Monopoly Regulation in the Presence of Consumer Demand-Reduction∗

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I study a monopoly regulation in the setting where consumers can engage in demand-reducing investments. I first show that, when the regulator ignores the buyers' investments, the excess investment occurs. Next, I analyze the case where the regulator takes consumers' investments into account and compare the optimal policy under asymmetric information with the first-best policy. Optimal policy results in higher average price, higher level of consumer investment, but lower prices for efficient firms, compared to the first-best.
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1. Introduction

In utility sectors, consumers often save the demand by engaging in some investments. For example, household can use of looftop solar energies or introduce of electricity-efficient consumer electronics to reduce the demand for electricity. Business enterprises also engage in energy-saving investments in the face of various environmental regulations.[1] Such demand-saving activities often have important effects on the rate-setting of the regulated firms. As reviewed by Costello and Hemphill (2014), the consequence of such an interaction between rate-setting and demand-reduction is sometimes called as "death-spiral", the situation where a high rate leads to demand-reducing investments, which damages the utility's financial viability and requires even higher rates to break even. The aim of this paper is to study the design of optimal regulatory mechanisms in the face of such demand-reducing activities.

Specifically, I study the model of optimal monopoly regulation á la Laffont and Tirole (1993), in the setting where consumers can engage in demand-reducing investments.

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[1]See Matsumura and Yamagishi (2017) for the examples of such investments.

I first consider the case where the regulatory mechanism is designed ignoring the consumers' investments. In this case, the resulting level of investments is too high in terms of aggregate welfare. Thus, the optimal mechanism should be designed so as to limit the consumers' investments. This result is consistent with the view that to deal with the problem of death-spiral, the rate should be set at a lower level. Next, I proceed to the analysis of optimal regulation policy explicitly taking the consumers' investments into account and study the effects of asymmetric information between regulator and monopolist on the optimal policy. I show that the presence of asymmetric information results in the higher average price than the first best, which leads to the higher level of buyers' investments. Thus, the presence of asymmetric information exacerbates the problem of excess investments. Finally, I show that the regulated prices for the most efficient monopolists under asymmetric information are set below the first best levels. This result contrasts with the standard "no distortion at the top" principle that the regulated price for the most efficient types corresponds with the first best. These results would provide some theoretical guidance for policy design in utility sectors subject to a demand-reducing investments, such as gas and electricity.

2. Model

I consider the model of monopoly regulation á la Laffont and Tirole (1993), where a continuum of consumers can engage in demand-reducing investments. I set the primitives of the model below.

Consumers Consumers derive the utility $S_x(q) - pq - \psi x$, where q is the amount of purchase, p is the unit price of the good, $x \in \{0, 1\}$ is the variable that indicates whether a buyer engages in an investment, $\psi \in [0, \Psi]$ is the heterogeneous investment cost. I assume that ψ is distributed according to a strictly increasing smooth distribution function G with the density function g. I also assume that S_1 and S_2 satisfy; (i) $S_x' > 0$ for $x = 0, 1$, (ii) $S_x'' < 0$ for $x = 0, 1$, and (iii) $S_1' < S_0'$. The first two properties guarantee that the demand function is downward sloping, and the last assumption guarantees that the investment decision ($x = 1$) reduces the demand. Given the investment decision x, the first-order condition

$$S_x'(q) - p = 0 \tag{1}$$

yields the demand function $D_x(p)$ and the corresponding indirect utility function $V_x(p) = S_x(D_x(p)) - pD_x(p)$. Note that $V_x'(p) = -D_x(p)$.

Monopolist The monopolist incurs a constant marginal cost $\beta \in [\beta_L, \beta_H]$ and a fixed cost K of production. Thus, the profit of the monopolist at a price level p and the sales q is given by

$$(p - \beta)q - K. \tag{2}$$

β is privately known by the monopolist and distributed according to the strictly increasing smooth distribution function F with the density function f. I assume that the function F/f is increasing.

