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# Regulating Complementary Input Supply: Production Cost Correlation and Limited Liability

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ABSTRACT

**Regulating Complementary Input Supply: Production Cost Correlation and Limited Liability**

by Jos Jansen

We study the optimal regulation of complementary input supply. The regulator chooses for either a monopolist producing two complementary inputs in fixed proportion, or two independent firms producing one input each. Under independent input supply, non-monotonic regulatory schemes become optimal for high correlation between input production costs. The optimal regulatory choice depends on the correlation between costs, and on the producers' liability structure. Under limited liability monopolistic input supply gives a higher expected welfare whenever the correlation coefficient is sufficiently small and positive. For higher correlation independent input supply is chosen, and the regulatory scheme is non-monotonic in total costs.

ZUSAMMENFASSUNG

**Regulierung des Angebots komplementärer Inputs: Korrelation von Produktionskosten und beschränkte Haftung**

Dieser Beitrag untersucht die optimale Regulierung des Angebots zweier komplementärer Inputs. Der Regulierer entscheidet sich dabei entweder für einen Monopolisten, der zwei komplementäre Inputs in einem konstanten Verhältnis zu einander produziert oder für zwei unabhängige Firmen, die jeweils einen der Inputs produzieren. Bei unabhängigem Angebot des Inputs sind nicht monotone Regulierungsverträge optimal für den Fall einer hohen Korrelation zwischen den Produktionskosten der Inputs. Die optimale Regulierungsentscheidung hängt von der Korrelation zwischen Kosten und der Haftungsstruktur des Produzenten ab. Bei beschränkter Haftung führt das Inputangebot durch einen Monopolisten zu einer höheren erwarteten Wohlfahrt, wenn der Korrelationskoeffizient klein genug und positiv ist. Für höhere Korrelation wird das unabhängige Angebot der Inputs gewählt und die Regulierungsverträge sind hinsichtlich der Gesamtkosten nicht monoton.

# 1 Introduction

In most regulated industries the production of final output requires the production of more than one input. For example, for public utilities production and distribution are two distinct activities. In the telecom industry long-distance and local telephony services can be distinguished. Moreover, these inputs are perfectly complementary goods that are used in fixed proportions to produce the final output. Traditionally, final output is supplied by a regulated monopolist that produces both inputs. In the 1980s and 1990s, several countries decided to break up some of these monopolies. For example, in the US telecommunication market the long-distance telephony supply was separated from local telephony supply, and the supply of local telephone services was delegated to local monopolies. The new AT&T provides long-distance services and several Baby Bells serve the local markets.[1] In many European countries the incumbent PTTs still provide both local and long-distance telephone services.

In this setting a regulator faces the following organizational choice. Either all inputs are produced by one multi-product monopolist, or each input is produced by an independent input producer. A change of the industry's organization changes incentives of the industry's firms. The regulator can use this fact by choosing the firm's organizational structure such that the producers' incentives are best suited for maximizing social welfare. This regulatory choice is studied in this paper.

We abstract from technological reasons for choosing a certain organization of input supply. If the regulator would be fully informed about the inputs' production costs, and if he would have enough regulatory instruments, the firm's organizational structure would not matter. However, in a more realistic setting, the regulator is not completely informed about the input producers' costs. In order to receive truthful cost messages from the input supplier(s), the regulator has to pay the supplier(s) socially costly informational rents.

[1]The 1996 Telecommunications Act has allowed the Baby Bell in the long-distance telecom market, but this has not effectively changed the market structure so far.

To economize on these transfers, the regulator must commit to refrain from production in more states of nature than would otherwise be socially desirable. In the second-best solution, the regulator trades off the social cost of transfers against allocative efficiency. In such a situation the organization of input supply matters.

Optimal organization is determined by two conflicting effects. First, there is the "informational externality" effect, which is studied by Baron and Besanko (1992) and Gilbert and Riordan (1995). When one producer overstates his cost, this decreases the other producer's incentive to overstate his cost. Since independent input suppliers do not learn each other's cost message at the moment of message sending, the input producers are not able to correct their messages for this externality. Under monopolistic input supply the monopolist internalizes this externality. This gives the monopolist less incentives to overstate the individual input production costs. Therefore, the regulator saves informational rents by choosing monopolistic input supply. Second, there is the yardstick competition effect, as studied by Nalebuff and Stiglitz (1983) and Shleifer (1985). When production of the two inputs requires comparable technologies, the costs for providing these inputs is likely to be correlated. In that case, under independent input production each producer's cost message to the regulator gives some information about the other producer's cost. The regulator can exploit this fact by punishing the producers for sending messages that give unlikely cost combinations and by rewarding more likely ones. Thereby the regulator can extract some of the producers' surplus. Because a monopolistic input supplier can coordinate his cost messages, such a scheme does not work under monopolistic input supply.

Dana (1993) studies a similar organizational problem in a model where the supplied inputs are substitutes. The paper by Dana shows that for low enough correlation coefficients, monopolistic input supply is the regulator's optimal choice. For all other values of the correlation coefficient the yardstick competition effect still dominates. As we observed, there are important regulated industries in which the goods supplied are complements. In this paper we study the optimal regulatory scheme for these industries both under monopolistic and independent input supply. We show that a similar result holds true for an industry with perfectly complementary goods. The regulatory schemes that underpin the optimal organization of input supply, however, are quite different from that in Dana (1993). When inputs are needed in fixed proportions to produce the output, it would be socially wasteful to choose a regulatory scheme that does not respect these proportions. This means that quantity discrimination between independent input suppliers is not desirable. Therefore the regulator must rely more on the transfers to discriminate between independent suppliers.

