is the immediate response of China's

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Central Government, which was a comprehensive safety inspection of all nuclear plants in operation, and suspension of approval for new nuclear power stations (Hook, 2011; The Guardian, 2012). China's response mirrors Germany's decision to immediately shut down eight of its 17 reactors and to close the rest by 2022, and Italy's widely-supported referendum in 2011 to reject nuclear power (Baetz, 2011; Faris, 2011; Joskow and Parsons, 2012).

In North America, the future of nuclear power is once again being questioned. The concern over the Fukushima accident is compounded by the aging fleet of nuclear reactors, slowing growth in the demand for electricity, high nuclear power-plant maintenance costs, and a sharp decline in the cost of renewable generation technologies (U.S. Energy Information Administration, 2013; U.S. Department of Energy, 2013; Wald, 2013; California Energy Commission, 2014). One option to maintain resource adequacy for a grid's reliable operation after a nuclear plant is shuttered is to expand conventional generation, whose marginal unit is typically fueled by natural gas (Shahidehpour et al., 2005; Woo et al., 2012; California Energy Commission, 2014). Two timely and relevant questions thus arise: (1) To what extent will the market price increase as a result of a nuclear plant shutdown? (2) What can be done to mitigate the anticipated price increase?

Answers to these questions will aid resource planning and procurement. Further, the answers are of interest to four distinct market agents: (1) consumers, whose retail electricity prices are directly related to wholesale prices; (2) wholesale-market participants that engage in power trading and hedging; (3) power-plant owners seeking to forecast their revenues from sales of generation into those wholesale markets; and (4) generation-project developers seeking to determine the potential profitability of investments in new generating capacity.

This paper documents a regression analysis of a large sample of hourly real-time electricity-market price data for the California grid managed by the California Independent System Operator (CAISO). Based on the detailed renewable-generation data first made available by the CAISO in April 2010, our sample period of 33 months of hourly data from April 2010 through December 2012, which comprises some 24,000 observations, is sufficiently long as to reflect the large variations in the state's real-time hourly prices, loads, nuclear capacity availability, and renewable generation. Our analysis answers the two questions posited above: namely, in 2013 the increase in wholesale prices resulting from the shutdown of the San Onofre plant is estimated to have raised the CAISO real-time market prices by $6/MWH to $9/MWH. And these price increases could have been offset by a combination of demand reduction, increases in solar generation, and increases in wind generation. These findings support California's energy policy for demand-side management (DSM) and renewable energy development to mitigate the adverse price effect of the state's current and future nuclear power-plant retirements.

The paper makes three principal contributions to the literature:

- To the best of our knowledge, the paper provides the first analysis of the real-time electricity-market price increase that is the direct result of a nuclear plant shutdown in California. This analysis has global implications well beyond the borders of California, inasmuch as the state represents the ninth largest economy in the world.[1]
- The paper affirms California's adopted energy policy for DSM and renewable energy, which may be similarly pursued in other markets that face nuclear plant shutdowns or construction moratoria (e.g., North America and Europe).
- We set forth a transparent regression-based approach for analyzing the fundamental drivers of real-time market prices, thus enriching the extant literature on the merit-order effect of renewable generation.

The paper is organized as follows. Section 2 contains a brief literature review of the price effects of nuclear generation, renewable generation, and DSM. It also describes the major features of the California electricity market, describes our data sample, and proposes our regression specification. Section 3 presents the regression results. Section 4 discusses these results in terms of the hypotheses that we set forth in Section 2. The concluding Section 5 offers some broad inferences and general implications of our results.

2. Materials and methods

2.1. Literature review

Extant literature documents that a decrease in nuclear generation can have a large effect on energy prices in wholesale electricity markets, at least in the short term (Andersson and Hådén, 1997; Traber and Kemfert, 2012; Glomsrød et al., 2013). This is intuitively plausible since nuclear plants have low operating costs but high ramping costs, and are normally operated at or near available capacity. Thus nuclear plants have fairly flat or constant generation profiles (Pouret et al., 2009). Shutting down a nuclear plant shrinks supply in the wholesale electricity market, which ceteris paribus leads to an increase in the market price. By contrast, an increase in renewable generation with zero fuel cost, such as small run-of-the-river hydro, solar and wind, expands supply in the wholesale market. If the increase in renewable generation is sufficiently large, it can reverse the price increase caused by the shutdown of the nuclear plant.

The price-reduction effect of an expansion in renewable generation has been demonstrated through model simulations (e.g., Morales and Conejo, 2011; Trabor and Kemfert, 2011), as well as through regression analysis, using data for electricity markets in Spain (Gelabert et al., 2011; Gil et al., 2012), Germany (Sensfuß et al., 2008), Denmark (Munksgaard and Morthorst, 2008), Australia (Cutler et al., 2011), Texas (Woo et al., 2011a), PJM (Gil and Lin, 2013), and the Pacific Northwest (Woo et al., 2013). This price reduction is also known as the merit-order effect, wherein higher-cost fossil-fuel resources such as natural-gas generation are displaced by non-dispatchable renewable-energy resources (e.g., wind and solar power) (European Wind Energy Association, 2010).

While renewable generation can help reduce prices in the wholesale market, its incremental costs add to the total procurement costs that are ultimately borne by end-users. Such costs include the additional costs for interconnection, integration, and financial support (Barroso et al., 2010; Alagappan et al., 2011; Joskow, 2011; Green and Yatchew, 2012; Lam et al., 2013). As end-users ultimately bear the total cost of procurement, their aggregate bill impact is the sum of (a) the wholesale energy bill with the renewable-energy expansion in place and (b) the incremental cost of the expansion, less (c) the wholesale-market energy bill without the renewable-energy expansion. End-users thus see net bill reductions when $(b) < [(c) - (a)]$, where the latter difference is the savings in the wholesale energy bill. Because the price reduction applies to the aggregate load, the merit-order effect implies large bill savings (Gil and Lin, 2013). As a result, the net bill impact on end-users of renewable development can be surprisingly small.

Finally, a reduction in the system load via DSM that includes demand response (DR) can dampen any increase in the market price that would otherwise result from a nuclear plant shutdown (Figueiredo et al., 2005; Brattle Group, 2007; Woo et al., 2008, 2014; Su and Kirschen, 2009; Sreedharan et al., 2012). DSM offers

[1] ⟨http://www.lao.ca.gov/reports/2013/calfacts/calfacts_010213.aspx⟩.