Regulator The regulator can offer a menu $(p(\beta), s(\beta))$ of contracts that specifies the price p and the amount of subsidy s. I assume that the subsidy is costly due to shadow cost of public funds λ.

Let $x(\psi)$ be the investment decision of a consumer with investment cost ψ. Then the aggregate welfare with the price p, the subsidy s, and the marginal cost β is given by the sum of consumer surplus, producer surplus, and the welfare loss from subsidy:

$$\begin{aligned} &\mathbb{E}_\psi \left[S_{x(\psi)}(D_{x(\psi)}(p)) - pD_{x(\psi)}(p) - x(\psi)\psi\right] + (p-\beta)\mathbb{E}_\psi\left[D_{x(\psi)}(p)\right] - K - \lambda s. \\ =&\mathbb{E}_\psi\left[S_{x(\psi)}(D_{x(\psi)}(p)) - x(\psi)\psi - \beta D_{x(\psi)}(p)\right] - K - \lambda s. \end{aligned} \tag{3}$$

Timing The timing of this game is as follows:

1. The regulator offers a menu $(p(\beta), s(\beta))$ of contracts.
2. Consumers decide whether to engage in demand-reducing investments. At the same time, monopolist observes β and choose the contract $(p(\beta'), s(\beta'))$ that maximizes his profit.
3. Given the price $p(\beta')$ consumers choose the amount of purchase.

Here I assume that the regulator chooses the policy before the consumers engage in investments. This may be unrealistic in several situations where the investment decision takes a longer time than the regulatory decision. Even if a fraction of consumer investments are allowed to take place before the investment decision, the qualitative results are unchanged if at least there is some fraction of investment decisions which take place after the regulatory decision. Our analysis can also be seen as a normative one on how the regulator should design the policy when she can commit to a long-run policy.

3. Optimal Regulation

In this section, I study the optimal regulation under three scenarios: (i) complete information with exogenous investments, (ii) complete information with endogenous investments, and (iii) asymmetric information with endogenous investments. In the course of analysis, I study how the presence of demand-reducing investments affects the aggregate welfare and interacts with the asymmetric information.

To this end, I first consider how the consumers make investment decisions. Suppose that the monopolist with type β it regulated to set the price $p(\beta)$. Then the expected surplus is $E_\beta[V_x(p(\beta))]$ if the investment decision is x. Thus, a buyer with investment cost ψ chooses $x = 1$ if and only if $\psi \leq \bar{\psi}$, where

$$\bar{\psi} := E_\beta[V_1(p(\beta))] - E_\beta[V_0(p(\beta))]. \tag{4}$$

Let $\tilde{\psi}(\psi') := \mathbb{E}_\psi[\psi | \psi \leq \psi']$. Then, the expected aggregate welfare under $(p(\beta), s(\beta))$ can be written as

$$\begin{aligned} \mathbb{E}_\beta\Big[&G(\bar{\psi})[S_1(D_1(p(\beta))) - \beta D_0(p(\beta)) - \tilde{\psi}(\bar{\psi})] \\ &+ [1 - G(\bar{\psi})][S_0(D_0(p(\beta))) - \beta D_0(p(\beta))] - K - \lambda s(\beta)\Big]. \end{aligned} \tag{5}$$

3.1. Benchmark: Complete Information with Exogenous Investments

As a first benchmark, consider the setting where there is no asymmetric information between the monopolist and the regulator, and the regulator takes the consumers' investments as given.