The optimal regulatory scheme under independent input supply differs from that under monopolistic supply. Especially for highly correlated costs the optimal scheme under independent input supply is not monotonous in total costs, and, therefore, not feasible under monopolistic input supply. This gives rise to the yardstick competition effect. The occurrence of the yardstick competition effect depends on the regulator's possibility of punishing producers for sending unlikely (and unfavorable) cost messages. The regulator punishes a producer by letting him earn low profits or even suffer losses in some instances. The extent to which the regulator can force producers to suffer losses depends on the extent to which producers are protected by liability rules. We say that a producer's liability is limited when that producer cannot be forced to bear realized losses as a consequence of participating in the regulatory contract. This definition corresponds to limited zero-liability contracts as in Sappington (1983) and imposes an *ex post* participation constraint on the regulatory contract.

When producers have unlimited liability, they can be forced to bear *ex post* losses. Both Crémer and McLean (1985) and Demski and Sappington (1984) show that, under assumptions similar to ours — risk-neutral regulator and producers, positively correlated costs, and a binary support for the producers' state variables — the regulator can achieve the first-best solution under independent input supply.[2] He does this by punishing both producers severely in unlikely cost states. Under monopolistic input supply,

[2]These models study full rent extraction when products are substitutes. Similar optimal schemes are applicable when products are complementary. An exception to this regularity is the model described by Auriol and Laffont (1992). In that model the first-best solution is not reached for intermediate degrees of correlation because it contains an independently distributed cost component, besides a correlated one.

he can only reach a second-best solution (Baron and Myerson, 1982). That is, under unlimited liability, the yardstick competition effect dominates the "informational externality" effect for all positive correlation coefficients.

In order to fully extract producers' rents, the regulator must force the producers to bear *ex post* losses for unlikely cost combinations. For small, but positive correlation between the costs the scheme that implements the first-best solution relies on severe *ex post* losses. When producers are protected by limited liability, they cannot be forced to bear such losses. In that case the smaller the correlation between costs, the bigger the extent to which the regulatory scheme differs from the full rent extracting scheme. Therefore, the smaller the cost correlation, the smaller the extracted rents, and the weaker the yardstick competition effect.

If costs are independently distributed, there is no yardstick competition effect, while the "informational externality" effect still holds. Then under both limited and unlimited liability, monopolistic input supply is the best organizational choice for a regulator. This is illustrated in Baron and Besanko (1992) and Gilbert and Riordan (1995), respectively. If costs are perfectly correlated, the distinction between limited and unlimited liability disappears. In this situation the yardstick competition effect clearly dominates the "informational externality" effect. Moore (1992) shows that the first-best can be uniquely implemented under independent input supply.[3]

Recent studies analyze the optimal organization of regulated industries in different settings. Severinov (1997) studies how the optimal industrial organization of firms with independently distributed private information on production costs depend on the substitutability of products. Iossa (1999) studies optimal organization in a model in which firms have private information about a demand intercept. Jeon (1998), and Laffont and Martimort (1997) endogenize the cost of independent input supply by considering collusion between agents. Finally Dalen (1998) compares firms' incentives to invest in process innovation in a setting with correlated private cost infor-

[3]In order to obtain uniqueness, multi-stage mechanisms in combination with the subgame perfect equilibrium refinement are necessary. Multi-stage mechanisms are not studied in this paper. Nalebuff and Stiglitz (1983) and Shleifer (1985) show that the truthtelling first-best is one of the equilibria of the optimal mechanism.

mation.

The paper is organized as follows. The model of optimal organizational choice is described in section 2. In section 3 we derive the equilibrium choices of the regulator and the input producers given the choice on the organization of input production. A comparison between monopolistic and independent input supply is made in section 4. Section 5 concludes the paper.

# 2 The Model

The players of the regulation game are the regulator, and the production units of input 1 and 2. The production of one unit of an indivisible output with social value $V$ requires the supply of one unit of input 1 and one unit of input 2. The cost of producing input $i$, $\theta_i$ $(i = 1, 2)$, can be either high, $\overline{\theta}$, or low, $\underline{\theta}$, with $0 < \underline{\theta} < \overline{\theta}$. The players play a 5-stage game with incomplete information. Chronologically, the following choices are made.

In the first stage of the game the regulator chooses either monopolistic or independent input supply. This decision induces two subgames: the subgame after choosing monopolistic input supply, and the subgame for independent input supply. These subgames are described in the remainder of this section.

In the *monopolistic input supply* (MIS) subgame, the regulator sets a transfer scheme $T : \{2\underline{\theta}, \underline{\theta} + \overline{\theta}, 2\overline{\theta}\} \to \Re$ that specifies the transfer from the regulator to the monopolist in case the monopolist's report on total cost of production is $2\underline{\theta}$, $\underline{\theta} + \overline{\theta}$ and $2\overline{\theta}$, respectively. The transfer is not conditional on whether or not production takes place. Furthermore, the regulator lets production occur with probability $Q^M : \{2\underline{\theta}, \underline{\theta} + \overline{\theta}, 2\overline{\theta}\} \to [0, 1]$.[4]

[4]It suffices to focus attention to a regulatory scheme that depends on total reported costs $\widetilde{\Theta} = \widetilde{\theta}_1 + \widetilde{\theta}_2$ only, since the inputs are perfect complements. Because the inputs are produced in fixed proportion, the incentives of the regulator as well as the monopolist are symmetric in the components' costs. If the regulator would offer an asymmetic scheme, either the monopolist, or himself would be better off choosing only one of the schemes for $(\underline{\theta}, \overline{\theta})$ as well as $(\overline{\theta}, \underline{\theta})$. The regulator can therefore do no better than offering a scheme that is symmetric in cost reports.

In a model with divisible output, choosing $Q^M(.)$ would be regulation of quantities. In a fully regulated industry regulated quantity is in a one-to-one relation to price through consumers' demand. Then regulation of $Q^I(.)$ is equivalent to price regulation. Due to the linearity of the present model, it is optimal for the regulator to either require or forbid production with probability one.

