START-UP COSTS AND MARKET POWER: LESSONS FROM THE RENEWABLE ENERGY TRANSITION

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Motivation: The global share of electricity production from renewable resources has increased dramatically in the last decade (IEA (2020)). Increases in output from near-zero marginal cost renewables typically decrease the amount of production required by fossil-fuel plants (Bushnell and Novan, 2021), resulting in less pollution emissions and lower production costs (Kaffine et al., 2013; Gowrisankaran et al., 2016; Lamp and Samano, 2020; Sexton et al., 2021). However, fossil-fuel plants must increasingly stop and start production in response to changes in output from intermittent renewables (Schill et al., 2017). This complicates studies of competition for two reasons. First, an increase in output from renewables in an hour does not just affect competition in that hour - plants displaced by intermittent renewables must decide whether to incur the start-up costs necessary to compete at a later time. Second, traditional measures of market power based on markups in price above marginal cost do not account for the fixed costs of starting production and can thus overestimate the rents captured due to the exercise of market power (Mansur, 2008).

Methodology: We develop a dynamic framework to measure market power that accounts for start-up costs. In this framework, we specify a competitive benchmark - a counterfactual time series of plant output and market prices - that minimizes the daily total costs of dispatching power plants to satisfy demand in each hour of the day while setting prices that allow plants to recover their start-up and production costs. Our dynamic approach extends static methods that estimate price-cost markups using data on input costs and output (Borenstein et al., 2002; De Loecker and Warzynski, 2012; Syverson, 2019; De Loecker et al., 2020). In contrast to existing methods to estimate market power that account for fixed costs, our approach does not rely on an economic model of conduct to recover estimates of the rents captured by firms from exercising market power.

Primary Findings: Our first key finding is that using the marginal cost of production as the competitive benchmark price can result in substantial overestimates of the share of operating profits earned due to the exercise of market power. We show this by applying our dynamic framework to a setting with world-leading rooftop solar penetration rates: Western Australia (WA). Fossil-fuel plants in WA often shut down during the day in response to output from solar panels, starting back up in the evening when solar stops producing. These plants expect to recover the fixed costs associated with starting production via future markups above their variable cost. Due to this, the competitive prices calculated using our dynamic framework are 30% higher at sunset on average than those derived from traditional static methods that set the competitive price equal to the marginal cost of the marginal unit produced.

Our second key finding relates to how the clean energy transition affects competition in wholesale electricity markets. Namely, we demonstrate that increases in rooftop solar capacity correspond to increases in the exercise of market power in the evening. This is because some of the fossil-fuel units displaced by output from solar panels during the day choose not to incur the start-up costs necessary to produce at sunset, weakening competition in the evening. This solar-induced increase in market power has meaningful aggregate impacts: the annual operating profits earned by fossil-fuel units increased by 14% coincident with the doubling of rooftop solar capacity between 2015 and 2018, with the bulk of these increases concentrated in the evening. In contrast, we estimate that operating profits would have fallen by 22% from 2015 to 2018 under the counterfactual implied by our dynamic competitive benchmark. This indicates that the increase in operating profits over our sample period is driven primarily by increases in the exercise of market power in the evening.

Results from two additional empirical approaches further support that solar-induced increases in operating profits are likely to be driven by increases in the exercise of market power rather than increases in the prices that would prevail under our dynamic competitive benchmark. The first empirical approach is a regression framework similar to Davis and Hausman (2016) and Bushnell and Novan (2021) that links marginal additions of rooftop solar capacity to changes in market outcomes. The second approach is a simulation framework that explores the impact of larger-scale counterfactual changes in solar capacity on the market outcomes that would prevail under our dynamic competitive benchmark. The findings across the empirical approaches suggest that employing technologies that can

more cost-effectively compensate for fluctuations in output from renewables can improve the competitiveness of markets.

Policy Implications: The dynamic impacts of rooftop solar penetration on market outcomes speak to the growing importance of designing markets that properly account for the benefits associated with technologies that can rapidly adjust production or consumption. This can be accomplished through the following market design features that are not currently implemented in many electricity markets around the world.

First, market operators should allow suppliers to submit bids specifying their willingness to start up their units. Second, market mechanisms should be implemented to procure the "ancillary services" required to ensure grid stability and reliability of energy supply. Third, market operators should allow physical and purely financial participants to trade expected differences between hourly day-ahead and real-time prices across locations on the grid. Finally, the retail prices faced by end-users of electricity should adjust based on short-run variation in wholesale prices. Implementing real-time retail pricing would shift wholesale electricity demand from the evening to the day, reducing the need for fossil-fuel units displaced by solar during the day to start up to produce at the evening demand peak.

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