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THEORETICAL MODEL OF THE IMPACT OF REGULATION ON THE QUALITY OF SERVICE

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ABSTRACT

It is important to analyze theoretically the comparative static effects of changing parameters of the regulatory regime such as incentive power and time, and to see how the analysis depends on observability of various dimensions of quality. In this paper, we first review the theoretical literature on quality provision by unregulated and regulated monopolies. Then I present a theoretical model that studies how regulation affects quality provision by the firm. Finally, we also draw conclusions.

Keywords: *Quality of Service, Regulation, Impact*

1. INTRODUCTION

There is considerable variation in the power and the structure of incentive plans across states and utilities. This variation likely reflects the fact that states are not in the long-run equilibrium under an optimally designed regulatory plan but rather are experimenting to see what features work and what do not. It is important to analyze theoretically the comparative static effects of changing parameters of the regulatory regime such as incentive power and time, and to see how the analysis depends on observability of various dimensions of quality. In this chapter, I develop a simple theoretical model to analyze these comparative static effects. My analysis complements the existing literature on quality regulation, which focuses on designing the unique optimal plan rather than the effect of moving from one (perhaps suboptimal) plan to another.

I begin this paper by reviewing the theoretical literature on quality provision by unregulated and regulated monopolies. In general the literature agrees that incentive regulation (a high-powered contract) is associated with quality decline. However, when a quality dimension is verifiable and a quality provision (benchmark) can be included in the incentive regulation contract, the regulator may be able to induce the optimal quality level.

In the second part of this paper, I present a theoretical model that studies how regulation affects quality provision by the firm. The interaction between the firm and the regulator is modeled as a Stackelberg game in which the regulator is the leader. I start with a simple one-period contract with one-dimensional quality and then extend it for cases with multidimensional quality and multi-period contracts. I find that quality is increasing in the fine for low quality and decreasing in the power of the incentive scheme. I also find that an investment in quality increases with the discount factor and the power of the contract in the subsequent period.

2. LITERATURE SURVEY

Laffont and Tirole (1993) point out that, while considerable literature exists on the provision of quality by an unregulated monopoly, surprisingly little theoretical research has been devoted to quality issues in the regulated environment.

The subject of monopoly and quality began to appear in the literature in the 1970s. Spence (1975) and Sheshinski (1976) axe the seminal articles in this area. They compare the monopolistic outcome with the socially optimal outcome, and both find that monopoly distorts the optimal quality level.

They find that equilibrium quality may be too high or too low relative to the social optimum, with a number of cases emerging depending on the price elasticity of demand Pq and marginal valuation of quality Pxq. The most relevant case for the electric utility industry involves inelastic demand and Pxq<0. This is the case when the marginal

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consumer values quality less than the average consumer. The most intensive users of electricity are industrial consumers and their evaluation of quality is higher than the evaluation of residential customers. In this case, Spence's results suggest that in the absence of regulation, a profit maximizing monopolist's quality selection would be below the optimal level of quality. Spence also shows that in case when price is fixed, the firm always sets quality too low, because the firm's decision is based only on the marginal profit attached to an increase in quality, and it ignores marginal gains for all inframarginal consumers. Sheshinski (1976) also studies the quality impacts of price regulation and quality regulation on the monopoly's choice of quality. He also finds that, in the case of binding price regulation, introduction of price control always increases the output and decreases the quality produced by the monopoly.

A recent dissertation, Clements (2001), expands Sheshinski's graphical analysis to the case of combined quality and price regulation. Clements shows that introducing binding quality standards results in higher quality than in an unregulated case, because the firm under price regulation sets its quality level too low.

It should be noted that all models mentioned above make the simplifying assumptions that (1) quality is deterministic, and (2) it is observable and verifiable by the regulator and by consumers.

