Should the emergence of multi-utilities be encouraged? A partial answer based on the information cost of regulation.

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Abstract

Bundling traditionally distinct services into a multi-utility may increase or decrease the problems faced by the regulator. I compare the harmonized regulation of two services across two industrial structures: a multi-utility sells both services and two utilities sell one service each. The regulator does not know the marginal cost of providing each service, and the market is characterized by supply-side and demand-side interdependencies. I find that three parameters: correlation of costs, cross-price sensitivity of demand and social cost of public funds, will determine whether the information cost of regulation increases when the utility services are sold through a multi-utility. One interesting implication of the model is that a developed and a less developed country may reach different conclusions as to whether the emergence of a multi-utility should be encouraged or not.

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1 Introduction

Multi-utilities that provide varied utility services and are regulated by more than one regulator are starting to emerge in many countries. The policymakers must answer the crucial question of whether to encourage or discourage the emergence of multi-utilities. I give a partial answer to this question based on the information cost of regulation.

The information cost of regulation arises when the regulated firm has better information about its environment than does the regulator. In this case, the regulator must let the firm earn an extra rent to induce it to supply the socially optimal amount of products. The information cost of regulation can be defined as the social cost of leaving this information rent to the firm plus the social cost of deviating from the first-best supply of products. In order to minimize the information cost of regulation, the regulator must strike the right balance between rent extraction and allocational efficiency. This trade-off, and the resulting level of information cost of regulation, will be affected by the choice of industrial structure. Thus, the optimal regulatory mechanism and the optimal industrial structure should be jointly determined.

I examine the optimal industrial structure for the production of two regulated products. The regulatory context is characterized by: (1) the marginal cost of each product is known only to the producer; (2) these marginal costs may be positively or negatively correlated; and (3) the cross-price sensitivity of demand may be positive or negative. The regulator can choose between one firm supplying both products (monopoly) and two firms supplying one product each (duopoly). For each industrial structure, I derive the optimal regulation. Finally, I compare the information cost of regulation in the monopoly and the duopoly setting and derive a rule for the optimal industrial structure based on the combined effect of two parameters, the covariance of marginal costs and the cross-price sensitivity of demand.

The major contribution of this paper is to include both demand-side and supply-side interdependencies in a single model of multi-dimensional screening. Thus, it extends earlier work which has tended to examine the effect of demand-side and supply-side interdependencies separately, often including only one piece of privately known information. Although the analyzed problem is complex, the resulting model is relatively simple and offers an insight concerning the combined effect of cost correlation and cross-price sensitivity on the choice of optimal industrial structure.

The results presented in this paper can be understood and compared to the results of earlier work[1] by studying figure 1. The x-axis measures the cross-price sensitivity of demand, g, where $0 < g < 1$ means that the products are close substitutes, while $-1 < g < 0$ means that the products are close complements. The y-axis measures the covariance of marginal costs, ρ, where $\rho \in \langle -1/4, 1/4 \rangle$ and $|\rho| = 1/4$ means that the marginal costs are perfectly correlated. The model is simulated for a social cost of public funds (labeled λ) equal to 0.3 per unit of taxation.

First, monopoly tends to be the optimal industrial structure for complementary products and duopoly tends to be the optimal industrial structure for substitute products. This is because the cross-price sensitivity of demand affects a monopolist's incentive to reveal the truth about its marginal costs. Consider two substitute products. A price increase of one product will increase the demand for the other product. Thus, a firm offering both products finds it more profitable to exaggerate their marginal costs, than a firm offering only one. Consequently, the regulator must leave the multiproduct firm a higher rent to induce it to tell the truth. Gilbert and Riordan [6] and Iossa [7][2], among others[3], prove this *information externality* result formally in contexts where the marginal costs are not correlated

Second, duopoly tends to be the optimal industrial structure if the covariance

[1]A good overview of the literature on integrated versus component production is given in Armstrong and Sappington [1].

[2]Iossa [7] assumes information asymmetry with respect to the demand conditions for the firm. In her context, substitutes should optimally be supplied by a monopoly- and vice versa if the products are complements.

[3]Like Gilbert and Riordan [6], Baron and Besanko [3] and Da Rocha and de Frutos [5] analyzes settings where the products are perfect complements. See Severinov [13] for a more detailed analysis of the effects of both substitutability and complementarity on the optimal choice of industrial structure.

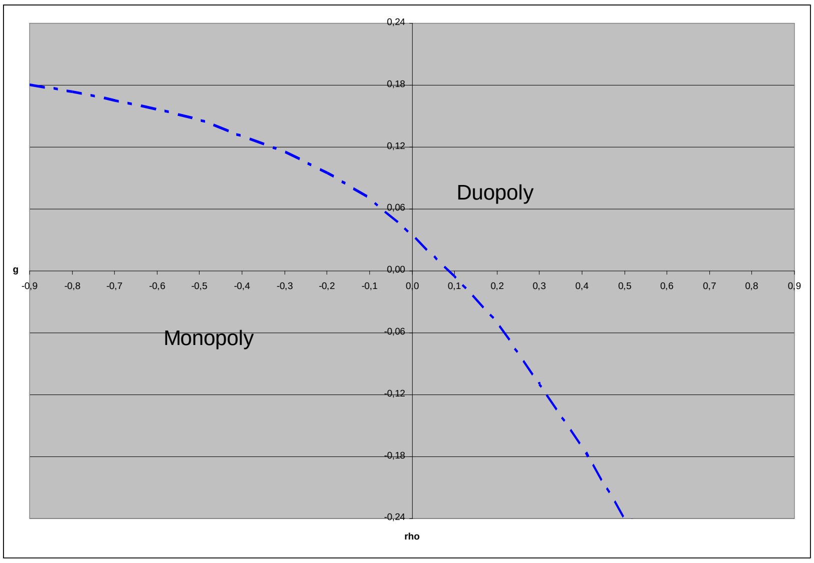

Figure 1: The regulator's choice of industrial structure. $\tilde{\rho}(g)$ in Proposition 6 is simulated for $\lambda = 0.3$. Duopoly is best for $\rho > \tilde{\rho}(g)$ (the dashed line) and monopoly is best for $\rho < \tilde{\rho}(g)$.

of marginal costs is high - and vice versa for monopoly. On one hand, a duopoly setting allows *yardstick competition*. Assuming limited liability, the rent extraction will increase with the absolute value of ρ, and for perfectly correlated costs, it will be possible to extract all rent from the firms and reach a first-best allocation of resources. On the other hand, a monopoly setting gives rise to *informational economies of scope*. Obviously, if the two marginal costs are perfectly negatively correlated, the firm cannot claim that both are higher than average. In fact, in this case, the regulator can obtain a first-best solution. However, as ρ increases, the regulator's possibility to utilize its knowledge about ρ in the optimal regulation of a multi-product firm decreases. Comparing these two effects in a context with independent products, Dana [4] shows that the information cost of regulation will be minimized if the regulator chooses to organize the industry as a duopoly when the correlation is high and as a duopoly when the correlation is low or negative. Dana's critical value of ρ is found in figure 1 as the point where the dashed line crosses the y-axis. Jansen [8] analyzes the case in which the marginal costs of two perfect complements are positively correlated. Jansen, like Dana, concludes that for sufficiently high levels of cost correlation, the industry should be organized as a duopoly. Jansen's critical value of ρ is found in figure 1 as the value of the dashed line when $g = -1$.

Third–and this paper's major finding–is that the optimal industrial structure should be determined on the basis of the combined effect of g and ρ; this is important because the two parameters interact and lead to choices that cannot be easily understood by merely adding up the results of the two strands of literature mentioned above. For example, in figure 1 the dashed line dividing the set in two, monopoly and duopoly, is not linear. Furthermore, the position and the curvature of the dashed line will depend on the value of the social cost of public funds. At one extreme, when the social cost of public funds is negligible, the dashed line in figure 1 almost coincides with the y-axis, indicating that the information externality effect described by Iossa [7] and Gilbert and Riordan [6] should govern the regulator's choice. At the other extreme, the dashed line in figure 1 flattens out, indicating that the trade-off between the benchmark competition effect and the informational economics of scope effect described in the work of Dana [4] and Jansen [8] becomes more important. However, for not negligible social cost of public funds, like the one simulated in figure 1, the regulator should make the choice of industrial structure based on the combined effect of g and ρ.