Nature chooses the costs for producing input 1 and 2 in the third stage of the game by drawing these costs from a symmetric probability density. The prior probabilities are shown in Table 2.1. In this table we depict prior probabilities $\Pr[\theta_1, \theta_2]$, for $\theta_1, \theta_2 \in \{\underline{\theta}, \overline{\theta}\}$.

| | $\theta_1$: $\underline{\theta}$ | $\theta_1$: $\overline{\theta}$ |
|---|---|---|
| $\theta_2$: $\underline{\theta}$ | $p^L$ | $q$ |
| $\theta_2$: $\overline{\theta}$ | $q$ | $p^H$ |

[Table 1: prior probabilities]

Note that the correlation coefficient is $\rho = \frac{p^L p^H - q^2}{(p^L+q)(p^H+q)}$. This means that when $q = \sqrt{p^L p^H}$ the production costs of the inputs are independently drawn from the distribution. When $q = 0$ there is perfect positive correlation between the production costs of the inputs. We assume that $\rho \geq 0$, or $0 \leq q \leq \sqrt{p^L p^H}$. The monopolist learns the production costs of both inputs, $\theta_1$ and $\theta_2$.The regulator is not informed about the production costs of input 1 and 2.

Due to the revelation principle (e.g. see Myerson 1982, Proposition 2), the regulator can focus on direct revelation mechanisms without loss of generality. Given the regulatory scheme, the monopolist sends a message about his total cost to the regulator in the fourth stage of the game. The monopolist sends message $\widetilde{\Theta} \in \{2\underline{\theta}, \underline{\theta} + \overline{\theta}, 2\overline{\theta}\}$, and the regulator's instruments are a function of these messages, $\{T(\widetilde{\Theta}), Q^M(\widetilde{\Theta})\}$.

Given these instruments and his cost message, the monopolist decides whether or not to participate in the regulatory scheme in the fifth stage of the game. In case he decides not to participate, he gets zero profits. Whenever the monopolist chooses to participate, the scheme is implemented in the last stage of the game.

Given the regulator's first-stage choices and the second-stage private information, the monopolist maximizes his expected profit. The regulator maximizes expected social welfare, which is defined as the sum of total expected profits and the net consumers' surplus, allowing for distributional distortions caused by taxes. If the monopolist participates in the scheme, then social welfare is defined as:

$$W^M(\widetilde{\Theta}, \Theta) = VQ^M(\widetilde{\Theta}) - (1+\lambda)T(\widetilde{\Theta}) + \Pi(\widetilde{\Theta}, \Theta)$$

where $V$ is the social value of the produced output, $\lambda$ represents the social cost of public funds,[5] and the monopolist's expected profit is:

$$\Pi(\widetilde{\Theta}, \Theta) = T(\widetilde{\Theta}) - \Theta Q^M(\widetilde{\Theta}),$$

with $\Theta, \widetilde{\Theta} \in \{2\underline{\theta}, \underline{\theta} + \overline{\theta}, 2\overline{\theta}\}$.

In the *independent input supply* (IIS) subgame, the regulator sets a transfer scheme $(t^1, t^2) : \{\underline{\theta}, \overline{\theta}\} \times \{\underline{\theta}, \overline{\theta}\} \rightarrow \Re \times \Re$ with transfers from the regulator to the producer of input 1 and 2, respectively. Furthermore he chooses a probability of production $Q^I : \{\underline{\theta}, \overline{\theta}\} \times \{\underline{\theta}, \overline{\theta}\} \rightarrow [0,1]$. The input production costs are drawn from the same prior probability distribution as under MIS. Each producer is privately informed about his own cost, while communication between the two input producers about their costs is not possible. The regulator is not informed about the production costs of input 1 and 2. Given the regulatory scheme, the input producers simultaneously and independently send a message about their costs to the regulator in the fourth stage of the game. Input producer $i$ sends message $\widetilde{\theta}_i$ for $i = 1, 2$, and the regulator's instruments are a function of these messages, $\{t^1(\widetilde{\theta}), t^2(\widetilde{\theta}), Q^I(\widetilde{\theta})\}$, where $\widetilde{\theta} = (\widetilde{\theta}_1, \widetilde{\theta}_2) \in \{\underline{\theta}, \overline{\theta}\} \times \{\underline{\theta}, \overline{\theta}\}$.

In the fifth stage of the game the input producers learn each others' costs and decide whether or not to participate in the regulatory scheme. This stage reflects the producers' limited liability. Unlimitedly liable producers would have to make their participation decision in the third stage of the game on basis of interim profit evaluation. If one input producer decides not to participate, both producers receive zero profit; if both input producers choose to participate, the regulatory scheme is implemented.

[5] In some other models of regulatory economics, e.g. Baron and Myerson (1982), social welfare is defined as the weighted sum of consumers' surplus and industry's profits, $W = VQ + \alpha\Pi$, with $0 \leq \alpha < 1$. Such a specification gives similar qualitative results.