Another strand of the literature started by Mussa and Rosen (1978) and developed by Besanko, Donnefield and White (1987, 1988) relaxes the first assumption and examines a more realistic model. The authors examine the effects of three widely used regulatory policies-minimum quality standards, maximum price regulation and rate of return regulation-using a model in which the monopolist is facing heterogeneous consumers with unobservable varying tastes for quality. They find that in the unregulated equilibrium, the monopolist reduces the quality offered to the groups with lower willingness to pay for quality to achieve the higher profitability of sales to other groups. When minimum quality standards and maximum price regulation are introduced, they force the regulated monopolist either to reduce the price offered to other consumers who prefer high quality goods or to increase the quality for consumers with low willingness to pay for quality. Therefore, both types of regulation raise the quality offered to consumers who prefer low quality goods, reducing the distortions faced by consumers. The authors also show that minimum quality standards dominate other types of regulation as long as the firm continues to serve all consumers after the standards have been imposed. However, this model is not applicable for the electric industry, where in general the quality is uniform for all consumers.

Laffont and Tirole (1986, 1993) and Lewis and Sappington (1991, 1992) apply principal-agent theory to the regulatory framework. They concentrate on the differences between verifiable and unverifiable quality. This approach allows examining the impact of incentive regulation on the quality choice of the regulated firm, taking into account asymmetry of information and the probabilistic nature of quality itself.

Lewis and Sappington (1992) find that optimal regulatory policy depends critically on the regulator's ability to monitor the firm's activities. They also analyze a procurement problem (1991) in which the quality of the delivered product can be observed by the buyer and the supplier, but may not be verifiable, i.e. may not be observed by any third party. They present a set of plausible conditions under which the equilibrium welfare of both buyer and supplier is higher when quality is verifiable than when it is unverifiable. They prove that when quality is verifiable and the buyer has all the bargaining power, he can better motivate the supplier by designing the optimal contract than when quality is unverifiable. Consequently, the cost of producing quality can be reduced relative to the unverifiable case. They also briefly address the possible extensions of their model to cases when quality has many dimensions. In this case the buyer may alter the induced levels of quality for verifiable dimensions in order to motivate the provision of other dimensions of quality that are not verifiable.

Laffont and Tirole (1993) show that the regulation of verifiable quality is formally analogous to the regulation of a multi-product firm, since the level of quality of a given product can be treated as a quantity of another fictitious product. They consider a one-dimensional output x with quality q. The social surplus and production costs are S (x, q) and C(β ,e,x,q), respectively; and where β is the efficiency parameter and e is the managers' effort. The revenue function is R (x,q)= P(x,q)x. The optimal contract is characterized by the following conditions:

$$\frac{p - C_x}{p} = \frac{\lambda}{1+\lambda}\frac{1}{\eta} \quad (1)$$

$$S_q + \lambda P_q x = (1+\lambda)C_q \quad (2)$$

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where λ is the shadow cost of public funds and η is the price elasticity of demand. In line with Spence (1975) and Sheshinski (1976), the last equation states that at the optimum the marginal benefit of quality (Sq) exceeds the marginal cost of quality (Cq) if the marginal consumer values marginal increases of quality less that the average consumer does(Sq/x>Pq).

For the cases of unverifiable quality, Laffont and Tirole (1993) present two sets of models: models with search goods and ones with experience goods.

Search goods models address cases in which quality is observable by consumers but not verifiable by regulators. The authors show that the optimal regulatory scheme can be induced by offering the regulated firm a menu of contracts that are linear in costs and in a quality index. The regulator can separate incentives to supply quality and those to reduce costs because she has two instruments: cost reimbursement rule and sales incentive. However, this result cannot be achieved if demand is inelastic, in which case the quantity is not a good estimate for the quality level. The authors also show that the level of quality is lower under incomplete information than under complete information if quantity and quality are the net complements, which is consistent with the electric industry case.