The paper is organized as follows: In section 2, I describe the formal model. In section 3 and 4, I solve regulator's optimization problem assuming information symmetry and information asymmetry, respectively. In section 5, I compare information costs of regulation in a monopoly and duopoly setting, and derive a rule for choosing the optimal industrial structure. In section 6, I present my conclusions. Proofs are given in Appendix B.

2 Model

Consider a regulated industry producing two interdependent products. The demand conditions are defined by the following gross consumer-surplus function

$$S(x_1, x_2) = a_1 x_1 + a_2 x_2 - 1/2 b_1 x_1^2 - 1/2 b_2 x_2^2 - g x_1 x_2$$

where x_s is the number of units of product s, $s = \{1, 2\}$, $\partial S/\partial x_s > 0$ and $\partial S^2/\partial^2 x_s < 0$. Furthermore, $b > |g| > 0$ and $g > 0$ for substitute products and $g < 0$ for complementary products. Since the consumers' gross consumer-surplus function is quasi-linear and additive, there will be no income effects in demand and the cross-price effect is a pure substitution effect between the pair of products and hence symmetric. To simplify further calculations, the parameter b is equal for both products and normalized to one, which implies that $g \in \langle -1, 1 \rangle$.

The marginal values of the two products give the prices clearing a market with supplies x_1 and x_2

$$p_1 = a_1 - x_1 - g x_2 \quad (1)$$

$$p_2 = a_2 - x_2 - g x_1. \quad (2)$$

Equivalently, the quantities clearing a market with prices p_1 and p_2 are

$$x_1 = \frac{a_1 - g a_2}{1 - g^2} - \frac{1}{1 - g^2} p_1 + \frac{g}{1 - g^2} p_2 \quad (3)$$

$$x^2 = \frac{a_2 - g a_1}{1 - g^2} - \frac{1}{1 - g^2} p_2 + \frac{g}{1 - g^2} p_1. \quad (4)$$

The regulator can choose between having one firm produce both products and having two firms produce one product each. To isolate the effect of industrial structure on the information cost of regulation, there are no economies of scope. Without loss of generality, the fixed costs are equal to zero. Thus, the total cost of producing the two products is

$$C(x_1, x_2) = c_1^i x_1 + c_2^j x_2$$

where c_1 and c_2 are the constant marginal costs of producing product 1 and 2. The superscripts i and j refer to the value of the marginal cost of product 1 and 2, respectively. Each can take one of two values, high (H) and low (L). The differences between them are equal for the two products: $c_1^H - c_1^L = c_2^H - c_2^L = \Delta > 0$. The marginal costs are drawn from a probability density which is common knowledge. The joint probabilities, α_{ij}, are shown in Table 1. Here, $\alpha_{HL} = \alpha_{LH} = \alpha_M$, where the subscript M means mixed marginal costs. The following indicator of covariance of marginal costs will be used: $\rho = \alpha_{HH}\alpha_{LL} - \alpha_M\alpha_M$, and so $\rho \in \langle -\alpha_M\alpha_M, \alpha_{HH}\alpha_{LL} \rangle$. Like in earlier analysis of adverse selection models in regulation[4], the demand and cost functions are common knowledge, while the total cost is not known[5].

	c_1^L	c_1^H
c_2^L	α_{LL}	α_M
c_2^H	α_M	α_{HH}

Table 1: Joint probabilities

Provided the firm truthfully announces its type, it will earn a rent equal to

$$R^{ij} = T^{ij} + \pi^{ij} \tag{5}$$

where π^{ij} is the firm's profit from operating in the market and T^{ij} is a public transfer.

The social welfare function can be written as the sum of the consumers', tax-payers' and industry's welfare

$$W_D^{ij} = S^{ij} - p_1 x_1^{ij} - p_2 x_2^{ij} - (1+\lambda)\left(T_1^{ij} + T_2^{ij}\right) + \left(R_1^{ij} + R_2^{ij}\right) \tag{6}$$

$$W_M^{ij} = S^{ij} - p_1 x_1^{ij} - p_2 x_2^{ij} - (1+\lambda)\,T^{ij} + R^{ij} \tag{7}$$

where the subscripts D and M denote duopolistic and monopolistic industrial structures, respectively, and λ is the social cost of public funds. Substituting for T^{ij} in the social welfare function yields

$$W_D^{ij} = w^{ij} - \lambda\left(R_1^{ij} + R_2^{ij}\right) \tag{8}$$

$$W_M^{ij} = w^{ij} - \lambda R^{ij} \tag{9}$$

[4]See Laffont and Martimort [10] for a presentation of adverse selection models in regulation.

[5]If the total cost was known, the marginal costs could be derived from the cost function based on observable quantities.

where $w^{ij} = S^{ij} + \lambda (p_1 x_1 + p_2 x_2) - (1+\lambda) \left(c_1^i x_1 + c_2^j x_2 \right)$ is the social value of trading quantities x_1 and x_2 and $\lambda \left(R_1^{ij} + R_2^{ij} \right)$ and $\lambda R^{ij}$are the social cost of leaving rent to the firm(s) when the state of marginal costs is equal to ij.

Applying the revelation principle (Myerson [12]), I restrict attention to direct revelation mechanisms inducing the firm(s) to truthfully reveal marginal costs c_1^i and c_2^j to the regulator, who sets the quantities and transfers as a function of the reports. The timing of the game is as follows: First, the regulator chooses the industrial structure and designs the regulatory mechanism. Second, the firm(s) observes the realized value of its own marginal cost(s) and reports it to the regulator who makes it public[6]. Finally, the firm sets prices in accordance with the regulatory contract chosen and transfers are made.

3 Information symmetry

Assuming complete information, the regulator can force efficient outputs while holding the firm's rent at zero. The regulator will set the transfer, T^{ij}, so that the socially costly rent R^{ij} is equal to zero in all states ij. The first-best output is derived by maximizing w^{ij} with respect to $x_1^{ij}$and x_2^{ij}. Since w^{ij} is independent of industrial structure, the first-best prices will be the same in the duopoly and monopoly settings. Consequently, there will be no difference in social welfare across industrial structures[7]. Using $\sim$ to denote first-best variables, the regulatory contract is given by

$$\tilde{x}_1^{ij} = \frac{1+\lambda}{1+2\lambda} \frac{a_1 - c_1^i - g\left(a_2 - c_2^j\right)}{1-g^2} \quad (10)$$

$$\tilde{x}_2^{ij} = \frac{1+\lambda}{1+2\lambda} \frac{a_2 - c_2^j - g\left(a_1 - c_1^i\right)}{1-g^2} \quad (11)$$

$$\tilde{R}^{ij} = 0.$$

[6] Iossa [7] stresses that in the duopolistic case it will always be optimal for the regulator to make the report public, since uncertainty on c_1 and c_2 would make the firms not meet the market demand.

[7] To focus on regulatory issues, I have assumed that there are no tecnological economies of scope.

The quantity of product s will decrease with its own marginal cost

$$\tilde{x}_1^{Lj} > \tilde{x}_1^{Hj} \text{ and } \tilde{x}_2^{iL} > \tilde{x}_2^{iH}. \tag{12}$$

Also, an increase in the other product's marginal cost, will increase the quantity of a substitute product and decrease the quantity of a complementary product

$$\begin{array}{lllll} g > 0 & \tilde{x}_1^{iH} > \tilde{x}_1^{iL} & \text{and} & \tilde{x}_2^{Hj} > \tilde{x}_2^{Lj} \\ g = 0 & \tilde{x}_1^{iH} > \tilde{x}_1^{iL} & \text{and} & \tilde{x}_2^{Hj} = \tilde{x}_2^{Lj} \\ g < 0 & \tilde{x}_1^{iH} < \tilde{x}_1^{iL} & \text{and} & \tilde{x}_2^{Hj} < \tilde{x}_2^{Lj}. \end{array} \tag{13}$$

4 Information asymmetry

4.1 The optimization problems

Consider first a duopoly setting in which two firms supply one product each. Firm s produces product s and has private information on the realization of c_s. The regulator designs a mechanism specifying the output and total transfer for each firm as a function of both firms' announced marginal costs where the state contingent vectors $(\mathbf{x}_s, \mathbf{T}_s)$ represents the menu of contracts for firm $\mathbf{s}$. Formally, the regulator's optimization problem is the following.

$$\max_{x_1^{ij}, x_2^{ij}, T_1^{ij}, T_2^{ij}} E\left[W_D\right] \tag{14}$$

subject to

$$\begin{array}{rcll} R_1\left(ij|\, i\right) & \geq & R_1\left(i\prime j|\, i\right) & IC \\ R_2\left(ij|\, j\right) & \geq & R_2\left(ij\prime|\, j\right) & IC \\ R_1\left(ij|\, i\right) & \geq & 0 & IR \\ R_2\left(ij|\, j\right) & \geq & 0 & IR \end{array} \tag{15}$$

The feasible mechanism must satisfy the above incentive compatibility (IC) and individual rationality (IR) constraints. I have used a short-hand notation for the marginal costs in the argument of the rent functions, and e.g. $R_2\left(ij\prime|\, j\right)$ should be understood as the ex-post rent of firm 2 when firms 1 and 2 report to be type i and

$j\prime$, respectively, and the true identity of firm 2 is j. Assuming limited liability, IR should hold ex-post.