Given the regulator's first-stage choices and the second-stage private information, each input producer maximizes his expected profit. If both input producers participate in the scheme, social welfare is defined as:

$$W^I(\widetilde{\theta},\theta) = VQ^I(\widetilde{\theta}) - (1+\lambda)[t^1(\widetilde{\theta}) + t^2(\widetilde{\theta})] + [\pi_1(\widetilde{\theta},\theta) + \pi_2(\widetilde{\theta},\theta)],$$

and firm $i$'s expected profit is:

$$\pi_i(\widetilde{\theta},\theta) = t^i(\widetilde{\theta}) - \theta_i Q^I(\widetilde{\theta}), \text{ with } \theta = (\theta_1,\theta_2) \text{ and } i = 1,2.$$

A sketch the timing of the game is depicted in Table 2.2. Denote the monopolist by M, and independent input supplier 1 (resp. 2) by I1 (resp. I2).

| | | |
|---|---|---|
| $t = 1.1$ | Regulator: MIS | Regulator: IIS |
| $t = 1.2$ | Regulator: $\{T(.), Q^M(.)\}$ | Regulator: $\{t^1(.), t^2(.), Q^I(.)\}$ |
| $t = 2$ | M learns costs: $(\theta_1,\theta_2) \in \{\underline{\theta},\overline{\theta}\}^2$ | I1 learns cost $\theta_1 \in \{\underline{\theta},\overline{\theta}\}$<br>I2 learns cost $\theta_2 \in \{\underline{\theta},\overline{\theta}\}$ |
| $t = 3$ | M sends message: $\widetilde{\Theta} \in \{2\underline{\theta}, \underline{\theta}+\overline{\theta}, 2\overline{\theta}\}$ | I1 sends message: $\widetilde{\theta}_1 \in \{\underline{\theta},\overline{\theta}\}$<br>I2 sends message: $\widetilde{\theta}_2 \in \{\underline{\theta},\overline{\theta}\}$ |
| $t = 4$ | | I1,I2 learn each others costs<br>I1,I2 accept/reject scheme |
| $t = 5$ | Implement scheme | Implement scheme |

[Table 2: sequence of moves]

We solve the game backwards. In the next section we solve the game up to the regulator's industrial organization choice. Section 4 closes the model's analysis by characterizing the optimal organizational choice for the regulator.

# 3 The Optimal Instruments

In this section we study the equilibrium strategies of the regulator and input producer(s) given the organization of input supply. In the first subsection we characterize the optimal regulatory scheme under monopolistic input supply. The second subsection characterizes the optimal scheme under independent input supply. All proofs are relegated to the Appendix.

## 3.1 Monopolistic Input Supply (MIS)

The regulatory problem under MIS is similar to that in Baron and Myerson (1982). This means that the regulator faces the following mechanism design problem:

$$\max_{\{T(.),Q^M(.)\}} E_\Theta\{W^M(\Theta,\Theta)\}$$

s.t.

$$\Pi(\Theta,\Theta) \geq \Pi(\widetilde{\Theta},\Theta) \tag{1}$$

$$\Pi(\Theta,\Theta) \geq 0, \text{ for all } \Theta,\widetilde{\Theta} \in \{2\underline{\theta},\underline{\theta}+\overline{\theta},2\overline{\theta}\}. \tag{2}$$

Inequality (1) is the incentive compatibility constraint, which states that it is optimal for the monopolist to reveal its true costs. Inequality (2) is the monopolist's participation constraint. A regulatory scheme that satisfies both (1) and (2), is called feasible. In this standard setting the regulatory instrument scheme is feasible if and only if the probability with which production occurs is non-increasing in the monopolist's cost message, i.e., $0 \leq Q^M(2\overline{\theta}) \leq Q^M(\underline{\theta}+\overline{\theta}) \leq Q^M(2\underline{\theta}) \leq 1$.

Given a non-increasing probability of the production scheme, we can easily derive the optimal transfers.

**Lemma 1** *For MIS the optimal transfers are such that they reimburse the monopolist's expected cost and give him an informational rent that is non-increasing in his costs:*

$$T(C) = \Theta Q^M(\Theta) + (\overline{\theta}-\underline{\theta})\sum_{\widetilde{\Theta}>\Theta} Q^M(\widetilde{\Theta}), \textit{ for } \Theta \in \{2\underline{\theta},\underline{\theta}+\overline{\theta},2\overline{\theta}\}.$$

Analogous to Baron and Myerson (1982), this second-best transfer scheme is non-increasing in the monopolist's cost message.

After substituting for the optimal transfers in the expected welfare function, the maximization problem becomes:

$$\max_{\{Q^M(.)\}} \{Q^M(2\overline{\theta})p^H w^M(2\overline{\theta}) + Q^M(\underline{\theta}+\overline{\theta})2qw^M(\underline{\theta}+\overline{\theta}) + Q^M(2\underline{\theta})p^L w^M(2\underline{\theta})\}$$

s.t. $0 \leq Q^M(2\overline{\theta}) \leq Q^M(\underline{\theta}+\overline{\theta}) \leq Q^M(2\underline{\theta}) \leq 1,$

with

$$w^M(\Theta) = V - (1+\lambda)\Theta - \lambda \frac{\Pr[\theta_1 + \theta_2 < \Theta]}{\Pr[\theta_1 + \theta_2 = \Theta]}(\overline{\theta} - \underline{\theta}), \text{ for } \Theta \in \{2\underline{\theta}, \underline{\theta} + \overline{\theta}, 2\overline{\theta}\},$$

the "virtual welfare" at cost $\Theta$, i.e., the social value of the output minus the social costs of production minus informational rents. Because informational rents are non-negative, the second-best probabilities of production are such that in some cases production does not occur despite the fact that it would be desirable in the first-best. The probability scheme trades off allocative efficiency and informational rent saving.

It is easily verified that the "virtual welfare" is non-increasing in production costs for probabilities $q$ that exceed the critical value:

$$q^M = \frac{p^H(1-p^H)}{2(p^H \frac{1+\lambda}{\lambda} + 1)}.$$

At the optimum, production takes place whenever the "virtual welfare" is non-negative, which gives a non-increasing probability scheme. This is stated in the following lemma.

