Demand Uncertainty and Risk-aversion: Why Price Caps May Lead to Higher Prices

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Abstract

Standard oligopoly theory suggests that price caps will tend to constrain the price of a good over the short-term and increase production. Firms become price-takers when the amount produced is less than where the price cap intersects the demand function. Recently imposed price caps in California, however, have resulted in anecdotal evidence that suggests that this might not always be the case. Typical explanations for increases in price and decreases in production are sociological and psychological in nature. While these lines of reasoning may go a long way in explaining the observed fact, the absence of an economic explanation is rather unsatisfying. In this note we give such an economic explanation by examining a simple economic model. We enhance a standard Cournot model through the introduction of demand uncertainty and agents' risk aversion. Multiple examples show that the introduction of a price cap in this model may indeed lead to higher prices and lower production quantities. Very interestingly, even a price cap set above the equilibrium prices obtained with no price cap, can result in lower output and higher prices.

1 Motivation

Price caps are sometimes imposed in order to constrain the price of a commodity when the price of the commodity exceeds levels that are considered equitable or efficient.[1] In the case of static demand and supply, the idea is that a price cap acts as an upper level for firms that engage in strategic behavior. Indeed, standard oligopoly theory suggests that price caps will tend to constrain the price of a good over the short-term and increase production. This is because firms become price-takers when the amount produced is less than where the price cap intersects the demand function, the "price-cap-quantity." If production were below the price cap quantity then any firm would be better off by increasing total production to at least the price-cap-quantity, since at quantities below the price-cap-quantity its marginal revenue is equal to the price cap level minus its marginal production costs. As a result, as long as the marginal production cost is below the price cap, together all firms produce at least as much as the price-cap-quantity.[2]

Recently imposed price caps in the electricity markets in California, however, have resulted in anecdotal evidence that suggests that this might not always be the case.[3] Figure 1 from the California Power Exchange (2000) illustrates the observed phenomenon. It shows the price duration curve for successive price cap regimes during the summer of 2000. As the price cap on electric power was lowered the average price of electricity increased. At a price cap of \$750/MWh the average price was \$106; at a price cap of \$500/MWh, the average price was \$126; and a price cap of \$250 resulted in an average price of \$134. Granted that many factors affect the price of electricity, there is widespread belief that the price caps were somehow responsible for increased prices.[4] Typical explanations for increases in price and decreases in production are sociological and psychological in nature. For instance, some say that the price cap becomes a "target" for traders, who try to "trade up" to the limit.[5] While these lines of reasoning may go a long way in explaining the observed fact, the absence of an economic explanation is rather unsatisfying. In this note we give such an

[1]For a discussion of some of the issues and references see Reitzes et al. (2000).

[2]This point of view is echoed by a Federal Energy Regulatory Commissioner in discussing price caps: "If you cap those prices, you eliminate any incentive to withhold ... you may as well sell into the market at a capped price as long as you're covering your running cost and making a reasonable profit." See Walsh (2001).

[3]The authors wish to emphasize that they are not making conclusions in this paper about the exercise or abuse of market power in California. Rather, they are simply examining the question of whether there is economic theory that supports the notion that price caps could increase prices.

[4]See the Staff Report to the FERC (2000) and the dissent by Curtis Hebert in this report for the views of some regulators.

[5]See for instance Ackerman (2000): "Put in a price cap, and the traders have a target for which to shoot ... as the price cap level dips down, the average trading price climbs even as the so-called 'dysfunctional' price spikes are eliminated."

economic explanation by examining a simple economic model.

The hypothesis is that under certain conditions, risk-averse, oligopolistic firms further restrict their output in the presence of a price cap and uncertain demand. By acting as a bound on returns, the price cap serves to limit risk. The further that output is restricted, the more risk is limited. The uncertain demand represents several aspects of many real markets, and the electricity markets in California in particular. Demand itself is uncertain. With respect to electricity, actual weather can vary from the predicted, hence demand which is strongly linked to weather also varies. Moreover, in California, the payoff from sales of a product was uncertain due to a regulatory regime that threatened to take back some of the earnings of producers.[6] To see if there is an economic explanation for increased prices under a price cap, we enhance a standard Cournot model through the introduction of demand uncertainty and agents' risk aversion. Multiple examples show that the introduction of a price cap in this model may indeed lead to higher prices and lower production quantities.[7]

In Section 2 we describe our model with demand uncertainty and risk-averse agents. Section 3 lists some numerical results. In Section 4 we conclude this note.