Consider next a monopoly setting in which a single firm supplies both products 1 and 2 and has private information on the realization of c_1 and c_2. The regulator designs a mechanism specifying the outputs and total transfer as a function of the firm's announced marginal costs where the state contingent vectors $(\mathbf{x}_1, \mathbf{x}_2, \mathbf{T})$ represent the menu of contracts. Formally, the regulator's optimization problem is the following.

$$\max_{x_s^{ij}, T^{ij}} E\left[W_M\right] \tag{16}$$

subject to

$$\begin{array}{lcll} R\left(ij|\, ij\right) & \geq & R\left(i\prime j\prime|\, ij\right) & IC \\ R\left(ij|\, ij\right) & \geq & 0 & IR \end{array} \tag{17}$$

I solve the optimization problems in two steps. First, I solve a relaxed optimization problem, in which I include only the upward IC constraints; that is, I consider only the possibility that a low-cost producer will be tempted to pretend it is a high-cost producer. Since the IC constraints are linear in the regulated quantities, they define a convex set. Thus, if the solution to the relaxed problem also satisfies the omitted IC constraints, it is the solution to the fully constrained problem.

4.2 Solving the relaxed optimization problems

The ICs in a duopoly and a monopoly setting are given in Appendix A. Considering only upward ICs, the difference between the duopoly and monopoly cases arises in state LL. In the duopoly setting, the regulator must compensate each firm for the profit it could earn by unilateral deviation. Thus, the total rent to be paid in state LL is

$$R^{LL} = R_1^{LL} + R_2^{LL} = x_1^{HL}\Delta + x_2^{LH}\Delta. \tag{18}$$

In the monopoly setting, the firm can choose between three mutually exclusive mimicking strategies: it can deviate with respect to the true cost of product 1 or 2, or both. Thus, the total rent to be paid in state LL is

$$R^{LL} = \max\left\{\left(x_1^{HH} + x_2^{LH}\right)\Delta, \left(x_2^{HH} + x_1^{HL}\right)\Delta, \left(x_1^{HH} + x_2^{HH}\right)\Delta\right\} \tag{19}$$

where the list includes the rents the firm can gain from mimicking LH, HL and HH, respectively. Note that due to the symmetry assumptions, the industry will in state LL always mimic LH and HL with equal probability. Denoting this probability γ, one can rewrite the equations (18) and (19) as in Proposition 1.

The complete solution to the optimization problem for a monopoly is given in Linnerud [11] and was initially developed in a more general context by Armstrong and Rochet [2]. In Appendix B, the proof of Proposition 1 for a duopoly is given.

Proposition 1 *The solutions to the regulator's relaxed optimization problems in a duopoly and a monopoly setting are characterized by:*

i. *rents*

$$\begin{aligned}
R^{LL} &= \left[\gamma\left(\bar{x}_1^{HL} + \bar{x}_2^{LH}\right) + (1-\gamma)\left(\bar{x}_1^{HH} + \bar{x}_2^{HH}\right)\right]\Delta \\
R^{LH} &= \bar{x}_1^{HH}\Delta \\
R^{HL} &= \bar{x}_2^{HH}\Delta \\
R^{HH} &= 0,
\end{aligned}$$

ii. *quantities*

$$\begin{aligned}
\bar{x}_1^{LL} &= \tilde{x}_1^{LL} \quad && \textit{and} \quad \bar{x}_2^{LL} = \tilde{x}_2^{LL} \\
\bar{x}_1^{LH} &= \tilde{x}_1^{LH} + g\cdot I_M && \textit{and} \quad \bar{x}_2^{LH} = \tilde{x}_2^{LH} - I_M \\
\bar{x}_1^{HL} &= \tilde{x}_1^{HL} - I_M && \textit{and} \quad \bar{x}_2^{HL} = \tilde{x}_2^{HL} + g\cdot I_M \\
\bar{x}_1^{HH} &= \tilde{x}_1^{HH} - I_{HH} && \textit{and} \quad \bar{x}_2^{HH} = \tilde{x}_2^{HH} - I_{HH}
\end{aligned}$$

where

$$\begin{aligned}
I_M &= \frac{\lambda}{1+2\lambda}\frac{1}{1-g^2}\frac{\alpha_{LL}\gamma}{\alpha_M}\Delta \\
I_{HH} &= \frac{\lambda}{1+2\lambda}\frac{1-g}{1-g^2}\frac{\alpha_M + \alpha_{LL}(1-\gamma)}{\alpha_{HH}}\Delta,
\end{aligned}$$

iii. *probabilities*

$$\begin{array}{ll} \textit{duopoly:} & \gamma = 1 \\ \textit{monopoly:} & \gamma \in \left[0, \dfrac{1}{2}\right]. \end{array}$$

The regulatory contracts derived under full information are not incentive compatible when the industry possesses private information. To induce truth telling the regulator must leave an information rent to firms which produce low-cost products. This rent can be optimally reduced by distorting the quantities.

Consider first a duopoly setting in which the regulator offers first-best contracts to the two firms, yielding a zero rent if they truthfully report their types. In state LL, firm 1 can gain a positive rent of $\tilde{x}_1^{HL}\Delta$ by pretending to be type H. This is the rent the regulator must give the firm to induce it to tell the truth. The rent can be reduced by distorting x_1^{HL} downwards. For independent products, the regulator will choose x_1^{HL} so as to balance the allocational efficiency losses caused by providing less than the first-best quantity of product 1 against the social cost of leaving a rent to the firm. However, for complementary and substitute products, a change in the quantity of one product changes the consumers' marginal valuation of the other product. Thus, a reduction in x_1^{HL}, should be accommodated by an increase (decrease) in x_2^{HL} if the products are substitutes (complements).

Consider next a monopoly setting. The quantities are distorted in a similar way as under duopoly, but the magnitude of deviation from first-best values will differ across industrial structures. In the duopoly setting, R^{LL} is only dependent on $\bar{x}_1^{HL}$ and $\bar{x}_2^{LH}$, while in the monopoly setting, R^{LL} depends to a lesser extent ($\lambda < 1$) on these quantities. Consequently, for a given demand parameter g, the regulator will always distort quantities in states LH or HL more and quantities in state HH less, in a duopoly compared to a monopoly setting.

In the remainder of this section I take a closer look at the solution to the relaxed optimization problem under monopoly. Here, three patterns of binding upward IC constraints may occur. Each corresponds to a mimicking strategy that solves the maximization problem in (19). In state LL, the monopoly may be attracted to LH and HL, but not to HH (case A), be equally attracted to LH, HL and HH (case

B) or be attracted to only HH (case C). From (19) it is clear that necessary and sufficient conditions for these cases to occur are

$$\begin{aligned} &\text{A:} \quad \bar{x}_1^{HL} > \bar{x}_1^{HH} \ \text{ and } \ \bar{x}_2^{LH} > \bar{x}_2^{HH} \\ &\text{B:} \quad \bar{x}_1^{HL} = \bar{x}_1^{HH} \ \text{ and } \ \bar{x}_2^{LH} = \bar{x}_2^{HH} \\ &\text{C:} \quad \bar{x}_1^{HL} < \bar{x}_1^{HH} \ \text{ and } \bar{x}_2^{LH} < \bar{x}_2^{HH}. \end{aligned} \tag{20}$$

Furthermore, each case implies a specific value of γ

$$\begin{aligned} \gamma^A &= \tfrac{1}{2} \\ \gamma^B &= \tfrac{\alpha_M(\alpha_M+\alpha_{LL}) - g\alpha_M\left(\alpha_M+\alpha_{LL}+\alpha_{HH}\frac{1+\lambda}{\lambda}\right)}{\alpha_{LL}(\alpha_{HH}+\alpha_M-g\alpha_M)} \\ \gamma^C &= 0 \end{aligned} \tag{21}$$

where $0 < \gamma^B < \frac{1}{2}$. Imagine that the regulator has chosen menu C, so that $\bar{x}_1^{HL} < \bar{x}_1^{HH}$ and $\bar{x}_2^{LH} < \bar{x}_2^{HH}$. In this case, if state LL occurs, the firm's most profitable mimicking strategy will be to report that both products are produced at high marginal costs. Thus, the probability of LL mimicking LH, or equivalently HL, is equal to zero. Inserting $\gamma = 0$ in the expressions for quantities given in Proposition 1, yields the optimal quantities and rents in case C.

