Assuming full information and no transactions costs, wholesale electricity markets that set prices based on society's value of lost load during periods of scarcity and short-run marginal generation costs during other periods provide sufficient revenues for an optimal generation mix to recover all of its costs. Boiteux (1960); Joskow (2007); Stoft (2002) provide detailed expositions of this result. Thus, generating resources having difficulty recovering their costs in a wholesale market does not reflect necessarily any market failure. Rather, financial strains on some generating resources may be market signals indicating that the mix of generation capacity is not socially optimal. In such a case, generating technologies that are unable to recover costs should exit the market while technologies that would earn positive rents should enter.

This idealized functioning of wholesale electricity markets is challenged by the institutional designs of some markets, which can create incentives for cross-subsidization of electricity services. A number of jurisdictions, including the state of Ohio, employ a corporate-separation approach to unbundling the electricity supply chain. Dormady (2017) discusses the corporate-separation market structure in Ohio. He notes that three of the four investor-owned electricity utilities in Ohio retain ownership of generation resources, which are held by corporate affiliates. Conversely, the fourth investor-owned utility in Ohio retains no generation resources, which have been divested. Dormady et al. (2019a,b) show that transmission, distribution, and retail customers of the three utilities with corporate affiliates pay regulated rates that are above the level

3.2. Effect of Affiliate PPA on Equilibrium Behavior with Exogenous Transfer Payment

To begin, we assume that $\sigma(q_s, Q_{-s})$ is paid exogenously and ignore its effect on demand. This simplification allows for a straightforward analysis and suggests some potential directions for future work on the dynamics of Nash-Cournot equilibria generally. The incentives that are engendered by the proposed profit guarantee in this setting are a consequence of the following, more general result, about Nash-Cournot

Assumption 3. $P(Q)$ is relatively inelastic, with:

$$P'(Q) \cdot \frac{Q}{P(Q)} \leq -1, \forall Q \geq 0. \tag{5}$$

Assumption 4. Firm s accounts for at most half of total equilibrium production, i.e.:

$$q_s^* \leq \frac{1}{2} Q^*. \tag{6}$$

Assumptions 3 and 4 are consistent with the short-run price elasticity of electricity demand that is estimated by Burke and Abayasekara (2018) and the energy-supply mix of many wholesale electricity markets, including that in Ohio. Assumption 4 requires that market concentration be measured on a per-firm basis. That is to say, it is insufficient for a single subsidized generator to serve at most half of the market. Rather, if a single firm holds multiple subsidized generators, their collective supply must be at most half of the market. Assumptions 3 and 4 do not guarantee that $\tilde{P}(Q)$ satisfies Assumptions 1 and 2. Thus, Proposition 1 does not hold necessarily in this context. However, with all of Assumptions 1–4, we have the following result.

Proposition 2. Under Assumptions 1–4

Numerical Case Study

This section presents a numerical case study, through which we demonstrate our theoretical analysis, with a particular focus on Proposition 2 and Corollary 1. We compute equilibrium solutions under different cost settings for a market that consists of six generating firms, one of which is subsidized. Furthermore, we assume that the subsidized firm is part of a holding company that owns another affiliated unsubsidized

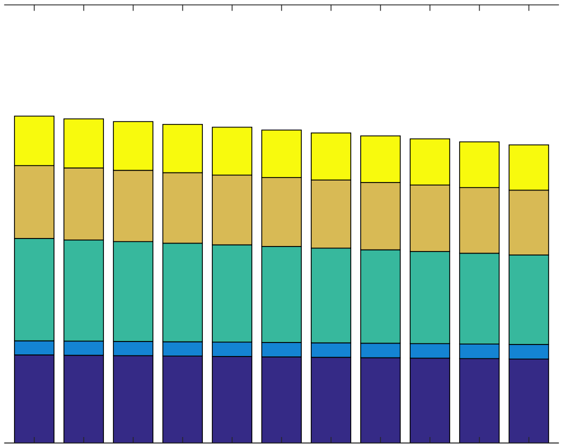
[illegible]

Generating Firm	Marginal Cost ($/MWh)	Fixed Cost ($)	Capacity (MW)
Unaffiliated			
1	29	1 200	4 000
2	25	1 400	4 000
3	26	1 500	4 000
4	27	1 200	4 000

that is output is an Nash-Cournot equilibrium.

4.2. Case-Study Results

We begin by analyzing a case with $c_s = 33$, q^{min}



when the subsidized firm is relatively inexpensive. Relatedly, we neglec

is non-positive if:

$$\frac{d}{dq_j}q_i^*, \tag{A.6}$$

is. q_i^* is defined by FONC (A.2). Di�erentiating (A.2) implicitly gives:

$$\frac{d}{dq_j}q_i^* = -\frac{\partial^2}{\partial q_i^* \partial q_j}\pi_i^*(q_i^*, Q_{-i}^*) \Big/ \left[\frac{\partial^2}{\partial q_i^{*2}}\pi_i^*(q_i^*, Q_{-i}^*\right.$$

As for the first term in the right-hand side of (A.13), we assume hereafter that $\tilde{P}(q_i^* + Q_{-i}^*) \geq c_i$ (otherwise, $q_i^* = 0$ and the result is true trivially). Thus, the sign of the first term in the right-hand side of (A.13) depends on the sign of:

$$\frac{d}{dq_s} q_i^*. \tag{A.17}$$

q_i^* is defined by (A.12), the implicit derivative of which is:

$$\frac{d}{dq_s} q_i^* = -\frac{\partial^2}{\partial q_i^* \partial q_s} \tilde{\pi}_i^*(q_i^*, Q_{-i}^*) \Big/ \left[\frac{\partial^2}{\partial q_i^{*2}} \tilde{\pi}_i^*(q_i^*, Q_{-i}^*) \right]. \tag{A.18}$$

The SONC of firm i's problem requires that:

$$\frac{\partial^2}{\partial q_i^{*2}} \tilde{\pi}_i^*(q_i^*, Q_{-i}^*) \leq 0. \tag{A.19}$$

Thus, the sign of (A.18) depends on the sign of:

$$\frac{\partial^2}{\partial q_i^* \partial q_s} \tilde{\pi}_i^*(q_i^*, Q_{-i}^*) = q_i^* \frac{\partial^2}{\partial q_i^* \partial q_s} \tilde{P}(q_i^* + Q_{-i}^*) + \frac{\partial}{\partial q_s} \tilde{P}(q_i^* + Q_{-i}^*). \tag{A.20}$$

We consider now two cases, which depend on how large c_s is relative to the equilibrium price.

Case $c_s \geq P(q_i^* + Q_{-i}^*)$