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Abstract

This note analyzes a simple Cournot model where firms choose outputs and capacities facing varying demand and price-cap regulation. We find that binding price caps set above long-run marginal cost increase (rather than decrease) aggregate capacity investment.

Keywords

capacity, investment, Cournot competition, price cap

JEL Classification

D24, D43, L13, L51

1 Introduction

We employ a simple Cournot model to analyze the investments effects of price caps under imperfect competition. In this model, each firm solves a peak-load pricing problem[1] facing imperfect competition and price-cap regulation. Our analysis thus combines capacity choice under imperfect competition[2] with price-cap regulation.[3] This note is perhaps most closely related to Hobbs and Pang (2007), who observe that imposing price caps can destroy uniqueness properties in oligopoly models. However, these authors adopt an operations-research approach incorporating uncertainty and do not study the investment effects of imposing price caps. In a related paper, Grobman and Carey (2001) focus on the investment effects of price caps but abstract from imperfect competition.

In our model, firms choose their capacity so as to match their largest equilibrium output. Consequently, a firm's capacity is typically binding in periods with peak demand and slack in periods with lower demand. The effects of price caps on capacity investments crucially depend on the level at which they are set: Clearly, a (non-binding) price cap set above the equilibrium peak price does not affect investment. A price cap set below the long-run marginal cost of the most efficient firm, in turn, makes investment unprofitable and leads to excess demand and market break-down in peak periods in the absence of (non-price) rationing. More interestingly, a binding price cap set above the long-run marginal cost of the most efficient firm does increase (rather than decrease) aggregate investment, even though it limits the scarcity rents that firms can generate in peak periods. The result follows from the fact that the price cap forces firms to produce a higher aggregate output than in the unrestricted equilibrium. Firms are willing to produce this output—and make the necessary capacity investments—provided that the price cap exceeds their long-run marginal cost.

2 The Model

We study a simple Cournot model where firms choose capacities and outputs endogenously. Suppose n firms indexed by $i = 1, ..., n$ compete in a market

[1]See Laffont and Tirole (1993, p. 21) for a concise description of the peak-load pricing problem. Crew et al. (1995) provide a comprehensive survey.

[2]Kreps and Scheinkman (1983) is the classic reference. See, e.g., Gabszewicz and Poddar (1997), Genc et al. (2007), and Zhuang and Gabriel (2008) for more recent contributions.

[3]See Armstrong and Sappington (2008) for a survey of recent developments in the theory of regulation.

with inverse demand $P^t(Q^t)$, where $Q^t \equiv \sum_i q_i^t$ denotes aggregate output and the superscript indicates period $t = 1, ..., T$. Assume that demand is concave, such that $P^{t\prime}(Q^t) < 0$ and $P^{t\prime\prime}(Q^t) \leq 0$ for all t. Each firm i chooses a fixed capacity $K_i \geq 0$ to be used during the T periods. The investment cost is $c_i^0 K_i$. The short-run marginal cost is c_i for $q_i^t \leq K_i$ and $+\infty$ for $q_i^t > K_i$. The long-run marginal cost is $(c_i + c_i^0)$. That is, each firm i faces a peak-load pricing problem with elastic and deterministic market demand under imperfect competition.

Apart from the non-negativity constraints on capacity K_i and outputs $q_i^t, t = 1, ..., T$, each firm i faces two restrictions: First, its output can never exceed the capacity level K_i. Second, the market price $P^t(Q^t)$ is subject to a price cap $\bar{p}$ that may or may not be binding. The profit-maximization problem of firm i is thus given by

$$\begin{aligned} \max_{\mathbf{q}_i, K_i} \pi_i(\mathbf{q}_i, K_i) &= \sum_t \left(P^t(Q^t) - c_i\right) q_i^t - c_i^0 K_i \qquad (1) \\ &\text{s.t.} \\ K_i &\geq q_i^t \text{ for all } t \\ \bar{p} &\geq P^t(Q^t) \text{ for all } t \\ q_i^t &\geq 0 \text{ for all } t \\ K_i &\geq 0, \end{aligned}$$

where $\mathbf{q}_i = [q_i^1, q_i^2, ..., q_i^T]$ is the vector of firm i's outputs. The associated Lagrangian is given by

$$\begin{aligned} \mathcal{L}_i(\mathbf{q}_i, K_i, \boldsymbol{\lambda}_i, \boldsymbol{\mu}, \boldsymbol{\psi}_i, \gamma_i) &= \sum_t (P^t(Q^t) - c_i) q_i^t - c_i^0 K_i \qquad (2) \\ &+ \sum_t \lambda_i^t (K_i - q_i^t) + \sum_t \mu^t (\bar{p} - P^t(Q^t)) \\ &+ \sum_t \psi_i^t q_i^t + \gamma_i K_i, \end{aligned}$$