Experience goods models address the cases that are most relevant for the electric industry, where consumers observe quality only after purchasing. Consistent with the previous literature, Laffont and Tirole (1993) argue that for these models, incentives to supply quality and those to reduce costs are inherently in conflict. They refer to crowding-out effect which implies that the more important quality is, the lower will be the power of the optimal incentive scheme. The only mechanisms that can induce high quality under these conditions are (1) if the buyer (regulator) could develop a reputation for punishing the firm if the firm has supplied low quality and (2) if the buyer could infer information about probability of future trade by observing the current quality level. They concentrate on the second mechanism and look for a socially optimal regulatory scheme, using a two-period model. They find that when quality is important and the discount factor is low, the firm must be given a low-powered incentive scheme.

Another strand of literature that is not directly related to quality but can be applied to quality issues is represented by the seminal papers by Holmstrom and Milgrom (1987, 1991). The authors study a moral hazard model with agent risk aversion rather than adverse selection, focusing on how an agent chooses among different activities (tasks). They find that desirability of providing incentives for any task decreases with the difficulty of measuring performance in any other activities that make competing demand on the agent's time and attention. This result may explain a substantial part of the puzzle why incentive contracts are so much less common than one-dimensional theories would predict. Their analysis implies that if some dimensions of quality are not verifiable, then setting benchmarks for other dimensions may induce the agent to substitute resources away from unverifiable dimensions to verifiable ones. In a regulatory example, if the two tasks under consideration are cost reduction and quality provision, incentive regulation can undermine quality and result in crowding-out effect, because some dimensions of quality are unverifiable and high-powered contracts create more incentives for cost cuts This point is related to similar points raised by Lewis and Sappington (1991) and Laffont and Tirole (1993) mentioned above.

It should be noted, that aforementioned models examine quality provision under the socially optimal contract, implemented as a menu of linear contracts. While the social optimum may be the ideal that regulators converge to in the long run, in the short run, the regulators may experiment with various regulatory regimes, learning about their properties through experience. In this case, it is a useful comparative statics exercise to examine the effects of exogenously-given incentive regulation regimes, ranging in power from cost-plus to price caps. In the next section I develop a simple model that allows studying the effects of the power of an incentive contract, its structure and duration on the quality provision by a regulated firm.

3. THE THEORETICAL MODEL

Since the power of incentive plans, as well as the set of quality benchmarks (if any) established by regulators, differ considerably across utilities, it is important to design a model which will allow us to study how the regulated firm's investment in quality depends on the power of the incentive contract, and what the firm's choices are if some dimensions of quality are non-verifiable

The model described below is closest to Laffont and Tirole (1993:pp 227-231). While Laffont and Tirole have two periods and the second period contracting depends on the quality in the first period

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(i.e., the firm will not be asked to produce in the second period if the first period product has low quality), I make an assumption somewhat more realistic for the electric industry, that by the end of the period the regulator can issue a penalty to the firm for low quality if quality is verifiable. The focus of my analysis is different as well: I study the comparative statics effect of moving from one regulatory regime to another rather than focusing on the uniquely optimal one.

3.1 Description of the Model

The regulated firm produces for the buyer (regulator) one unit of goods at cost

$$C = \beta + q - e$$

Where $\beta = [\underline{\beta}, \overline{\beta}]$ is an efficiency parameter of the firm, q is the level of "care" about quality or investment in quality, and a is the level of cost reducing effort that the firm chooses. Parameters β, q, e are private information for the firm. Effort a involves a disutility $\psi(e)$, with $\psi' > 0$, $\psi'' > 0$, $\psi''' \geq 0$. Let q^* denote a quality benchmark in the incentive regulation contract. The regulator observes quality $\hat{q}$, a noisy signal of the quality q. With probability $\pi(q) \in [0,1]$, $\hat{q} \geq q^*$ and the quality is viewed as acceptable; with probability $1 - \pi(q) \hat{q} < q^*$ the quality is viewed to be below acceptable level. It is assumed $\pi' > 0, \pi'' < 0, \pi''' \leq 0$. The regulation only observes cost C and $\hat{q}$, and cannot observe β, e, or q. Both the firm and the lator are risk neutral.