2 An Extended Cournot Model

A Cournot model is used to explore the affect of price caps with risk-averse agents and uncertain demand.[8] We consider a Cournot oligopoly model with $N \geq 1$ firms. In the special case $N = 1$ the model reduces to a monopoly. We denote a firm's supply quantity by $q_n, n = 1, \ldots, N$ and the aggregate quantity on the market by $Q = \sum_{i=1}^{N} q_n$. The aggregate quantity of all firms but firm n will be denoted by Q_{-n}. Firms have constant marginal cost $c_n \geq 0$ of supplying their (homogeneous) product. The firms face uncertain demand for their product. The inverse demand function $p_s(Q)$

[6] There were calls starting in July 2000 for generators to return some or most of their revenue through the regulatory process, and later threats of a retroactive windfall profits tax. See the article in the Electric Daily (08-29-2000), the Staff Report to the FERC (2000), and Leopold (2000).

[7] The authors wish to emphasize that there is no judgement made in this article about the appropriateness or inappropriateness of various firms' conduct. That is well beyond the scope of this paper. The question is whether assuming *arguendo* that there was some degree of an ability to engage in strategic behavior, could the effect of a price cap be to raise prices?

[8] Cournot models are widely used, including in the analysis of electricity markets. See Daughety (1988) for an anthology of work on Cournot models and general application. Reitzes et al. (2000) give a general description of the use of Cournot models in electricity markets. Bushnell (1998), Borenstein and Bushnell (1998), and Scott and Read (1999) are all particular applications of the Cournot framework to electricity. For a textbook treatment of the Cournot model refer to Tirole (1988).

depends on the state of nature $s = 1, \ldots, S$, with $S > 1$, that realizes, but which is unknown to the firms when they make their supply decision q_n. Firms have identical beliefs about the future states, that is, they have the same probability distribution F over the S possible states. We assume that $F_s > 0$, so that all states under consideration have a positive probability of occurrence. In addition, the firms face a price cap $P > 0$, that is, the price they can charge for their product equals $\min\{P, p_s(Q)\}$ in state s.

The firms are risk averse. So, contrary to the standard Cournot model, firm n does not just maximize its (expected) profit

$$\pi_n(Q, q_n) = \sum_{s=1}^{S} F_s(\min\{P, p_s(Q)\} - c_n)q_n$$

but instead maximizes a utility function of its profit. We assume that the firms have identical (strictly) concave utility functions u with $u(\pi) \in \Re$. Firm n's objective is now to choose q_n to maximize its utility $u(\pi)$. A Cournot Nash equilibrium is defined to be a combination of quantities $(\bar{q}_1, \bar{q}_2, \ldots, \bar{q}_N)$ such that all firms simultaneously maximize their utilities.

In the special case without uncertainty, where the demand functions are identical across all states, the model reduces to the standard Cournot model with profit maximization. The same fact holds true when u is linear and the firms are risk neutral.

3 Price Caps and Higher Prices

For our illustrative examples we parameterize our model. We assume that firms have mean-variance utility functions. [9] Each firm's utility function is $u(\pi) = \mathrm{E}(\pi) - \beta \mathrm{Var}(\pi)$ where $\beta \geq 0$ indicates an aversion to profit variance. There are $S = 2$ states of nature. We use (shifted) constant elasticity (inverse) demand functions of the form

$$p_s(Q) = \left(\frac{Q + a}{y_s}\right)^{\frac{-1}{\eta}}$$

where $a > 0, 1 > \eta > 0$ and $y_s > 0$ for $s = 1, 2$. In the following we discuss three examples. In the first example we consider a monopolist, show how a price cap can decrease the firm's optimal production quantity, and perform some sensitivity analysis. Most importantly, we give an intuitive economic explanation for the production quantity decrease. Example 2 then presents some examples of a duopoly in which a price cap leads to lower production quantities. Finally, example 3

[9] When risk is involved, a firm's production decisions can be modeled as a portfolio. While various measures of risk aversion could be explored, the mean-variance measure provides a standard way to explore the issue of risk aversion.

shows that the result is also possible for an oligopoly with several firms.