Some important differences between the three menus should be noted. In menus A and C the regulator will always need information about both products in order to regulate one product. In menu B the regulator can fix the quantities of the high-cost products without having information about the other product's marginal cost. In fact, if the products are independent in demands, the regulator can regulate even the low-cost products without using information about the other product. Finally, in menu C the quantities are only distorted if the state HH occurs and the allocation of resources is equal to the first-best solution in three out of four contracts.

Finally, I consider the conditions under which the regulator should offer menus A, B or C to the firm. The solution to this question can be found by inserting the expressions for optimal quantities given in Proposition 1 and the probabilities γ given in (21) in the necessary and sufficient conditions for menus A, B and C given in (20). The resulting conditions can be reformulated in terms of ρ, and Linnerud [11] proves that there exists a $g^* \in \langle 0, 1 \rangle$ given by

$$g^* = \frac{\lambda\alpha_M}{\lambda\alpha_M + (\lambda + 1 - \alpha_{LL})\,\alpha_{HH}} \tag{22}$$

so that for $g \leq g^*$case B will occur if and only if

$$\rho > \rho^1 \equiv \frac{\alpha_M \alpha_M}{\alpha_{HH}} - \frac{\alpha_M}{\alpha_{HH}} \left(1 + \frac{2+\lambda}{\lambda} \alpha_{HH}\right) (\alpha_M + \alpha_{HH}) \cdot g, \qquad (23)$$

otherwise case A will occur, and for $g > g^*$case B will occur if and only if

$$\rho > \rho^2 \equiv -\alpha_M + \left(\alpha_M + \alpha_{LL} + \frac{1+\lambda}{\lambda} \alpha_{HH}\right) (\alpha_M + \alpha_{HH}) \cdot g, \qquad (24)$$

otherwise case C will occur[8]. The choice between menus A, B and C depends on how ρ relates to ρ^1 and ρ^2, where the values of these two functions depend on the joint probability distribution of marginal costs and g. This is illustrated in figure 2. Since, for a given joint probability distribution of marginal costs, both ρ^1 and ρ^2 vary monotonically with g, they will cross only once at $g = g^*$. Furthermore, ρ^1 and ρ^2 will always cross below the lowest feasible value of ρ, that is, below $-\alpha_M \alpha_M$. Thus, we can rule out the case in which ρ is smaller than both $\rho^1$and ρ^2.

4.3 Solving the fully constrained optimization problem

Consider first the monopoly. The omitted ICs are the downward constraints (labeled $M1' - M5'$ in Appendix A) and the sideways constraints (labelled $M6$ and $M6'$ in Appendix A). Inserting the expressions for monopoly quantities and rents given in Proposition 1, it can be shown that they are all satisfied in menus A, B and C. Thus, Proposition 1 together with the probabilities γ in (21), gives the complete solution to the fully constrained optimization problem for a monopoly.

Consider next the duopoly. The omitted ICs are the downward constraints (labeled $D1' - D4'$ in Appendix A). Taking the sum of each pair of ICs, like $D1$ and $D1\prime$, yields the following monotonicity conditions

$$\bar{x}_1^{LL} - \bar{x}_1^{HL} = \bar{x}_2^{LL} - \bar{x}_2^{LH} > 0 \qquad (25)$$

and

$$\bar{x}_1^{LH} - \bar{x}_1^{HH} = \bar{x}_2^{HL} - \bar{x}_2^{HH} > 0 \qquad (26)$$

[8] The two identities $\rho = \alpha_{HH}\alpha_{LL} - \alpha_M \alpha_M$ and $1 = \alpha_{HH} + \alpha_{LL} + 2\alpha_M$ define a set of two equations in four unknowns. Thus, for given values of α_{HH} and ρ, the right hand sides of ρ^1 and ρ^2 will only depend on the g and λ.

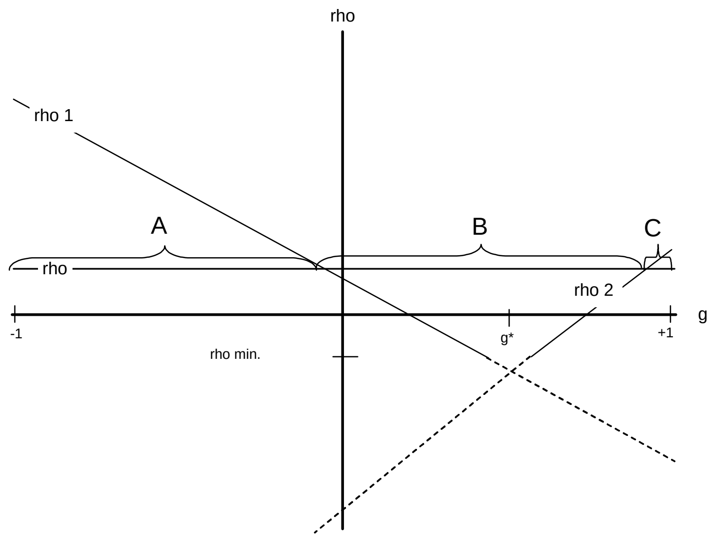

Figure 2: The regulator's choice of menu to offer a monopolist for a given joint probability distribution of marginal costs. For $\rho < \rho^1$ choose menu A; for $\rho \geq \rho^1$ and $\rho \geq \rho^2$ choose menu B; for $\rho < \rho^2$ choose menu C.

Inserting the expressions for duopoly quantities given in Proposition 1, shows that condition (25) will always be satisfied while condition (26) may be broken for $g < 0$. If condition (26) is broken, a partial pooling of contracts across types will be necessary to ensure incentive feasible contracts. Since the occurence of the partial pooling solution will not alter the results of the welfare comparisons in section 5, I will not present this solution here[9].

5 A comparison across industrial structures

In this section I compare the optimal regulation in a duopoly and a monopoly setting, and identify criteria for determining when a duopoly yields lower information cost of regulation than a monopoly - and vice versa. To facilitate the calculations, I restrict attention to situations in which the marginal costs are given by a uniform distribution. That is, I make the additional assumption that $\alpha_{HH} = \alpha_{LL} = \alpha$, which

[9]Details can be found at my website: http://www.hisf.no/ansatt/vis/kristin.linnerud

implies that $\alpha_M = 1/2 - \alpha$, $\rho = \alpha - 1/4$ and $\rho \in \langle -1/4, 1/4 \rangle$.

The optimal regulation in the duopolistic and monopolistic case differs. Thus, the information cost of regulation, stemming from allocational efficiency losses and socially costly information rents, may differ. Since the regulator's object function is the same in the monopolistic and duopolistic cases, and the differences in the IR-constraints are inconsequential[10], the different solutions must result from different IC constraints. Disregarding the possibility of a partial pooling solution in the duopoly setting, the differences between the optimal regulation across industrial structures are summed up as follows:

$$
\begin{aligned}
R^{LL} &= \left[\gamma\left(x_1^{HL} + x_2^{LH}\right) + (1-\gamma)\left(x_1^{HH} + x_2^{HH}\right)\right]\Delta & (27)\\
I_M &= \frac{\lambda}{1+2\lambda}\frac{1}{1-g^2}\frac{\alpha\gamma}{1/2-\alpha}\Delta & (28)\\
I_{HH} &= \frac{\lambda}{1+2\lambda}\frac{1-g}{1-g^2}\frac{1/2-\alpha\gamma}{\alpha}\Delta & (29)
\end{aligned}
$$

where $\gamma = 1$ in a duopoly and $\gamma \in \left[0, \frac{1}{2}\right]$ in a monopoly setting. For a given demand parameter g, the regulator will always distort quantities in states LH or HL more and quantities in state HH less, if the industry has a duopolistic instead of a monopolistic structure.