The interaction between the firm and the regulator is modeled as a Stackelberg game in which the regulator is the leader. At the first stage the regulator offers the firm the linear contract:

$$T(C,q) = \begin{cases} a - bC & \text{if } \hat{q} \geq q^* \\ a - bC - F & \text{if } \hat{q} < q^* \end{cases} \quad (3)$$

where a is the fixed payment and $b \in [0,1]$ is the degree of cost sharing. The extreme cases when b=1 and b=0 correspond to fixed price (price cap) and cost plus regulation. F is the fine in case of low (unsatisfactory) quality($\hat{q} < q^*$). Note that F can be also viewed as a degree of observability (i.e., if F=0, quality is non-observable). In the second stage, the firm accepts or rejects contract. If the firm accepts the contract and chooses $\{e, q\}$, the firm's utility function is.

$$U = a - bC - F[1 - \pi(q)] - \psi(e)$$

At the third stage, the regulator observes the level of quality $\hat{q}$ and cost C, and pays the firm according to condition (3).

The firm's utility maximization with respect to the choice variables q and e generates the following first order conditions:

$$\psi'(e) = b \quad (4)$$

$$\pi'(q)F = b \quad (5)$$

The second order conditions are satisfied since $F\pi'' < 0$ and $F\pi''\psi'' > 0$. The first equation states that marginal disutility of efforts is equal to marginal cost savings for the firm. A fixed price contract (b=1) induces the highest level of cost reducing efforts $\psi'(\overline{e}) = 1$, while the cost-plus contract induces the minimum level of effort $\psi'(\underline{e}) = 0$. The second equation states that the marginal cost increase associated care is equal to the marginal change in expected punishment.

Proposition 1. Quality is increasing with the fine F for low quality and decreasing with the power of the incentive scheme b. If the regulator chooses a more powerful contract (high level of b), a more severe punishment must be used to induce the same level of quality.

Proof: Totally differentiating the first order condition (5) with respect to the severity of the fine F and rearranging yields:

$$\frac{dq}{dF} = -\frac{b}{F^2 \pi''} > 0$$

Totally differentiating the first order condition (5) with respect to the power of incentive contract b yields

$$\frac{dq}{db} = \frac{1}{F\pi''} < 0$$

Q.E.D

3.2 Mufti-Dimensional Quality

Let quality be multidimensional, i.e. $q = (q_1, q_2 \cdots, q_n)$. Total cost and utility functions of the regulated firm are

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$$C = \beta + \sum_{i=1}^{n} q_i - e$$

$$U = a - bC - \sum_{i=1}^{n} F_i (1 - \pi^i) - \psi(e)$$

where F_i is a punishment (fine) for the quality dimension $\pi^i(q_1, q_2 \cdots, q_n)$ is the probability that the observed value $\hat{q}_i$ of quality dimension i is higher than its benchmark level $q_i{}^*$. Assume that π^i is increasing and concave in own quality level: $\pi_i{}^i > 0$ and $\pi_{ii}{}^i < 0$, where subscripts denote partial derivatives. Concerning cross partials, we will say q_i and q_j , $j \neq i$, are complements if $\pi_{j \neq i}{}^i > 0$, substitutes if $\pi_{j \neq i}{}^i < 0$, and independent if $\pi_j{}^i = 0$. We also assume $\pi_{ji}{}^i = 0$

The firm's utility maximization with respect to q_i , $i = 1, 2, \cdots, n$ yields the set of first order conditions:

$$q_i : \pi_i^i = \frac{b}{F_i} - \frac{1}{F_i} \sum_{j=1, j \neq i}^{n} F_j \pi_j{}^i \qquad (6)$$

Second order conditions are satisfied since the matrix $\begin{bmatrix} \pi_{11}^1 & \pi_{12}^1 & \cdots & \pi_{1n}^1 \\ \pi_{21}^2 & \pi_{22}^2 & \cdots & \pi_{2n}^2 \\ \cdots & \cdots & \cdots & \cdots \\ \pi_{n1}^n & \pi_{n2}^n & \cdots & \pi_{nn}^n \end{bmatrix}$ is a diagonal matrix with all diagonal elements less than zero, implying that all principal minors of order k have $(-\hat{1})^k$, for all $k = 1, 2, \cdots, n$, n

Proposition 2. If investments q_i and q_k are complements, then increasing the contractual punishment F_k for shortfalls in quality q_k induce a higher level of care for q_i.