Example 1: Consider a model with a monopolist (so $N = 1$) and the following parameters.

$$a = 16, \eta = 0.2, \beta = 0.01, c = 0, F_1 = F_2 = 0.5, y_1 = 55, y_2 = 50.$$

Without a price cap the optimal production quantity of the monopolist equals $q^* = 4$. The coefficient $\beta = 0.01$ is sufficiently small so that this quantity is exactly the same as the optimal production quantity for a risk-neutral firm[10]. After the firm picks its production quantity the uncertainty is resolved. If state 1 occurs, then the price will be $p_1(q^*) = 157.276$, if state 2 occurs, the price will be $p_2(q^*) = 97.656$.

Now suppose that a price cap is introduced. Let $P = 1.1 \cdot p_1(q^*)$. This price cap leads now to a drop of more than 25% in the optimal production quantity to $q^* = 2.980$. With this quantity the prices will be $p_1(q^*) = P = 173.004$ and $p_2(q^*) = 126.873$. Note that in both states the price has risen after the introduction of the price cap. Figures 2 and 3 illustrate the impact of the price cap.

[FIGURES 2 AND 3 ABOUT HERE]

Figure 2 shows the inverse demand functions. Without a price cap the firm faces the two inverse demand functions p_1 and p_2. The difference between these two function indicates the uncertainty the firm is facing. At $q^* = 4$ the utility is maximized. After the price cap $P > p_1(q^*)$ is introduced, the uncertainty below $q^* = 4$ is reduced. Clearly, such a price cap cannot lead to an increase in the production quantity, because such an increase would have been feasible without a price cap, but was apparently not optimal. Hence, a price cap exceeding the two possible equilibrium prices either has no impact or reduces the optimal quantity. If the firm were risk neutral then the price cap would not affect the production quantity, but for sufficiently risk-averse firms the optimum shifts to the left into the region of reduced uncertainty.

Figure 3 shows the firm's resulting objective functions both with and without a price cap. The reduced uncertainty due to the price cap leads to a substantial increase in the firm's utility for quantities below the previously optimal production quantity. What is most interesting in this picture is that it shows how even though the price cap exceeds the equilibrium prices obtained with no price cap, it still has an effect on the outcome. Since the alternative demand functions are closer together with the price cap, then risk to the firm is lower. In other words, since the price

[10] It is straightforward to prove that for all sufficiently small positive values of β the optimal production quantity is identical to the optimal quantity for $\beta = 0$.

cap bounds prices, it also restricts the risk that a firm faces. As output decreases, the difference in returns between the lower and upper outcomes get closer together because of the cap resulting in lower risk. For a moderate decrease in production quantity the firm gains more in risk reduction than it loses in profits.

We want to emphasize that the phenomenon of a price increase due to the introduction of a price cap is robust. Small changes in the price cap P, in the elasticity η, the coefficient β, the probabilities F_s, the uncertainty parameters y_s and the marginal cost c do not change the qualitative result that the introduction of the price cap leads to a reduction in the produced quantity and an increase in the expected price. We do not provide a complete sensitivity analysis here but illustrate the impact of some parameter changes. Table 1 reports the percentage reduction in the optimal quantity for various combinations of P, β, and y_1 for the parameter values $a = 16, \eta = 0.2, c = 0, F_1 = F_2 = 0.5, y_2 = 50$. Only when the price cap becomes very low and there is small uncertainty the introduction leads to a quantity increase. Table 2 shows the impact of changes in the marginal cost c and the elasticity η for the parameter values $a = 16, \beta = 0.02, F_1 = F_2 = 0.5, y_1 = 52.5, y_2 = 50$.

	$y_1 = 55$			$y_1 = 52.5$			
Cap	β			β			
$\frac{P}{p_1(q^*)}$	0.0075	0.01	0.02	0.01	0.02	0.05	0.075
0.8	-3.11	2.01	2.37	-17.07	-8.74	- 2.72	- 1.21
0.9	5.86	11.06	15.25	- 7.21	1.56	8.13	9.84
1.0	13.56	18.80	25.98	1.27	10.39	17.48	19.38
1.1	20.26	25.50	35.03	0	18.05	25.61	27.70
1.2	26.15	31.38	42.75	0	24.76	32.73	35.01

TABLE 1: Sensitivity analysis with respect to P, β and y_1.