The next step is to compare the information cost of regulation across industrial structures. Choosing the same approach as Dana [4], I consider a situation in which the regulator will procure the state contingent output vectors $\mathbf{x}_1$ and $\mathbf{x}_2$ at the lowest possible cost. Since the output vectors are fixed, welfare can be determined by the size of the cost-minimizing transfers. Restricting the possible values of the state contingent vectors somewhat, the cost minimizing transfers can be derived directly from the binding constraints in the relaxed implementation problems. These cost-minimizing transfers are equal to the sum of regulator transfer(s) and market revenue derived in Proposition 1. Consequently, a comparison of procurement costs under

[10] This was pointed out by Dana [4]. Intuitively, if the regulator was required to satisfy ex-post IR constraints of two profit centers within the monopoly and allowed to fix transfers T^1 and T^2 for each profit center, this would not alter the solution in Proposition 3-5.

duopolistic and monopolistic industrial structure can be made using the expressions for optimal transfers implicitly given in Proposition 1. On this basis, I arrive at the following lemma.

Lemma 1 *Let* $\mathbf{t}_1(\mathbf{x}_1) + \mathbf{t}_2(\mathbf{x}_2)$ *and* $\mathbf{t}(\mathbf{x}_1, \mathbf{x}_2)$ *denote the cost minimizing transfers that implement the output vectors* $\mathbf{x}_1$ *and* $\mathbf{x}_2$ *under duopolistic and monopolistic industrial structures, respectively. If the output vectors satisfy the following conditions:*

$$\begin{aligned} x_1^{HL} - x_1^{HH} &= x_2^{LH} - x_2^{HH} \\ \max\left\{x_1^{HH}, x_1^{HL}\right\} &\leq \min\left\{x_1^{LL}, x_1^{LH}\right\} \\ \max\left\{x_2^{HH}, x_2^{LH}\right\} &\leq \min\left\{x_2^{LL}, x_2^{HL}\right\}, \end{aligned}$$

the cost of procurement will be

i, $E(\mathbf{t}) < E(\mathbf{t}_1 + \mathbf{t}_2)$ *iff* $x_1^{HL} - x_1^{HH} > 0$

ii. $E(\mathbf{t}) = E(\mathbf{t}_1 + \mathbf{t}_2)$ *iff* $x_1^{HL} - x_1^{HH} = 0$

iii. $E(\mathbf{t}) > E(\mathbf{t}_1 + \mathbf{t}_2)$ *iff* $x_1^{HL} - x_1^{HH} < 0$

The first restriction put on the output vectors, $x_1^{HL} - x_1^{HH} = x_2^{LH} - x_2^{HH}$, simplifies the analysis. Since this condition is satisfied by the duopoly and monopoly quantities presented in Proposition 1, it does not affect the subsequent welfare comparisons across industrial structures. The next two restrictions put on the fixed output vectors, ensure that the omitted IC constraints in *both* the duopolistic and monopolistic structures are satisfied. They imply that the regulator will never procure a lower quantity if the marginal cost is low instead of high.

Return to the optimal regulation problems, and the quantities given in Proposition 1. In circumstances in which the sign of $\bar{x}_1^{HL} - \bar{x}_1^{HH}$ is not opposite in the duopoly and monopoly settings, Lemma 1 can be used to decide which industrial structure yields the lowest information cost of regulation. Consider for example that for given values of ρ and g, the duopoly quantities satisfy $\bar{x}_1^{HL} - \bar{x}_1^{HH} = 0$ while the monopoly quantities satisfy $\bar{x}_1^{HL} - \bar{x}_1^{HH} > 0$. Here, the duopoly quantities can be supplied at the same cost from either one firm producing both products or two firms producing one product each. However, the welfare can be further increased if the regulator asks the monopoly to produce the monopoly quantities given in Proposition 1.

In the monopoly and duopoly setting, the sign of $\bar{x}_1^{HL} - \bar{x}_1^{HH}$ will be determined as follows

		Monopoly		Duopoly
$\bar{x}_1^{HL} - \bar{x}_1^{HH} > 0$	iff	$\rho < \rho^1$	iff	$\rho < \rho^D$
$\bar{x}_1^{HL} - \bar{x}_1^{HH} = 0$	iff	$\rho > \rho^1$ and $\rho > \rho^2$	iff	$\rho = \rho^D$
$\bar{x}_1^{HL} - \bar{x}_1^{HH} < 0$	iff	$\rho < \rho^2$	iff	$\rho > \rho^D$

where

$$\begin{aligned}
\rho^1(\rho, g) &\equiv \frac{(1/4-\rho)^2}{1/4+\rho} - \frac{1/4-\rho}{1/4+\rho}\left(1+\frac{2+\lambda}{\lambda}(\rho+1/4)\right)\cdot 1/2\cdot g \\
\rho^2(\rho, g) &\equiv -1/4+\rho+\left(1/2+\frac{1+\lambda}{\lambda}(\rho+1/4)\right)\cdot 1/2\cdot g \\
\rho^D(\rho, g) &= -\left(1/4-\rho+\frac{1+\lambda}{\lambda}(\rho+1/4)\right)(1/4-\rho)\cdot g.
\end{aligned}$$

ρ^1 and ρ^2 are given in (23) and (24) and ρ^D is derived in Appendix B. Keeping ρ fixed, ρ^1, ρ^2 and $\rho^D$are linear functions of g. They cross for $g = g^*$ given in (22). For $g \in \langle -1, g^* \rangle$, $\rho^1$is strictly higher than ρ^D. For higher values of g, ρ^1 and ρ^D are both below feasible values of ρ. Consequently, referring to Lemma 1, only three cases of interest may occur: 1) $\rho \leq \rho^D$, 2) $\rho^D < \rho < \rho^1$ and 3) $\rho \geq \rho^1$. Thus, restricting attention to how ρ relates to ρ^1 and ρ^D, I solve the two equations

$$\rho^1(\rho, g) = \rho \text{ and } \rho^D(\rho, g) = \rho \tag{30}$$

with respect to ρ. Proposition 3 and Figure 3 illustrate how the solution to (30) can be used to determine the optimal industrial structure on the basis of g and ρ.

Proposition 2 *For each $g \in \langle -1, 1 \rangle$ there exist a $\rho = r^D(g)$ and a $\rho = r^1(g)$ which solve (30). $r^D(g)$ and $r^1(g)$ are nonlinear and strictly decreasing in g. Also, $r^D(g)$ $< r^1(g)$ and these two functions approach the same value as g approaches its upper limit* 1. *Based on Lemma 1, the information cost of regulation is minimized if for each g the regulator chooses monopoly when $\rho \leq r^D(g)$ and duopoly when $\rho \geq r^1(g)$.*

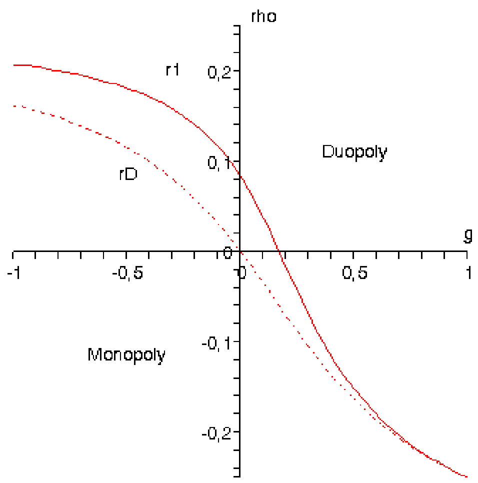

Figure 3: The regulator's choice of industrial structure. For $\rho \leq \rho^D$, monopoly is best. For $\rho \geq \rho^1$, duopoly is best. Lemma 1 does not indicate which industrial structure is best when $\rho^D < \rho < \rho^1$. The model is simulated for $\lambda = 0.3$.