**Lemma 2** *For MIS and $q \geq q^M$, production takes place with certainty whenever the "virtual welfare" is positive, and there is no production otherwise:*

$$Q^M(\Theta) = \begin{cases} 1, \ \textit{if } w^M(\Theta) \geq 0 \\ 0, \ \textit{otherwise} \end{cases}, \textit{for } \Theta \in \{2\underline{\theta}, \underline{\theta} + \overline{\theta}, 2\overline{\theta}\}.$$

For lower values of $q$ (high correlation) the "virtual welfare" is no longer monotonous in costs, since $w^M(\underline{\theta} + \overline{\theta}) < w^M(2\overline{\theta})$. Analogous to Myerson (1981) the solution is found by equalizing the probabilities of production for costs $(\underline{\theta} + \overline{\theta})$ and $2\overline{\theta}$, and maximizing expected welfare given that constraint. This is stated in the following lemma.

**Lemma 3** *For MIS and $q < q^M$, (i) if both production units have low costs, production takes place with certainty whenever the "virtual welfare" is positive:*

$$Q^M(2\underline{\theta}) = \begin{cases} 1, \ \textit{if } w^M(2\underline{\theta}) \geq 0 \\ 0, \ \textit{otherwise,} \end{cases}$$

*(ii) for other cost combinations, production takes place with certainty whenever the conditional expected "virtual welfare" of production, given at least one high cost production unit, is positive:*

$$Q^M(\underline{\theta}+\overline{\theta}) = Q^M(2\overline{\theta}) = \begin{cases} 1, \ \text{if } 2qw^M(\underline{\theta}+\overline{\theta}) + p^H w^M(2\overline{\theta}) \geq 0 \\ 0, \ \text{otherwise.} \end{cases}$$

In the next subsection we analyze the optimal regulatory scheme under independent input supply.

## 3.2 Independent Input Supply (IIS)

The regulatory problem under IIS is related to that in Dana (1993). While Dana studies an industry with substitutable inputs, we study complementary input supply. Since the inputs are needed in fixed proportions to produce the output, it would be socially wasteful to choose discriminatory probabilities of production. This reduces the number of instruments that the regulator can use effectively. The regulator solves the following mechanism design problem:

$$\max_{\{t^1(.),t^2(.),Q^I(.)\}} E_\theta\{W^I(\theta,\theta)\}$$

s.t.

$$E_{\theta_j}\{\pi_i(\theta,\theta)\} \geq E_{\theta_j}\{\pi_i[(\widetilde{\theta}_i,\theta_j),\theta]\}, \quad \text{for all } i,j=1,2,\ j\neq i, \text{ and } \theta_i,\widetilde{\theta}_i \in \{\underline{\theta},\overline{\theta}\} \tag{3}$$

$$\pi_i(\theta,\theta) \geq 0, \text{ for all } i=1,2, \text{ and } \theta_1,\theta_2 \in \{\underline{\theta},\overline{\theta}\}. \tag{4}$$

Inequalities (3) are the input producers' incentive compatibility constraints. The regulatory instruments induce truthful cost revelation in Bayesian equilibrium. Restriction (4) is the *ex post* participation constraint. Due to the limited liability assumption, an input producer must receive non-negative profits in all states of nature to induce his participation.

The regulator must give a low-cost input producer an informational rent that eliminates the producer's incentive to overstate his cost. Also for this problem there is a critical value, $q^I$, above which the "virtual welfare" is non-increasing in total production costs. This critical value is equal to:

$$q^I = \frac{1}{4}\sqrt{p^H}\left\{\sqrt{p^H\left(1+\frac{6}{\lambda}+\frac{1}{\lambda^2}\right)+8} - \sqrt{p^H}\left(\frac{1+3\lambda}{\lambda}\right)\right\}.$$

Notice that $q^I \leq \frac{1}{3}(1-p^H)$.[6] For $q \geq q^L$ (relatively low correlation between producers' costs) the transfer scheme is similar to the MIS scheme, which is stated in the following proposition.

**Proposition 1** *For IIS and $q \geq q^I$ the optimal transfers are such that they reimburse the producers' expected costs and they give an informational rent to each low-cost producer:*

$$t^1(\theta_1, \theta_2) = \theta_1 Q^I(\theta_1, \theta_2) + (\overline{\theta} - \underline{\theta}) \sum_{\widetilde{\theta}_1 > \theta_1} Q^I(\widetilde{\theta}_1, \theta_2), \text{ for } \theta_1, \theta_2 \in \{\underline{\theta}, \overline{\theta}\}.$$

*Producer 2 receives similar transfers.*

These transfers do not implement truth-telling in a unique Bayesian equilibrium. For each producer with low cost, $\underline{\theta}$, the transfer scheme makes him indifferent between truth-telling and cost overstating, irrespective of the other producer's message sending strategy. We can avoid "bad" equilibria and approximately maintain the optimal expected welfare level by slightly changing the regulatory scheme. This is stated in the following proposition.

**Proposition 2** *Define $\Delta\theta = \overline{\theta} - \underline{\theta}$. For IIS and $q \geq q^I$ the regulator can stay arbitrarily close to the optimal welfare level and induce truthful revelation of the producers' costs as a (interim) dominant strategies Bayesian equilibrium, by making the following changes to the optimal regulatory scheme, for $\varepsilon, \delta > 0$ small, with $\varepsilon \ll \Delta\theta$. Increase $t^1(\underline{\theta}, \underline{\theta})$, $t^1(\underline{\theta}, \overline{\theta})$, $t^2(\underline{\theta}, \underline{\theta})$ and $t^2(\overline{\theta}, \underline{\theta})$ with $\varepsilon$.*
*(i) If $Q^I(.) = 0$, choose $Q^I(\underline{\theta}, \underline{\theta}) = 2(\frac{\varepsilon}{\Delta c} + \delta)$ and $Q^I(\underline{\theta}, \overline{\theta}) = Q^I(\overline{\theta}, \underline{\theta}) = \frac{\varepsilon}{\Delta c} + \delta$.*
*(ii) If only $Q^I(\underline{\theta}, \underline{\theta}) = 1$, choose $Q^I(\underline{\theta}, \overline{\theta}) = Q^I(\overline{\theta}, \underline{\theta}) = \frac{\varepsilon}{\Delta c} + \delta$.*
*(iii) If only $Q^I(\overline{\theta}, \overline{\theta}) = 0$, choose $Q^I(\underline{\theta}, \overline{\theta}) = Q^I(\overline{\theta}, \underline{\theta}) = 1 - (\frac{\varepsilon}{\Delta c} + \delta)$.*
*(iv) If $Q^I(.) = 1$, choose $Q^I(\underline{\theta}, \overline{\theta}) = Q^I(\overline{\theta}, \underline{\theta}) = 1 - (\frac{\varepsilon}{\Delta c} + \delta)$ and $Q^I(\overline{\theta}, \overline{\theta}) = 1 - 2(\frac{\varepsilon}{\Delta c} + \delta)$.*