In this setting, the regulator only needs to satisfy the participation constraint:

$$(p(\beta) - \beta)\Big(G(\bar{\psi})D_1(p(\beta)) + [1 - G(\bar{\psi})]D_0(p(\beta))\Big) - K + s(\beta) \geq 0. \tag{6}$$

Since the subsidy is costly, the regulator sets

$$s(\beta) = K - (p(\beta) - \beta)\Big(G(\bar{\psi})D_1(p(\beta)) + [1 - G(\bar{\psi})]D_0(p(\beta))\Big).$$

As a result, the aggregate welfare is rewritten as

$$\begin{aligned}\mathbb{E}_\beta\Big[&G(\bar{\psi})[S_1(D_1(p(\beta))) + [\lambda p(\beta) - (1+\lambda)\beta]D_0(p(\beta)) - \tilde{\psi}(\bar{\psi})] \\ &+ [1 - G(\bar{\psi})][S_0(D_0(p(\beta))) + [\lambda p(\beta) - (1+\lambda)\beta]D_0(p(\beta))] - (1+\lambda)K\Big].\end{aligned} \tag{7}$$

In this case, the optimal price schedule $p(\cdot)$ is obtained by maximizing the objective function with respect to $p(\beta)$ for each β. The first-order condition for $p(\beta)$ is

$$\begin{aligned}&G(\bar{\psi})\left[D_1'(p(\beta))\Big((1+\lambda)p(\beta) - (1+\lambda)\beta\Big) + \lambda D_1(p(\beta))\right] \\ &+[1 - G(\bar{\psi})]\left[D_0'(p(\beta))\Big((1+\lambda)p(\beta) - (1+\lambda)\beta\Big) + \lambda D^0(p(\beta))\right] = 0,\end{aligned} \tag{8}$$

which is rearranged to

$$\frac{p(\beta) - \beta}{p(\beta)} = \frac{\lambda}{1+\lambda}\frac{1}{\eta(p(\beta), \bar{\psi})}, \tag{9}$$

where

$$\eta(p, \bar{\psi}) := -\frac{G(\bar{\psi})D_1'(p) + [1 - G(\bar{\psi})]D_0'(p)}{G(\bar{\psi})D_1(p) + [1 - G(\bar{\psi})]D_0(p)}p > 0 \tag{10}$$

is the price elasticity of demand. This is the standard Lerner formula obtained in the models of monopoly regulation with a cost of public funds.

Now consider the welfare consequence of buyer investments. Let $\bar{\psi}$ be determined by the condition (4) and let $\bar{\psi}$ slightly increase from the equilibrium level. After some algebra, its effect on the welfare can be written as

$$\begin{aligned}&g(\bar{\psi})\mathbb{E}_\beta\left[((1+\lambda)p(\beta) - (1+\lambda)\beta)\left[D^1(p(\beta)) - D^0(p(\beta))\right]\right] \\ =&g(\bar{\psi})\mathbb{E}_\beta\left[\lambda\frac{D_1(p(\beta)) - D_0(p(\beta))}{\eta(p(\beta), \bar{\psi})}\right] < 0.\end{aligned} \tag{11}$$

This immediately implies the following proposition.

Proposition 1. *Under the complete information, if the regulator sets the policy taking the consumers' investments as given, the amount of the investments is too high in terms of social welfare.*

This proposition gives an implication that the optimal regulation should be designed so as to keep consumers from engaging in too many investments. With this proposition in mind, let me proceed to the analysis of optimal regulation in the presence of consumers' investments.

3.2. Regulation under Complete Information

In this subsection, I let the regulator take the consumers' investment into account, maintaining the complete information assumption.

The problem of the regulator is to maximize

$$\mathbb{E}_\beta\Bigg[G(\bar{\psi})[S_1(D_1(p(\beta))) + [\lambda p(\beta) - (1+\lambda)\beta]D_0(p(\beta)) - \tilde{\psi}(\bar{\psi})] \\ + [1-G(\bar{\psi})][S_0(D_0(p(\beta))) + [\lambda p(\beta) - (1+\lambda)\beta]D_0(p(\beta))] - (1+\lambda)K\Bigg]. \tag{12}$$

subject to equation (4).