It remains to determine the optimal industrial structure for $\rho \in \left\langle r^D, r^1 \right\rangle$. From Lemma 1, it follows that for a given g, $E\left[W_M\left(r^D\right)\right] > E\left[W_D\left(r^D\right)\right]$ and $E\left[W_M\left(r^1\right)\right] < E\left[W_D\left(r^1\right)\right]$. In Appendix B, I show that $dE\left[W_D\right]/d\rho - dE\left[W_M\right]/d\rho > 0$ for $\rho \in \left\langle r^D, r^1 \right\rangle$. Thus, $E\left[W_M\left(\rho\right)\right]$ and $E\left[W_D\left(\rho\right)\right]$ will cross once and only once in this interval. This forms the basis for the Proposition below.

Proposition 3 *For a given g there exists a $\rho = \tilde{\rho}(g) \in \left\langle r^D(g), r^1(g) \right\rangle$ so that the information cost of regulation will be minimized if for $\rho < \tilde{\rho}(g)$ the industry is organized as a monopoly, and for $\rho > \tilde{\rho}(g)$ the industry is organized as a duopoly.*

Proposition 4 is illustrated in figure 1. Here $\tilde{\rho}(g)$ is derived by finding the values (g, ρ) for which the social welfare is equal in the duopolistic and monopolistic case when the firm(s) are regulated according to Proposition 1.

The cost of raising funds from the taxpayers, λ, will influence the position and curvature of $r^D(g)$ and $r^1(g)$, and thus $\tilde{\rho}(g)$. Corollary 1 illustrates how the results of Proposition 3 and 4 will be affected when λ at one extreme takes on the value zero and at the other approaches infinity.

Corollary 1 *(i) As $\lambda \to 0$, $r^D(g)$ and $r^1(g)$ coincide with the y-axis and the choice of optimal industrial structure can be made solely on the basis of the sign of g; when $g < 0$, monopoly is optimal and when $g > 0$, duopoly is optimal. However, for $\lambda = 0$, the choice of industrial structure will not affect the social welfare. (ii) As $\lambda \to \infty$, $r^D(g)$ and $r^1(g)$ flatten out, and while the choice of optimal industrial structure must still be made on the basis of the combined effect of ρ and g, the role of ρ becomes more important.*

Corollary 1 is not proved mathematically, but is illustrated by numerical examples in figures 4 and 5. The reasons behind this result can be found by studying equations (27)–(29). For $\lambda = 0$, the output will be set at first-best values in both the monopoly and dupoly setting and the social cost of leaving rent to the firm will be zero. Thus, the choice of industry structure has no impact on social wealth. Next, for λ close to zero, the regulator should put greater emphasis on achieving a first-best allocation of resources and less emphasis on rent-extraction. Consequently, the most important difference between the monopoly setting and the duopoly setting stems from the information rent in state LL. Since, for substitute products, $\tilde{x}_1^{HL} < \tilde{x}_1^{HH}$ and $\tilde{x}_1^{HL} < \tilde{x}_1^{HH}$, the rent left for the industry in state LL is smallest in a duopoly setting. And, for complementary products, the rent left for the industry is smallest in a monopoly setting.

As λ approaches infinity, more emphasis is put on reducing the information rent. Now, recall from the introduction of this paper that the information rent will (1) in a monopoly setting depend on the the *information externality effect* (created by g) and the *informational economies of scope effect* (created by ρ); and (2) in a duopoly setting depend on the *benchmark competition effect* (created by ρ). For complementary products with positively correlated marginal costs, two countervailing effects occur. On one hand, the incentives to deviate from truthtelling is reduced if the industry is organized as a monopoly; on the other, the regulator's ability to extract rent is best organizing the industry as a duopoly and using benchmark competition. Also, for substitute products with negatively correlated marginal costs, two countervailing effects occur. On one hand, the incentives to deviate from truthtelling

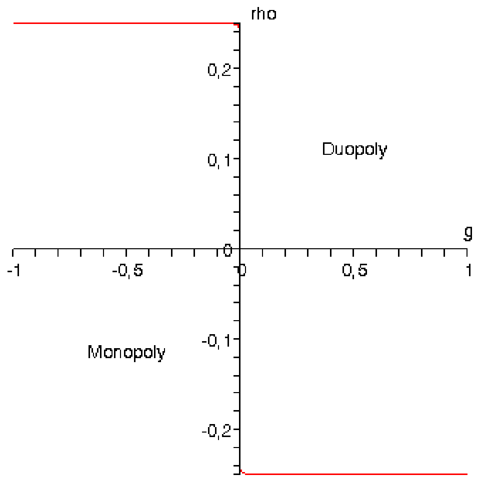

Figure 4: The model is simulated for $\lambda = 1/25000$.

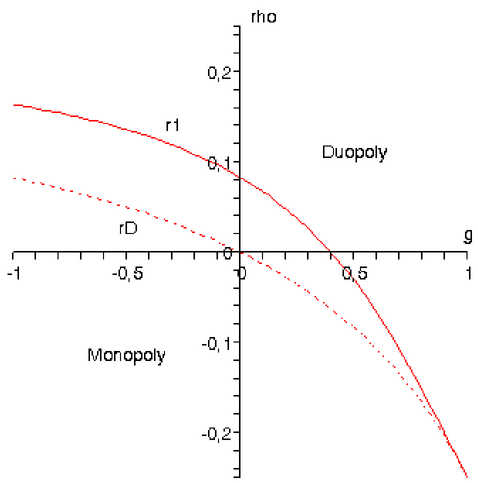

Figure 5: The model is simulated for $\lambda = 25000$

is reduced if the industry is organized as a duopoly; on the other, the regulator's ability to extract rent is best organizing the industry as a monopoly and making use of the informational economies of scope effect. Notice, that as the social cost of public funds increases, the regulator becomes less concerned about the industry's incentive to deviate from truthtelling and more concerned about his'/her's ability to extract rent. Since the demand-side interdependencies, g, influences the industry's incentive to lie and the supply-side interdependencies, ρ, influences the regulators ability to extract rent–the regulator should to an increasing extent be guided by the degree of cost correlation when choosing the optimal industrial structure.

6 Conclusion

What are the policy implications of the model presented in this paper? If the regulator thinks that the social cost of public funds are negligible, then the choice of industrial structure should be based solely on whether the products are close substitutes or complements. This result is in line with the works of Gilbert and Riordan [6] and Iossa [7]. However, if the regulator thinks the social cost of public funds is not negligible, then they should base their choice of industrial structure on the model in this paper, that is, on the combined effect of ρ and g. This model includes the findings by Dana [4] and Jansen [8] as special cases.

The social cost of public funds is affected by the country's institutions and macroeconomic characteristics, and can be viewed as exogenous to any particular regulatory sector. Laffont $[9, Pp.1-2]$ suggests that λ may be approximately 0.3 in developed countries, and well above 1 in less developed countries. Thus, if a country runs a budget surplus and its tax system is designed not to distort productive activity, the policymakers may encourage the emergence of multi-utilities as long as the utility services complement each other. However, in a less developed country, the policymakers may reach an opposite conclusion for the same pair of utility services. Their focus will be more on rent extraction and less on allocational efficiency. As a result, the level of cost correlation will have more to say on their choice of optimal industrial structure.

A IC constraints

In the duopolistic case there are 8 IC constraints.

$$
\begin{aligned}
R_1^{LL} &\geq R_1^{HL} + x_1^{HL}\Delta && D1 \\
R_1^{HL} &\geq R_1^{LL} - x_1^{LL}\Delta && D1\prime \\
R_1^{LH} &\geq R_1^{HH} + x_1^{HH}\Delta && D2 \\
R_1^{HH} &\geq R_1^{LH} - x_1^{LH}\Delta && D2\prime \\
R_2^{LL} &\geq R_2^{LH} + x_2^{LH}\Delta && D3 \\
R_2^{LH} &\geq R_2^{LL} - x_2^{LL}\Delta && D3\prime \\
R_2^{HL} &\geq R_2^{HH} + x_2^{HH}\Delta && D4 \\
R_2^{HH} &\geq R_2^{HL} - x_2^{HL}\Delta && D4\prime.
\end{aligned}
$$

In the monopolistic case there are 12 IC constraints.

$$
\begin{aligned}
R^{LL} &\geq R^{LH} + x_2^{LH}\Delta && M1 \\
R^{LH} &\geq R^{LL} - x_2^{LL}\Delta && M1\prime \\
R^{LL} &\geq R^{HL} + x_1^{HL}\Delta && M2 \\
R^{HL} &\geq R^{LL} - x_1^{LL}\Delta && M2\prime \\
R^{LH} &\geq R^{HH} + x_1^{HH}\Delta && M3 \\
R^{HH} &\geq R^{LH} - x_1^{LH}\Delta && M3\prime \\
R^{HL} &\geq R^{HH} + x_2^{HH}\Delta && M4 \\
R^{HH} &\geq R^{HL} - x_2^{HL}\Delta && M4\prime \\
R^{LL} &\geq R^{HH} + x_1^{HH}\Delta + x_2^{HH}\Delta && M5 \\
R^{HH} &\geq R^{LL} - x_1^{LL}\Delta - x_2^{LL}\Delta && M5\prime \\
R^{HL} &\geq R^{LH} - x_1^{LH}\Delta + x_2^{LH}\Delta && M6 \\
R^{LH} &\geq R^{HL} + x_1^{HL}\Delta - x_2^{HL}\Delta && M6\prime.
\end{aligned}
$$

B Proofs

Proof of Proposition 1.