Proof: Totally differentiating the first-order conditions (6) with respect to F_k yields:

$$\frac{\partial q_i}{\partial F_k} = -\frac{\pi_i{}^k}{F_i \pi_{ii}{}^i} > 0$$

Where $\pi_J{}^K > 0$ since q_i and q_k are complements. Q.ED.

In line with findings by Holmstrom and Milgrom (1991) and Lewis and Sappington (1991), Proposition 2 implies that it may be beneficial for the regulator to adjust the structure of fines to account for complementarity (substitutability) among different dimensions of quality. It also follows from Proposition 2 that designing the structure of punishment even for the verifiable dimensions of quality the regulator should be aware about the correlations between these dimensions, i.e., let us assume that the regulator specifies a fine for high levels of System Average Interruption Frequency Index (SAIFI), but does not set a benchmark for System Average Interruption Duration Index (SAIDI). These two dimensions of quality may be either complements and substitutes. The utility then may invest more in equipment to lessen the frequency of outages but reduce the size of its staffthat responds to outages and restores the system. As a result, the number of outages may be reduced but duration may increase.

Another important aspect of an incentive regulation contract is the contract duration. It is worth examining how the investment in quality can be adjusted over time depending on contract duration.

3.2 Mufti-Period Quality

In practice, contracts implementing regulation are specified for a specific period of time, usually more than one year. In this subsection I expand the basic model into multi-period case. In particular, I will analyze a two-period model, where in the first period the firm is offered an incentive contract with parameters (a_1, b_1, F) . The firm also learns the parameters of the regulatory contract for the subsequent period (a_2, b_2, F) . It is interesting tol examine how the firm's investment in quality in the first period depends on the time discount factor and the anticipated power of the incentive contract in the next period. We assume that a benchmark for quality $q = q^*$ and a punishment F remain constant, but the utility chooses a quality $q_i (i = 1, 2)$ for each period independently. In addition, we assume that the probability $\hat{q}_i \geq q^*$ for each period i depends on quality choices in the current and preceding period(if any), i.e. $\pi^1(q_1)$ and $\pi^2(q_1, q_2)$. Assume $\pi_1{}^2 > 0$ implying that investment in quality

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in the previous period has a positive effect on probability of high quality today. We also assume the marginal productivity of investment in the second period is falling with the investment in the first period $\pi_{12}{}^2 < 0$ and $\pi_{11}{}^2 = 0$. To insure the second order conditions hold, we also assume that

$$\pi_{11}{}^1\pi_{22}{}^2 - \delta(\pi^2{}_{12})^2 > 0$$

In each period the firm's cost function is

$$C_i = \beta + q_i - e$$

Assume that e and β do not change through time. The firm's utility function for a time period t is

$$U_i = a_i - b_i C - F(1-\pi^i) - \psi(e)$$

The present discounted value of the stream of the firm's instantaneous utilities is

$$U = U_1 + \delta U_2$$

where δ is a time discount factor. The firm's utility maximization with respect to q_1 and q_2 yields the following first order conditions:

$$F(\pi_1{}^1 + \delta\pi_1{}^2) = b_1 \quad (7)$$

$$F\pi_2{}^2 = b_2 \quad (8)$$

The second-order conditions hold since $\pi_{11}{}^1\pi_{22}{}^2 - \delta(\pi^2{}_{12})^2 > 0$.