	$c = 10$			$c = 25$		
Cap	η			η		
$\frac{P}{p_1(q^*)}$	0.175	0.1875	0.2	0.175	0.1875	0.2
0.8	-1.65	-5.57	-9.78	-3.15	-6.93	-11.46
0.9	9.83	5.56	1.24	9.48	5.14	0.51
1.0	19.63	15.06	10.65	20.17	15.38	10.68
1.1	28.08	23.26	18.78	29.29	24.15	19.41
1.2	35.41	30.40	0	37.14	31.75	0

TABLE 2: Sensitivity analysis with respect to c and η.

Example 2: Consider a model with $N = 2$ firms and the following parameters.

$$a = 12, \eta = 0.2, \beta = 0.01, c = 0, F_1 = F_2 = 0.5, y_1 = 55, y_2 = 50.$$

Without a price cap the optimal production quantities of the two firms equal $q_1^* = q_2^* = 4$.[11] The equilibrium prices are $p_1(8) = 157.276$ and $p_2(8) = 97.656$ for states 1 and 2, respectively.

Suppose a price cap of $P = 1.1 \cdot p_1(8)$ is introduced. This price cap leads to a drop of more than 16.5% in the optimal production quantities to $q_1^* = q_2^* = 3.3383$. With this total quantity of $Q^* = 6.6766$ the prices will be $p_1(Q^*) = P = 173.004$ and $p_2(Q^*) = 137.518$. In both states the price has risen after the introduction of the price cap. Figure 4 is the analogue to Figure 3 for the case of the duopoly. The two curves show the utility of a firm as a function of its production quantity with the competitor's quantity set at the corresponding equilibrium levels. We see that just as in the monopoly case the price cap reduces the optimal production quantity. In equilibrium, both firms produce less and therefore the objective function with the price cap is above the previous objective function without the cap. Note that the two price functions do not meet since we are holding the quantity for the other producer at the Nash quantity for the particular scenario.

[FIGURE 4 ABOUT HERE]

Table 3 reports results from some sensitivity analysis with the following parameter values, $a = 12, \eta = 0.2, F_1 = F_2 = 0.5, y_1 = 55, y_2 = 50$.

[11] As in the monopoly case in the previous example, the optimal production quantity equals the value for the model with risk-neutral firms for all sufficiently small values of β.

	$c=0$				$c=10$		
Cap	β				β		
$\frac{P}{p_1(q^*)}$	0.005	0.0075	0.01	0.0125	0.005	0.0075	0.01
0.8	-8.50	-2.05	1.28	3.33	-6.46	-0.78	2.16
0.9	-2.20	3.89	7.07	9.04	-0.16	5.48	8.69
1.0	3.24	9.05	12.10	14.02	5.34	10.95	14.38
1.1	0	13.58	16.54	18.40	0	15.78	19.40
1.2	0	17.63	20.50	22.32	0	20.09	23.88

TABLE 3: Sensitivity analysis with respect to P, β and c.

Example 3: Consider a model with $N = 4$ firms and the following parameters,

$$a = 8, \eta = \frac{1}{6}, \beta = 0.0175, c = 0, F_1 = F_2 = 0.5, y_1 = 52.5, y_2 = 50.$$

Without a price cap the optimal production quantities of the two firms equal $q_n^* = 4$, for $n = 1, \dots, 4$. The equilibrium prices are $p_1(16) = 109.569$ and $p_2(16) = 81.762$ for states 1 and 2, respectively. With a price cap of $P = p_1(16)$ the optimal production quantity decreases by more than 3.5% to $q_n^* = 3.858$.

4 Conclusion

The purpose of this note has been to give an economic explanation for the anecdotal observations that price caps on electric power markets may have led to higher instead of lower prices. Standard oligopoly theory suggests that this is not the case. Price caps result, over the short run, in increased production as long as the price cap is below the marginal cost of production. By taking into account firms' risk aversion, we show how, on the contrary, price caps can result in less production and higher average prices. We have built a simple model of risk-averse oligopolists in a standard Cournot framework to show how price caps can act as a risk limiter for firms. Because at lower quantities of production a price cap constrains the volatility of prices, a firm could be better off by restricting its production and thus lowering its risk. Moreover, the level of the price cap can be above the equilibrium levels obtained without a price cap. As a policy matter, this suggests, as well, that setting a price cap as a guard against some future, yet unrealized price level might backfire and result in higher prices in some circumstances.