[6] Since $q^I$ increases in $\lambda$, it suffices to check whether $\lim_{\lambda \to \infty} q^I = \frac{1}{4}\sqrt{p^H}(\sqrt{p^H + 8} - 3\sqrt{p^H}) \leq \frac{1}{3}(1-p^H)$. That is, $\frac{1}{12}[3\sqrt{p^H(p^H+8)} - (4 + 5p^H)] \leq 0$. Since this function increases in $p^H$, and for $p^H = 1$ the function equals 0, $q^I \leq \frac{1}{3}(1-p^H)$ is established. Note that $q < q^I \leq \frac{1}{3}(1-p^H)$, is equivalent to $q < p^L$.

For lower $q$ (high correlation) the regulator rewards producers by paying them informational rents only if they both report low costs, but not otherwise. This gives the producers optimal incentives to reveal their costs. This is stated in the following proposition.

**Proposition 3** *For IIS and $q < q^I$ the optimal transfers reimburse each producer's expected cost and give an informational rent only if both producers report low production costs:*

$$\begin{aligned} t^1(\underline{\theta}, \underline{\theta}) &= \underline{\theta} Q^I(\underline{\theta}, \underline{\theta}) + (\overline{\theta} - \underline{\theta})[Q^I(\overline{\theta}, \underline{\theta}) + \frac{q}{p^L} Q^I(\overline{\theta}, \overline{\theta})] \\ t^1(\theta_1, \theta_2) &= \theta_1 Q^I(\theta_1, \theta_2), \text{ for } (\theta_1, \theta_2) \neq (\underline{\theta}, \underline{\theta}). \end{aligned}$$

*Producer 2 receives similar transfers.*

These transfers do not implement truth-telling in an (interim) dominant strategy Bayesian equilibrium. Moreover, dominance cannot be obtained by means of arbitrary small changes in the regulatory scheme. This is stated in the following proposition.

**Proposition 4** *For IIS and $q < q^I$ an arbitrary small change in the optimal regulatory scheme does not give truth-telling as a Bayesian equilibrium in (interim) dominant strategies whenever $Q^I(\overline{\theta}, \overline{\theta}) > 0$.*

Since a Bayesian equilibrium cannot be obtained in dominant strategies, the cost messages that producers send to the regulator will depend on their expectations about the other producer's cost message strategy. This problem could be overcome by using non-direct revealing mechanisms, as in Moore (1992).

Propositions 2 and 4 imply that the possibility of implementation of the optimal expected welfare level by dominant strategies, depends on $q$. Whenever producers' costs are only slightly correlated, implementation in dominant strategies is possible. For highly correlated costs, this is no longer the case.

After substituting the optimal transfers in the regulator's optimization problem and observing that this problem is symmetric in probabilities $Q^I(\underline{\theta}, \overline{\theta})$

and $Q^I(\overline{\theta},\underline{\theta})$, we obtain the following optimization problem:

$$\max_{\{Q^I(.)\}}\{Q^I(2\overline{\theta})p^H w^I(\overline{\theta},\overline{\theta})+Q^I(\underline{\theta}+\overline{\theta})q[w^I(\underline{\theta},\overline{\theta})+w^I(\overline{\theta},\underline{\theta})]+Q^I(2\underline{\theta})w^I(\underline{\theta},\underline{\theta})\}$$
$$\text{s.t. } 0\leq Q^I(\theta_1+\theta_2)\leq 1, \text{ for } \theta_1,\theta_2\in\{\underline{\theta},\overline{\theta}\},$$

where

$$w^I(\widetilde{\theta})=V-(1+\lambda)(\widetilde{\theta}_1+\widetilde{\theta}_2)-\lambda\frac{\sum_{i=1}^2 \Pr[\theta_i<\widetilde{\theta}_i,\theta_j=\widetilde{\theta}_j]}{\Pr[\theta=\widetilde{\theta}]}(\overline{\theta}-\underline{\theta})$$

is the "virtual welfare" at costs $(\widetilde{\theta}_1,\widetilde{\theta}_2)$ under IIS. Due to symmetry $w^I(\underline{\theta},\overline{\theta})=w^I(\overline{\theta},\underline{\theta})$, which makes $w^I(.)$ a function of total costs only. Given the optimal transfer scheme of IIS, incentive constraints do not put any restriction upon the probabilities of production. Note that under MIS the probability scheme was required to be non-increasing in total costs.

It is easy to check that the following proposition holds.

**Proposition 5** *For IIS the optimal probabilities of production are such that production takes place with certainty whenever the virtual value of welfare is positive:*

$$Q^I(\theta_1+\theta_2)=\begin{cases}1, & \textit{if } w^I(\theta_1+\theta_2)\geq 0\\ 0, & \textit{otherwise}\end{cases}, \textit{ for } \theta_1,\theta_2\in\{\underline{\theta},\overline{\theta}\}.$$

For small values of $q$ (i.e. $q<q^I$, high correlation) monotonicity of $w^I(.)$ breaks down. In that case, the optimal $Q^I(.)$ is no longer monotonous in total production costs. By making $Q^I(\underline{\theta}+\overline{\theta})$ smaller than $Q^I(2\overline{\theta})$ the regulator saves informational rents. Under IIS the regulator chooses a probability of production scheme that is not feasible under MIS. Therefore the choice for IIS enables the regulator to save more rents than under MIS.