Let μ^* be the Lagrangian multiplier to the constraint (4). Then, the first-order condition can be written as

$$g(\bar{\psi})\mathbb{E}_\beta\left[((1+\lambda)p(\beta) - (1+\lambda)\beta)\left[D^1(p(\beta)) - D^0(p(\beta))\right]\right] + \mu^* = 0, \tag{13}$$

$$G(\bar{\psi})\left[D_1'\left((1+\lambda)p(\beta) - (1+\lambda)\beta\right) + \lambda D_1(p(\beta))\right] \\ +[1-G(\bar{\psi})]\left[D_0'\left((1+\lambda)p(\beta) - (1+\lambda)\beta\right) + \lambda D_0(p(\beta))\right] + \mu^*\left[D_1(p(\beta)) - D_0(p(\beta))\right] = 0, \tag{14}$$

and (4). Putting them together, the equilibrium price schedule $p(\beta)$ satisfies

$$\frac{p(\beta)-\beta}{p(\beta)} = \underbrace{\frac{\lambda}{1+\lambda}\frac{1}{\eta(p(\beta),\bar{\psi})}}_{\text{Standard inverse elasticity}} \\ + \underbrace{\left(\frac{D_1(p(\beta)) - D_0(p(\beta))}{p(\beta)\left(\frac{G(\bar{\psi})}{g(\bar{\psi})}D_1'(p(\beta)) + \frac{1-G(\bar{\psi})}{g(\bar{\psi})}D_0'(p(\beta))\right)}\right)\mathbb{E}_\beta\left[(p(\beta)-\beta)\left[D_1(p(\beta)) - D_0(p(\beta))\right]\right]}_{\text{Investment reduction term}} \tag{15}$$

The investment reduction term in the equation (15) is negative as long as prices are not below marginal cost. In this case, as mentioned in the previous subsection, the optimal regulated price should be lowered so that the buyers' investments are reduced. Let $p^*(\cdot)$ and $\bar{\psi}^*$ be the price schedule and the corresponding threshold consumer in the optimal regulatory mechanism under complete information.

3.3. Regulation under Asymmetric Information

In this subsection, I solve the regulator's problem taking the information asymmetry into account.[2] The regulator needs to set the menu of contracts so as to satisfy the incentive compatibility constraints:

$$\beta = \arg\max_{\beta'}(p(\beta') - \beta)\Big(G(\bar{\psi})D_1(p(\beta')) + [1-G(\bar{\psi})]D_0(p(\beta'))\Big) - K + s(\beta'). \tag{16}$$

[2]For the detail of each derivation step, see Laffont and Tirole (1993) Chapter 2

Thus, the envelope theorem yields the following:

$$s(\beta) = (p(\beta_H) - \beta_H)q(\beta_H, \bar{\psi}) - K + s(\beta_H) - (p(\beta) - \beta)q(\beta, \bar{\psi}) + K + \int_{\beta}^{\beta_H} q(y, \bar{\psi})dy, \quad (17)$$

where $q(\beta, \bar{\psi}) := \Big(G(\bar{\psi})D_1(p(\beta)) + [1 - G(\bar{\psi})]D_0(p(\beta)) \Big)$.

As standard in the literature, $s(\beta_H) = K - (p(\beta_H) - \beta_H)q(\beta_H, \bar{\psi})$ so that the participation constraint for the most inefficient monopolist binds since the rent is costly.

A standard integral-by-parts manipulation yields the following expression:

$$\mathbb{E}_{\beta}[s(\beta)] = \mathbb{E}_{\beta}\left[-\left(p(\beta) - \beta - \frac{F(\beta)}{f(\beta)} \right) q(\beta) + K \right]. \quad (18)$$