Consider the optimization problem given in (14) and (15). Since a low-cost firm will always earn a strictly higher rent than a high-cost firm when they choose the same contract, the only potentially binding IR constraints are

$$R_1^{HH}, R_1^{HL}, R_2^{HH}, R_2^{LH} \geq 0.$$

As a first step, I consider only the upward IC constraints, $D1 - D4$. The potentially binding constraints are assigned the Lagrangian multipliers, γ_s^{ij} and η_s^{ij} where γ and η are the multipliers associated with IR and IC constraints, respectively, the subscript denote the product/firm and the superscript denote the true state of marginal costs. Making use of the social welfare function in equation (8), the relaxed optimization problem can be written as:

$$\begin{aligned}
&\max_{x_1^{ij}, x_2^{ij}, R_1^{ij}, R_2^{ij}} L = \textstyle\sum_{ij} \alpha_{ij} \left\{ w^{ij} - \lambda \left(R_1^{ij} + R_2^{ij} \right) \right\} \\
&+\gamma_1^{HH} R_1^{HH} + \gamma_1^{HL} R_1^{HL} + \gamma_2^{HH} R_2^{HH} + \gamma_2^{LH} R_2^{LH} \\
&+\eta_1^{LL} \left[R_1^{LL} - R_1^{HL} - x_1^{HL} \Delta \right] \\
&+\eta_1^{LH} \left[R_1^{LH} - R_1^{HH} - x_1^{HH} \Delta \right] \\
&+\eta_2^{LL} \left[R_2^{LL} - R_2^{LH} - x_2^{LH} \Delta \right] \\
&+\eta_2^{HL} \left[R_2^{HL} - R_2^{HH} - x_2^{HH} \Delta \right]
\end{aligned}$$

where

$$\begin{aligned}
w^{ij} &= (1+\lambda) \left[\left(a_1 - c_1^i \right) x_1^{ij} + \left(a_2 - c_2^j \right) x_2^{ij} \right] - \\
&\quad (1+2\lambda) \left[1/2 \left(x_1^{ij} \right)^2 + 1/2 \left(x_2^{ij} \right)^2 + g x_1^{ij} x_2^{ij} \right]
\end{aligned}$$

The FOCs $\frac{\partial L}{\partial R_1^{ij}} = 0$ imply the following set of multipliers

$$\begin{aligned}
\eta_1^{LL} &= \eta_2^{LL} = \alpha_{LL} \lambda, \ \eta_1^{LH} = \ \eta_2^{HL} = \alpha_M \lambda, \\
\gamma_1^{HL} &= \gamma_2^{LH} = \left(\alpha_M + \alpha_{LL} \right) \lambda, \ \gamma_1^{HH} = \ \gamma_2^{HH} = \left(\alpha_M + \alpha_{HH} \right) \lambda.
\end{aligned}$$

Since all the multipliers are strictly positive, the IC constraints for low-cost firms and the IR constraint for high-cost firms must all bind. The resulting rents are given in Proposition 1 for $\gamma = 1$. Inserting the expressions for the rents, the optimization problem can be reformulated as follows

$$\begin{array}{l} \max\limits_{x_1^{ij}, x_2^{ij}} E\left(W_D\right) = \\ \alpha_{LL}\left\{w^{LL} - \lambda\left(x_1^{HL}\Delta + x_2^{LH}\Delta\right)\right\} + \\ \alpha_M\left\{w^{LH} - \lambda\left(x_1^{HH}\Delta\right)\right\} + \\ \alpha_M\left\{w^{HL} - \lambda\left(x_2^{HH}\Delta\right)\right\} + \\ \alpha_{HH}\left\{w^{HH}\right\} \end{array}$$

From the FOCs $\frac{\partial E(W_D)}{\partial x_s^{ij}} = 0$, each quantity, x_s^{ij}, is determined by two equations in two unknowns.

End of Proof.

Proof of Lemma 1.

The implementation problem in the duopolistic and monopolistic cases are given by

$$\begin{array}{l} \min\limits_{t_s^{ij}} E\left[t_1^{ij} + t_2^{ij}\right] \\ \text{subject to} \\ \begin{array}{rcll} t_1^{ij} - c_1^i x_1^{ij} & \geq & t_1^{i\prime j} - c_1^i x_1^{i\prime j} & IC-D1 \\ t_1^{ij} - c_2^j x_2^{ij} & \geq & t_2^{ij\prime} - c_2^j x_2^{ij\prime} & IC-D2 \\ t_s^{ij} - c_s^{i/j} x_s^{ij} & \geq & 0 & IR-Ds \end{array} \end{array}$$

and

$$\begin{array}{l} \min\limits_{t^{ij}} E\left[t^{ij}\right] \\ \text{subject to} \\ \begin{array}{rcll} t^{ij} - c_1^i x_1^{ij} - c_2^j x_2^{ij} & \geq & t^{i\prime j\prime} - c_1^i x_1^{i\prime j\prime} - c_2^j x_2^{i\prime j\prime} & IC-M \\ t^{ij} - c_1^i x_1^{ij} - c_2^j x_2^{ij} & \geq & 0 & IR-M \end{array} \end{array},$$

respectively. Considering only upward IC constraints the transfers which solves the optimization problems above are

$$
\begin{aligned}
t_1^{LL}+t_2^{LL} &= c_1^L x_1^{LL}+c_2^L x_2^{LL}+\Delta x_1^{HL}+\Delta x_2^{LH} \\
t_1^{LH}+t_2^{LH} &= c_1^L x_1^{LH}+c_2^H x_2^{LH}+\Delta x_1^{HH} \\
t_1^{HL}+t_2^{HL} &= c_1^H x_1^{HL}+c_2^L x_2^{HL}+\Delta x_2^{HH} \\
t_1^{HH}+t_2^{HH} &= c_1^H x_1^{HH}+c_2^H x_2^{HH}
\end{aligned} \tag{31}
$$

and

$$
\begin{aligned}
t^{LL} &= c_1^L x_1^{LL}+c_2^L x_2^{LL}+\gamma\left(x_1^{HL}+x_2^{LH}\right)\Delta+(1-\gamma)\left(x_1^{HH}+x_2^{HH}\right)\Delta \\
t^{LH} &= c_1^L x_1^{LH}+c_2^H x_2^{LH}+x_1^{HH}\Delta \\
t^{HL} &= c_1^H x_1^{HL}+c_2^L x_2^{HL}+x_2^{HH}\Delta \\
t^{HH} &= c_1^H x_1^{HH}+c_2^H x_2^{HH}
\end{aligned} \tag{32}
$$

in the duopolistic and monopolistic cases, respectively. I assume that the state contingent vector the regulator chooses to procure satisfy $x_1^{HL}-x_1^{HH}=x_2^{LH}-x_2^{HH}$. Thus, in the monopolistic case, the gain from mimicking type HL and LH for type LL will be the same, and the probabilities of these two strategies are the same and equal to γ.