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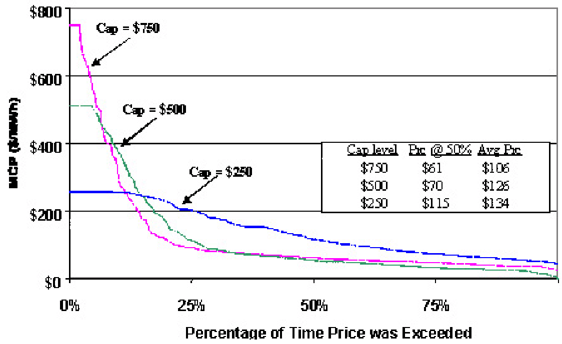

Figure 1. Price caps on California
Electricity Market

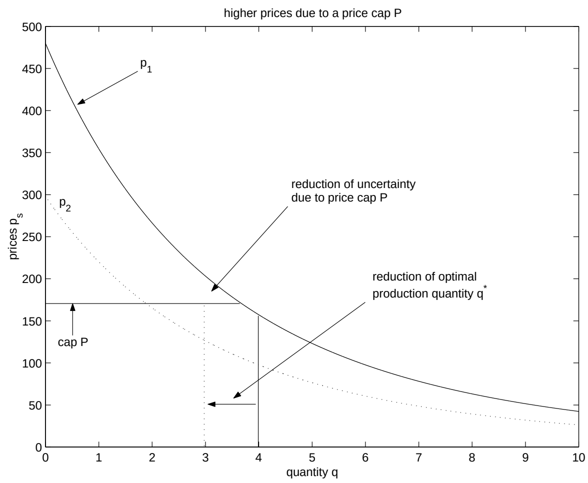

Figure 2. Inverse demand functions

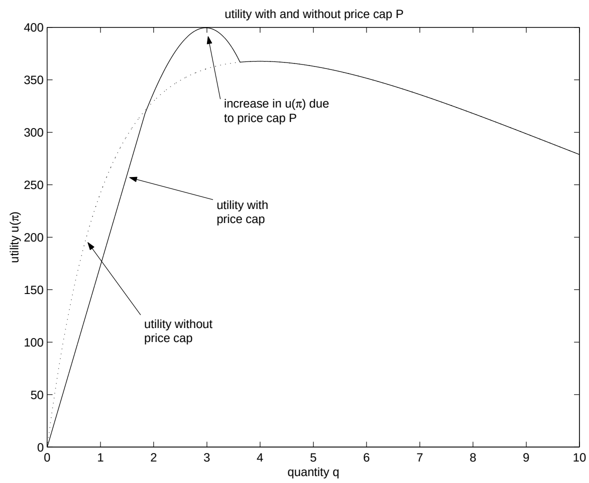

Figure 3. Utility function

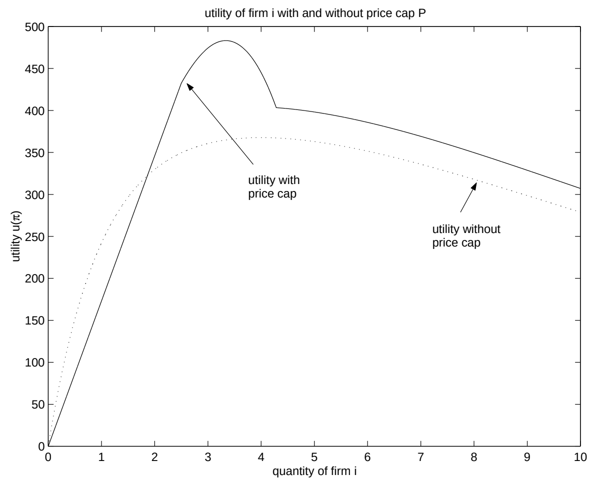

Figure 4. Utility function