The optimal transfer and probability of production schemes differ from those obtained in the substitutable products case studied by Dana (1993). As we noted before, it is not optimal to choose discriminatory probabilities of production when inputs are perfect complements. Because of this, the regulator has to rely more on the transfers to discriminate between input producers. He does this especially when cost correlation becomes high, i.e.

$q < q^I$, by shifting all informational rents to the $(\underline{\theta}, \underline{\theta})$ state of nature, which is not optimal in Dana (1993).

If the producers would have *unlimited* liability and costs are positively correlated, the first-best expected welfare can be implemented, see e.g. Crémer and McLean (1985). This requires a regulatory scheme with large *ex post* punishments and rewards for low degrees of correlation. For firms that are protected by limited liability laws these punishment are not feasible for the regulator. The best he can do then is choose the schemes of propositions 1, 3 and 5.

# 4 The Optimal Organizational Choice

The propositions in the previous section illustrate the difference between the optimal monopolistic and independent regulatory schemes. In this section we study which scheme yields the higher expected social welfare. The theorem's proof is relegated to the Appendix.

For high values of $q$ (low correlation coefficients) the optimal probabilities of production under both MIS and IIS are non-increasing in the producers' total cost. This means that there are transfer schemes that implement the optimal independent supply probabilities of production, $Q^I(.)$ under MIS. It is easy to show that the expected transfer payment that implements $Q^I(.)$ under MIS, $E_\Theta\{T(\Theta)\}$, is smaller than the expected total transfers under IIS, $E_\theta\{t^1(\theta)+t^2(\theta)\}$. In state $(\underline{\theta}, \underline{\theta})$ the regulator needs to give both independent input suppliers an incentive not to overstate their costs. A monopolistic input supplier with costs $(\underline{\theta}, \underline{\theta})$ must effectively only be induced not to say that he has intermediate cost $\underline{\theta} + \overline{\theta}$. Because the monopolist coordinates his cost messages, he internalizes the externality that a cost overstatement causes on the other input producer. This effect is called the "informational externality" effect.

For low values of $q$ (high correlation coefficients) the incentive constraints for the probabilities of production under MIS become binding. Because the optimal production probabilities under IIS do not obey these monotonicity constraints, they are not feasible for the MIS problem. The non-monotonous probability scheme saves informational rents. By conditioning each independent suppliers' informational rents on both suppliers' cost message, the regulator can extract some of their rents. This is called the yardstick competition effect. Due to this effect, IIS yields higher expected welfare than MIS for low $q$.

The following theorem shows how the optimal organizational structure depends on $q$. Define the critical values:

$$\bar{q}^1 = \frac{1}{4}\sqrt{p^H}\left[\sqrt{p^H\left(\frac{4}{\lambda}+\frac{1}{\lambda^2}\right)+4}-\sqrt{p^H}\left(\frac{1+2\lambda}{\lambda}\right)\right],\ \bar{q}^2 = \frac{p^H(1-p^H)}{p^H\left(\frac{1+2\lambda}{\lambda}\right)+1}, \text{ and}$$

$$\bar{v} = \frac{p^H}{p^H-2q}\left[(1+\lambda)2\overline{\theta}+\lambda\frac{2q}{p^H}(\overline{\theta}-\underline{\theta})\right]-\frac{2q}{p^H-2q}\left[(1+\lambda)(\underline{\theta}+\overline{\theta})+\lambda\frac{p^L}{2q}(\overline{\theta}-\underline{\theta})\right].$$

**Theorem 1** *The regulator chooses:*
*(i) MIS, for* $q \geq \max\{\bar{q}^1, \bar{q}^2\}$,
*(ii) MIS only if* $V < \bar{v}$, *for* $\bar{q}^1 < q < \bar{q}^2$,
*(iii) IIS only if* $V < \bar{v}$, *for* $\bar{q}^2 < q < \bar{q}^1$,
*(iv) IIS, for* $q \leq \min\{\bar{q}^1, \bar{q}^2\}$.

Figure 1 illustrates regions (i) until (iv) for $\lambda = 1$. Along the horizontal axis we depict $p^H$, while probability $q$ is along the vertical axis. The dotted line represents critical value $\overline{q}^1$, and the thin line stands for critical value $\overline{q}^2$.

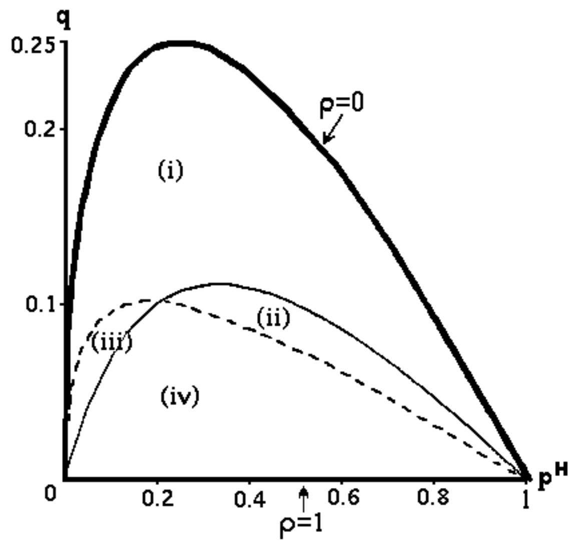


Figure 1: regions (i)-(iv)

The theorem confirms that the regulator prefers IIS for high correlation, while he prefers MIS for low correlation. This is intuitive given the presence of the yardstick competition and informational externality effect.