where $\boldsymbol{\lambda}_i = [\lambda_i^1, \lambda_i^2, ..., \lambda_i^T]$, $\boldsymbol{\mu} = [\mu^1, \mu^2, ..., \mu^T]$, $\boldsymbol{\psi}_i = [\psi_i^1, \psi_i^2, ..., \psi_i^T]$, and γ_i denote Lagrange multipliers. We characterize the properties of the Cournot-Nash equilibria using the necessary first-order Kuhn-Tucker conditions for local optima for all t:

$$
\begin{aligned}
\frac{\partial \mathcal{L}_i(\cdot)}{\partial q_i^t} &= P^t(Q^t) - c_i + (q_i^t - \mu^t)P^{t\prime}(Q^t) - \lambda_i^t + \psi_i^t = 0 \qquad (3)\\
\frac{\partial \mathcal{L}_i(\cdot)}{\partial K_i} &= -c_i^0 + \sum_t \lambda_i^t + \gamma_i = 0 \qquad (4)\\
\frac{\partial \mathcal{L}_i(\cdot)}{\partial \lambda_i^t} &= K_i - q_i^t \geq 0\\
\frac{\partial \mathcal{L}_i(\cdot)}{\partial \mu^t} &= \bar{p} - P^t(Q^t) \geq 0\\
\frac{\partial \mathcal{L}_i(\cdot)}{\partial \psi_i^t} &= q_i^t \geq 0\\
\frac{\partial \mathcal{L}_i(\cdot)}{\partial \gamma_i} &= K_i \geq 0\\
\lambda_i^t(K_i - q_i^t) &= 0\\
\mu^t(\bar{p} - P^t(Q^t)) &= 0\\
\psi_i^t q_i^t &= 0\\
\gamma_i K_i &= 0
\end{aligned}
$$

We first note the existence of a pure-strategy Cournot-Nash equilibrium, following Tirole (1988, p. 225). Condition (3) implicitly defines the function $q_i^t(Q^t)$, which is continuous and non-increasing.[4] The same holds for $\sum_i q_i^t(Q^t)$. Assuming compactness,[5] Brouwer's fixed-point theorem asserts that there is at least one fixed point such that $Q^t = \sum_i q_i^t(Q^t)$. Second, we emphasize that uniqueness is not guaranteed. In particular, if the price cap is binding and set sufficiently high for firms to break even, there are typically many pure-strategy Cournot-Nash equilibria. To see this, consider a period t where the price cap is binding such that $\bar{p} = P^t(Q^t)$. The corresponding Lagrange multiplier is given by $\mu^t = q_i^t > 0$, and aggregate output is fixed at $\bar{Q}^t \equiv Q^t(\bar{p})$. Given any quantity $Q_{-i}^t \leq \bar{Q}^t$, firm i's best response is $q_i^t(Q_{-i}^t) = \bar{Q}^t - Q_{-i}^t$ by construction. That is, if the price cap is binding, all output combinations $\sum_i q_i^t = \bar{Q}^t$ are pure-strategy Nash equilibria. Clearly, these equilibria are not payoff-equivalent from a firm's point of view: Given a fixed price level $\bar{p} > c_i + c_i^0$, firm i's profit is increasing in its output. The price cap thus introduces a coordination problem among firms. Aggregate output, however, is the same across the different pure-strategy Cournot-Nash equilibria for a given

[4]Observe that $q_i^t(Q^t)$ is non-increasing for $q_i^t \geq \mu^t$. This condition is always satisfied, because $\mu^t \in \{0, q_i^t\}$.

[5]That is, $\sum_i q_i^t(0) \geq 0$ and $\sum_i q_i^t(Q^t) < Q^t$ for any Q^t such that $P^t(Q^t) = 0$.

binding price cap.

To see how firm i's output decision interacts with its capacity decision, consider the Kuhn-Tucker conditions again. Condition (3) specifies that firm i acquires a scarcity rent $\lambda_i^t > 0$ if its capacity K_i is binding in equilibrium in period t. Assuming that it is profitable for firm i to produce a strictly positive output in at least one period (such that $\gamma_i = 0$), firm i thus invests in capacity until the marginal cost c_i^0 equals the sum of scarcity rents $\sum_t \lambda_i^t$ acquired in all periods t (see condition (4)). Note that firm i's capacity K_i is binding in periods with peak demand and typically slack in periods with lower demand. More importantly, firms always choose their individual capacities such that they match their highest equilibrium output exactly to avoid foregoing profitable sales in high-demand periods.[6]

Let us now consider how a binding price cap affects aggregate capacity investments. For a price cap to be binding, it must increase aggregate output relative to the unrestricted Cournot-Nash equilibrium. Since firms choose their capacities so as to match their highest equilibrium outputs, aggregate investment must also be higher under the price cap. However, this result does not hold without qualification: If the price cap is set such that the most efficient firm cannot cover its long-run marginal cost, demand in peak periods cannot be profitably satisfied, and the market breaks down in the absence of effective (non-price) rationing.

3 Linear Example

We illustrate our above analysis assuming that inverse demand is linear and given by $P^t(Q^t) = a^t - Q^t$. To simplify the graphical representation, suppose that there are only two firms $i = 1, 2$ and two periods $t = 1, 2$. Further assume that $a^1 = 6$ and $a^2 = 13$ (i.e., demand is low in period 1 and high in peak period 2), and $c_i = 0$ and $c_i^0 = 1$ for $i = 1, 2$. Finally, suppose that the price cap is set at $\bar{p} = 4$.