To be able to compare the transfers given in (31) and (32), I must ensure that the state-contingent quantity vectors satisfy the *omitted* IC constraints in *both* the monopolistic and duopolistic case. The omitted IC constraints in the duopolistic case, $D1\prime - D4\prime$, will be satisfied if and only if the local monotonicity conditions in (33) are satisfied. The omitted IC constraints in the monopolistic case, $M1\prime - M5\prime$ and $M6$ and $M6\prime$, will be satisfied if and only if conditions (33)-(35) are satisfied, where the last conditions (35) are equal to $M6$ and $M6\prime$ under the assumption that $x_1^{HL}-x_1^{HH}=x_2^{LH}-x_2^{HH}$.

$$x_1^{Lj} \geq x_1^{Hj} \text{ and } x_2^{iL} \geq x_2^{iH} \tag{33}$$

$$x_1^{LL} \geq x_1^{HH} \text{ and } x_2^{LL} \geq x_2^{HH} \tag{34}$$

$$x_1^{HL} \leq x_1^{LH} \text{ and } x_2^{LH} \leq x_2^{HL} \tag{35}$$

Conditions (33) - (35) can be rewritten as

$$\max\left\{x_1^{HH}, x_1^{HL}\right\} \leq \min\left\{x_1^{LL}, x_1^{LH}\right\} \tag{36}$$

$$\max\left\{x_2^{HH}, x_2^{LH}\right\} \leq \min\left\{x_2^{LL}, x_2^{HL}\right\}. \tag{37}$$

For a given vector of state contingent quantities, the expressions for cost minimizing transfers are equal to the sum of welfare maximizing transfers implicit in the expressions for optimal rents in proposition 1.i. and 3.i. plus revenues from sale:

$$\begin{aligned} \bar{t}_1^{ij} + \bar{t}_2^{ij} &= \bar{T}_1^{ij} + \bar{T}_2^{ij} + p_1 x_1^{ij} + p_2 \bar{x}_2^{ij} \\ \bar{t}^{ij} &= \bar{T}^{ij} + p_1 x_1^{ij} + p_2 \bar{x}_2^{ij}. \end{aligned}$$

Since the revenues from sale do not depend on the industrial structure, it follows that welfare comparisons can be made on the basis of the expected transfers $E\left(T_1^{ij} + T_2^{ij}\right)$ and $E\left(T^{ij}\right)$. Since $T_1^{ij} + T_2^{ij} = T^{ij}$ in the states HH, LH and HL, it suffices to compare transfers in the state LL. Thus, a monopolistic industrial structure will yield lower information cost of regulation if and only if for a given vector of state contingent quantities:

$$\begin{aligned} T^{LL} &\leq T_1^{LL} + T_2^{LL} \\ &\Updownarrow \\ x_1^{HH} + x_2^{HH} &\leq x_1^{HL} + x_2^{LH} \end{aligned}$$

Under the assumption that the procured quantities satisfy $x_1^{HL} - x_1^{HH} = x_2^{LH} - x_2^{HH}$, a necessary and sufficient condition for the above inequality to hold is:

$$x_1^{HL} - x_1^{HH} = x_2^{LH} - x_2^{HH} > 0. \tag{38}$$

The ranking of high-cost quantities in the monopolistic case is determined by how ρ relates to ρ^1 and ρ^2. ρ^1 and ρ^2 are defined in Proposition 5. The ranking of high-cost quantities in the duopolistic case can be expressed as follows

$$\bar{x}_1^{HL} - \bar{x}_1^{HH} = -\frac{1+\lambda}{1+2\lambda}\frac{1}{1-g^2}\Delta\left[g - \frac{\lambda}{1+\lambda}\left((1-g)\frac{\alpha_M}{\alpha_{HH}} - \frac{\alpha_{LL}}{\alpha_M}\right)\right],$$

where $\bar{x}_1^{HL} - \bar{x}_1^{HH} > 0$ when

$$\rho < \rho^D = -\left(\alpha_M + \frac{1+\lambda}{\lambda}\alpha_{HH}\right)\alpha_M \cdot g$$

This implies the following ranking of high-cost quantities in the duopolistic case:

$$\begin{aligned} \rho < \rho^D &\Rightarrow \bar{x}_1^{HL} - \bar{x}_1^{HH} > 0 \\ \rho = \rho^D &\Rightarrow \bar{x}_1^{HL} - \bar{x}_1^{HH} = 0 \\ \rho > \rho^D &\Rightarrow \bar{x}_1^{HL} - \bar{x}_1^{HH} < 0 \end{aligned}$$

For a given joint probability distribution of marginal costs,the equations ρ^1, ρ^2 and ρ^D vary monotonically with g and cross for $g = g^*$, as defined in Proposition 2.i., and at a value which is below the feasible interval for ρ. Thus, ρ^1, ρ^2 and ρ^D will relate to each other as follows:

$$\begin{aligned} g \in \langle -1, g^* \rangle &: \quad \rho^1 > \rho^D > \rho^2 \text{ and } \rho^2 < -\alpha_M\alpha_M \\ g = g^* &: \quad \rho^1 = \rho^D = \rho^2 \; < -\alpha_M\alpha_M \\ g \in \langle g^*, 1 \rangle &: \quad \rho^1 < \rho^D < \rho^2 \text{ and } \rho^1, \rho^D < -\alpha_M\alpha_M. \end{aligned}$$

End of Proof.

Proof of Proposition 4.

The maximum value functions for expected social welfare in the duopolistic and monopolistic case, respectively, are given by:

$$\begin{aligned} E[W_D] &= \alpha\left(w^{LL} + w^{HH}\right) + (1/2 - \alpha)\left(w^{LH} + w^{HL}\right) \\ &\quad -\lambda\Delta\left[\alpha\left(\bar{x}_1^{HL} + \bar{x}_2^{LH}\right) + (1/2 - \alpha)\left(\bar{x}_1^{HH} + \bar{x}_2^{HH}\right)\right] \\ &\quad \text{and} \\ E[W_M] &= \alpha\left(w^{LL} + w^{HH}\right) + (1/2 - \alpha)\left(w^{LH} + w^{HL}\right) \\ &\quad -\lambda\Delta\frac{1}{2}\left[\alpha\left(\bar{x}_1^{HL} + \bar{x}_2^{LH}\right) + (1 - \alpha)\left(\bar{x}_1^{HH} + \bar{x}_2^{HH}\right)\right] \end{aligned}$$

where

$$w^{ij} = (1+\lambda)\left(a_1 - c_1^i\right)\bar{x}_1^{ij} + (1+\lambda)\left(a_2 - c_2^j\right)\bar{x}_2^{ij} - (1/2 + \lambda)\left(\left(\bar{x}_1^{ij}\right)^2 + \left(\bar{x}_2^{ij}\right)^2 + 2g\bar{x}_1^{ij}\bar{x}_2^{ij}\right)$$

and $\gamma = \gamma^A = 1/2$. Using the envelope theorem, the change in expected social welfare as α, and equivalently ρ, increases can be written:

$$\begin{aligned}
\frac{dE[W_D]}{d\alpha} &= \frac{\partial E[W_D]}{\partial \alpha} \\
&= w^{LL} + w^{HH} - w^{LH} - w^{HL} - \lambda\Delta\left[\bar{x}_1^{HL} + \bar{x}_2^{LH} - \bar{x}_1^{HH} - \bar{x}_2^{HH}\right] \\
\frac{dE[W_M]}{d\alpha} &= \frac{\partial E[W_M]}{\partial \alpha} \\
&= w^{LL} + w^{HH} - w^{LH} - w^{HL} - \lambda\Delta\frac{1}{2}\left[\bar{x}_1^{HL} + \bar{x}_2^{LH} - \bar{x}_1^{HH} - \bar{x}_2^{HH}\right]
\end{aligned}$$

Consider the difference $dE[W_D]/d\alpha - dE[W_M]/d\alpha$. First, $dE[R^1 + R^2]/d\alpha - dE[R]/d\alpha > 0$, since, for $r^D < \rho < r^1$, the optimal quantities under duopoly satisfy $\bar{x}_1^{HL} < \bar{x}_1^{HH}$ and $\bar{x}_2^{LH} < \bar{x}_2^{HH}$ while the optimal quantities under monopoly satisfy $\bar{x}_1^{HL} > \bar{x}_1^{HH}$ and $\bar{x}_2^{LH} > \bar{x}_2^{HH}$. Second, $w^{LL} + w^{HH} - w^{LH} - w^{HL}$ is higher under duopoly than under monopoly, since, for a given joint probability distribution and a given demand parameter value g, the regulator will always distort quantities in states LH or HL more and quantities in state HH less if the industry has a duopolistic compared to a monopolistic structure. Consequently, $dE[W_D]/d\alpha - dE[W_M]/d\alpha > 0$ for $g \in \langle -1, g^* \rangle$ and $\rho \in \langle r^D, r^1 \rangle$.

End of Proof.

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