Thus, the expected welfare can finally be written as

$$\mathbb{E}_{\beta}\Bigg[G(\bar{\psi}) \left[S_1(D_1(p(\beta))) + \left(\lambda p(\beta) - (1+\lambda)\beta - \lambda \frac{F(\beta)}{f(\beta)} \right) D_1(p(\beta)) \right]$$
$$+ (1 - G(\bar{\psi})) \left[S_0(D_0(p(\beta))) + \left(\lambda p(\beta) - (1+\lambda)\beta - \lambda \frac{F(\beta)}{f(\beta)} \right) D_0(p(\beta)) \right] - (1+\lambda)K - G(\bar{\psi})\tilde{\psi}(\bar{\psi}) \Bigg]. \quad (19)$$

Let μ^{**} be the Lagrangian multiplier for the constraint (4). Then the first-order condition analogous to that under complete information is obtained:

$$g(\bar{\psi})\mathbb{E}_{\beta}\left[\left((1+\lambda)p(\beta) - (1+\lambda)\beta - \lambda \frac{F(\beta)}{f(\beta)} \right) [D_1(p(\beta)) - D_0(p(\beta))] \right] + \mu^{**} = 0 \quad (20)$$

and

$$G(\bar{\psi}) \left[D_1' \left((1+\lambda)p(\beta) - (1+\lambda)\beta - \lambda \frac{F(\beta)}{f(\beta)} \right) + \lambda D_1(p(\beta)) \right]$$
$$+ [1 - G(\bar{\psi})] \left[D_0' \left((1+\lambda)p(\beta) - (1+\lambda)\beta - \lambda \frac{F(\beta)}{f(\beta)} \right) + \lambda D_0(p(\beta)) \right] + \mu^{**} [D_1(p(\beta)) - D_0(p(\beta))] = 0 \quad (21)$$

Thus, a similar condition for the equilibrium price schedule $p(\cdot)$ is obtained as follows:

$$\frac{p(\beta) - \beta - \frac{\lambda}{1+\lambda}\frac{F(\beta)}{f(\beta)}}{p(\beta)} = \underbrace{\frac{\lambda}{1+\lambda}\frac{1}{\eta(p(\beta), \bar{\psi})}}_{\text{Standard inverse elasticity}}$$
$$\underbrace{+ \left(\frac{D_1(p(\beta)) - D_0(p(\beta))}{p(\beta)\left(\frac{G(\bar{\psi})}{g(\bar{\psi})} D_1'(p(\beta)) + \frac{1-G(\bar{\psi})}{g(\bar{\psi})} D_0'(p(\beta)) \right)} \right) \mathbb{E}_{\beta}\left[\left(p(\beta) - \beta - \frac{\lambda}{1+\lambda}\frac{F(\beta)}{f(\beta)} \right) [D_1(p(\beta)) - D_0(p(\beta))] \right]}_{\text{Investment reduction term}}. \quad (22)$$

3.4. Comparison

I have derived the conditions for the optimal regulation policies under complete and incomplete information. These conditions, however, do not give us clear-cut results on how the information asymmetry and the buyer investment interacts. Thus, I adopt linear-quadratic preference and uniform distribution specification do obtain a good intuition about the feature of optimal regulation policies.

Specifically, let $S(q,x) = Bx + aq - \frac{b}{2}(\theta x + q)^2$. Then $D^x(p) = \frac{a-p}{b} - \theta x$, $V_x(p) = \frac{(a-p)^2}{2b} - (a-p)\theta x + Bx$, and $\bar{\psi} = B - \theta \mathbb{E}_\beta[a - p(\beta)]$. Further, let ψ be distributed according to a uniform distribution, i.e., $G(\psi) = \psi/\Psi$.