It can be shown that an investment in quality in the first period q, increases with the discount factor 8. Totally differentiating the first order conditions with respect to a and rearranging yields

$$\frac{\partial q_1}{\partial \delta} = -\frac{\delta\pi_1{}^2\pi_{22}{}^2}{\pi_{11}{}^1\pi_{22}{}^2 - \delta(\pi^2{}_{12})^2} > 0$$

Since $\pi_{11}{}^1\pi_{22}{}^2 - \delta(\pi^2{}_{12})^2 > 0$, $\pi_1{}^2 > 0$ and $\pi_{22}{}^2 < 0$

Proposition 3. The firm's investment in quality increases with the power of the incentive contract in the subsequent period.

Totally differentiating (7) and (8) with respect to b_2 yields:

$$\pi_{11}{}^1\frac{\partial q_1}{\partial b_2} + \delta\pi^2{}_{12}\frac{\partial q_2}{\partial b_2} = 0$$

$$\pi_{22}{}^2\frac{\partial q_2}{\partial b_2} + \pi^2{}_{12}\frac{\partial q_1}{\partial b_2} = \frac{1}{F}$$

$$\frac{\partial q_1}{\partial b_2} = -\frac{\delta\pi^2{}_{12}}{\pi_{11}{}^1\pi_{22}{}^2 - \delta(\pi^2{}_{12})^2} > 0$$

Rearranging and substituting for $\frac{\partial q_2}{\partial b_2}$ we obtain since $\pi_{11}{}^1\pi_{22}{}^2 - \delta(\pi^2{}_{12})^2 > 0$ and $\pi^2{}_{12} < 0$. Q.E.D.

Basically, Proposition 3 implies that if the utility anticipates a reduction in the power of an incentive contact (for example, the utility has a price cap contract in the first period and expects a cost-plus contract in the second), it would invest less in quality in the current period, because in the subsequent period its investment in quality would be subsidized. This conclusion is rather intuitive given that the power of an incentive contract in this model is assumed to be exogenous. The main policy implication from Proposition 3 is that the longer commitment under a high-powered incentive contract can lead to the quality gains, if quality can be explicitly specified in the incentive contract. In addition, the regulator can induce a higher investment in subsequent periods, if the fine F is increasing through time, or, more realistically, the benchmark q^* is being adjusted through the period of the contract allowing for productivity gains, similar to the rate adjustments in price cap regulation.

4. CONCLUSIONS

Despite its simplicity, the model developed above yields some new insight into a firm's quality choices in a regulated environment. The analysis shows that the firm's care about quality is decreasing with the power of the regulation contract, but it is increasing in the fine associated with lower quality. In case of multi-period contracts, the firm's investment in quality is increasing with the discount factor and the anticipated increase in the power of the incentive contract in the subsequent period.

For multidimensional quality, in case all dimensions of quality can be specified in the contract, the regulator can achieve the desired levels of quality by experimenting with the structure of fines (Fl…Fn). If some dimensions of quality are not verifiable, but they are also correlated with

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verifiable dimensions, the regulator should adjust the vector of fines to account for possible complementarities between verifiable and unverifiable dimensions. This adjustment becomes more important if a high-powered regulatory scheme is used.

It is worth noting that the distinction between verifiable and unverifiable dimensions of quality is extreme. In general, one can allow quality to be verifiable at a cost. If a particular dimension is not very important, then it can be affected by changing the fines for other complimentary verifiable dimensions. With technological progress this dimension may become more important (or the cost of measuring may decrease), and the regulator may choose to require the regulated utility to measure and report this dimension, and then set a standard and a corresponding fine. A good example is the momentary average interruption frequency index, MAIFI, defined as outages of less than five minutes duration. These interruptions (if not measured directly) can be mitigated by setting more stringent standards for other outage-related indexes, SAIDI and SAIFI, because of some complementarity among these dimensions of quality. However, the increasing reliance on digital equipment, which is relatively sensitive to power interruptions, raises importance of MAIFI to consumers. It may explain why MAIFI, that had not been monitored until recently, is now being monitored for 22 percent of utilities in the U.S., and is included in calculations of performance benchmarks in six states .

The general conclusion that can be drawn from the model is that incentive regulation (high powered contracts) may reduce quality if the fine for low quality is not specified or is too low.

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