Figure 1 illustrates the best-response functions of firms 1 and 2. In period 1, the price cap requires $\bar{Q}^1 \geq 2$ and is not binding (equilibrium outputs are given by $q_1^1 = q_2^1 = 2$) such that best-response functions are standard. In period 2, the price cap requires $\bar{Q}^2 \geq 9$ and is binding (unrestricted equilibrium outputs are given by $q_1^1 = q_2^1 = 4$), the best-response functions $q_1^2(q_2^2)$ and $q_2^2(q_1^2)$ are kinked at $(3, 6)$ and $(6, 3)$, respectively, and all output combina-

[6] In this simple setting, there are no costs (e.g. depreciation) for having slack capacity in low-demand periods. With such costs, firms might not be willing to install sufficient capacity to produce the equilibrium output in peak periods.

tions on the straight line from $(3,6)$ to $(6,3)$ form pure-strategy Cournot-Nash equilibria. Since prices are high enough to cover long-run marginal cost, firms build sufficient capacities to produce equilibrium outputs. Note that the binding price cap forces firms to produce more than the unrestricted aggregate equilibrium output in the peak period, which induces them to make higher capacity investments to satisfy equilibrium demand (even though scarcity rents in the peak period are limited). More specifically, setting the price cap at $\bar{p} = 4$ increases aggregate output and thus aggregate capacity from 8 to 9. In equilibrium, firms have slack capacities in period 1, whereas capacities are binding in period 2, and the corresponding Lagrange multipliers are given by $\lambda_1^2 = \lambda_2^2 = 1$.

<Figure 1 around here>

4 Conclusion

We have analyzed what is arguably the simplest conceivable peak-load pricing model combining endogenous capacity choice under imperfect competition with price-cap regulation. Our analysis suggests that binding price caps set above long-run marginal cost increase (rather than decrease) aggregate capacity investment since they induce firms to increase aggregate output.

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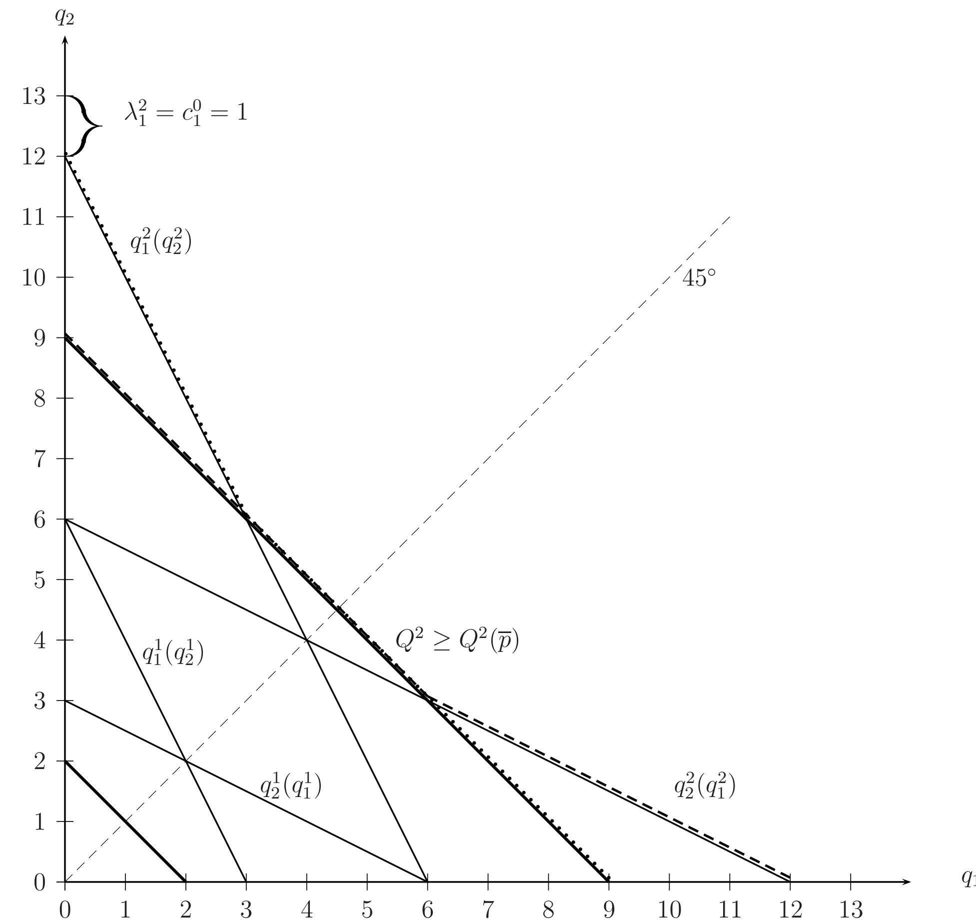

Figure 1: Best-response functions