Let $m^* := \mathbb{E}_\beta[p^*(\beta)]$ and $m^{**} := \mathbb{E}_\beta[p^{**}(\beta)]$. Then, the equilibrium conditions (15) and (22) for the regulation policies under complete and asymmetric information are given by

$$\frac{1+\frac{\lambda}{1+\lambda}}{b} p^*(\beta) - \frac{\beta}{b} - \frac{\lambda}{1+\lambda}\left(\frac{a}{b} - \bar{\psi}^*\theta\right) + \frac{\theta^2}{\Psi}(m^* - \mathbb{E}[\beta]) = 0. \tag{23}$$

and

$$\frac{1+\frac{\lambda}{1+\lambda}}{b} p^{**}(\beta) - \frac{1}{b}\left(\beta + \frac{F(\beta)}{f(\beta)}\right) - \frac{\lambda}{1+\lambda}\left(\frac{a}{b} - \bar{\psi}^{**}\theta\right) + \frac{\theta^2}{\Psi}\left(m^{**} - \mathbb{E}[\beta] - \mathbb{E}\left[\frac{F(\beta)}{f(\beta)}\right]\right) = 0. \tag{24}$$

Comparing these two equations, the following proposition is obtained:

Proposition 2. *The average regulated price is higher under the asymmetric information than the first-best level. That is, $m^{**} > m^*$. The equilibrium consumer investment is also higher under asymmetric information. That is, $\bar{\psi}^{**} > \bar{\psi}^*$.*

Proof. See Appendix. □

This result is straightforward. Since the asymmetric information generates information rent, the regulator has incentive to increase prices so as to reduce the rent given up to the monopolist. This incentive directly leads to the first statement of the proposition. As a result, the fraction of consumers who invest in demand-reducing activities increases, which is the second statement of the proposition.

As expected, the demand reduction due to the asymmetric information generates a downward pricing pressure on the regulator. The next proposition shows that for efficient firms, this downward effect dominates the upward effects of asymmetric information.

Proposition 3. *Under the asymmetric information, the optimal pricing for the most efficient type is lower than the first-best, i.e., $p^{**}(\beta_L) < p^*(\beta_L)$.*

Proof. See Appendix. □

The intuition behind this result can be understood by combining Proposition 2 and the famous “no distortion at the top" principle. As shown in Proposition 2, the presence of asymmetric information generates the upward pricing distortions on average. Expecting this distortion, more buyers engage in demand-reducing investments, which results in a weaker demand and higher threshold investment cost. These changes generate a downward pricing pressure to the regulator. Since there is no informational distortion for the most efficient types (no distortion at the top), this downward effect dominates for the efficient firms.

A. Appendix

Proof of Proposition 2 Suppose to the contrary that $m^* > m^{**}$. Then, we have $\bar{\psi}^* > \bar{\psi}^{**}$ since $\bar{\psi}^i = B - \theta a + \theta m^i$ for $i \in \{*, **\}$. Putting equations (23) and (24) together, we have

$$\frac{1 + \frac{\lambda}{1+\lambda}}{b} \left(p^{**}(\beta) - p^*(\beta)\right) - \frac{1}{b}\frac{F(\beta)}{f(\beta)} - \frac{\lambda}{1+\lambda}\theta\left(\bar{\psi}^* - \bar{\psi}^{**}\right) - \frac{\theta^2}{\Psi}\left(m^* - m^{**} + \mathbb{E}\left[\frac{F(\beta)}{f(\beta)}\right]\right) = 0 \tag{25}$$

This implies that $p^{**}(\beta) > p^*(\beta)$ for all β, which implies that $m^{**} > m^*$, a contradiction. Thus, we must have $m^{**} > m^*$ and $\bar{\psi}^{**} > \bar{\psi}^*$.

Proof of Proposition 3 Since $F(\beta_L)/f(\beta_L) = 0$, we have

$$\frac{1 + \frac{\lambda}{1+\lambda}}{b} \left(p^{**}(\beta_L) - p^*(\beta_L)\right) - \frac{\lambda}{1+\lambda}\theta\left(\bar{\psi}^* - \bar{\psi}^{**}\right) - \frac{\theta^2}{\Psi}\left(m^* - m^{**}\right) = 0 \tag{26}$$

Since $m^{**} > m^*$ and $\bar{\psi}^{**} > \bar{\psi}^*$ as shown above, we have $p^{**}(\beta_L) - p^*(\beta_L) < 0$.

References

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