An alternative interpretation of the theorem is the following. For big enough $q$ the regulator's choice of the industry's organization depends on the firms' liability structure. If firms have unlimited liability, the regulator can punish independent input suppliers severely for unlikely and unfavorable cost combinations, and thereby extract all informational rents. Limited liability puts a binding upper bound to the independent input suppliers' punishments which makes the regulator prefer monopolistic input supply. This means that both the cost correlation and the producers' liability structure influence the optimal organizational structure of complementary input supply.

# 5 Conclusion

In this paper we showed that the optimal organizational structure of regulating complementary input supply trades off two effects. The yardstick competition effect occurs when costs are correlated. A multi-product monopolist can coordinate the reports that he sends to the regulator. Independent firms, however, send reports independently. The regulator can extract some of the independent firms' rents by comparing the firms' reports and rewarding or punishing firms on the basis of this comparison. The second effect is the informational externality effect, and is most powerful when costs are independently distributed. Because independent firms send reports independently, they do not internalize the externality that their reports has on the other firm's payoff. The regulator must therefore give both firms an incentive to not overstate their costs. A monopolistic input supplier internalizes this externality, and this saves rents for the regulator. The yardstick competition is strongest when costs are highly correlated. When costs are independent, the yardstick competition effect disappears. This implies that complementary activities with highly correlated costs are best regulated by creating two separate firms each performing one activity only. In contrast, complementary activities with low cost correlation are best regulated by having one firm that performs both activities.

Not only cost correlation, but also the liability structure of input producers matters, when costs have a small, non-negative correlation coefficient. For small, non-negative correlation coefficients, a social welfare maximizing regulator prefers monopolistic input supply when the producers are protected by limited liability, while he prefers independent input supply under unlimited liability. Under unlimited liability and positive cost correlation, the regulator extracts all the independent suppliers' rents by punishing an input supplier severely in unfavorable and unlikely states of nature and rewarding them in other states. Limited liability makes these punishments infeasible, since producers must receive non-negative profits in all states of nature. Therefore, in industries consisting of suppliers with limited liability the yardstick competition effect is weaker than in industries with unlimitedly liable firms. Higher correlation coefficients make independent input supply more desirable for the welfare optimizing regulator under both limited and unlimited liability.

The regulatory schemes that implement the optimal expected welfare level in our model are quite different compared to that in Dana (1993), where goods are divisible substitutes.

In our model the choice between monopolistic and independent input supply is made before costs are reported, and are therefore, in a sense, exogenous. Endogenizing the organizational choice of the regulator by procuring the control over input production between two bidders could give interesting new insights in the current problem.

It could also be worthwhile to investigate the implications of this paper's insights for the problem of access pricing. In the problem of access pricing a monopolistic firm supplies both a bottleneck facility and a final good that makes use of this facility. There are also other final good suppliers that need the bottleneck facility. In comparison with this paper, the monopolistic firm's incentives to report costs truthfully are distorted, because his cost messages affect competition in the final goods market. If the regulator separates the facility provider from the final good producer, this distortion vanishes. This would save informational rents. However, separation triggers the informational externality effect, which costs the regulator rents. Whether or not separation of the monopolist is socially desirable, needs to be explored.

# 6 Appendix

The first subsection of this Appendix contains the proof to lemmas 1, 2 and 3, which concern optimal monopolistic input supply schemes. The second subsection gives the proof to propositions 1, 3 and 5, and to 2 and 4, which concerns the optimal regulatory schemes under independent input supply. The last subsection of this Appendix proves theorem 1, which concerns the optimal organization of input supply.

## 6.1 MIS: Proof of Lemmas 1, 2 and 3

Note that the welfare optimization problem under MIS is a linear programming problem. Suppose that the $2\overline{\theta}$-monopolist's participation constraint is binding with slack variable $\hat{s}^h = \lambda$, where $\lambda$ is the social cost of public funds. This gives transfer $T(2\overline{\theta})$ in lemma 1. Take the incentive compatibility constraint of a $(\underline{\theta} + \overline{\theta})$-monopolist overstating his cost binding, and set its slack variable $\hat{s}^{H|m} = \lambda(1 - p^H)$. This results in transfer $T(\underline{\theta} + \overline{\theta})$. Take the incentive compatibility constraint for a $2\underline{\theta}$-monopolist claiming to be $(\underline{\theta} + \overline{\theta})$ binding with slack variable $\hat{s}^{m|L} = \lambda p^L$. This determines transfer $T(2\underline{\theta})$ of lemma 1. Finally we suppose that neither the incentive constraints for understating costs are never binding, nor the participation constraints for low and middle total costs are binding. We can write down the following reduced dual problem for the remaining slack variables $s_Q^L, s_Q^m, s_Q^H$ of the probability feasibility constraints, $Q^M(.) \leq 1$, and the incentive compatibility constraint of a $2\underline{\theta}$-cost monopolist claiming to have total costs $2\overline{\theta}$, $s^{H|L}$:

$$\min_{s \geq \mathbf{0}} \left\{ s_Q^L + s_Q^m + s_Q^H \right\}$$

$$\text{s.t.} \begin{cases} s_Q^L \geq p^L[V - (1+\lambda)2\underline{\theta}] \\ s_Q^m - (\overline{\theta} - \underline{\theta})s^{H|L} \geq 2q[V - (1+\lambda)(\underline{\theta} + \overline{\theta}) - \lambda \frac{p^L}{q}(\overline{\theta} - \underline{\theta})] \\ s_Q^H + (\overline{\theta} - \underline{\theta})s^{H|L} \geq p^H[V - (1+\lambda)2\overline{\theta} - \lambda \frac{1-p^H}{p^H}(\overline{\theta} - \underline{\theta})] \end{cases}$$

for $s_Q^L, s_Q^m, s_Q^H, s^{H|L} \geq 0$.

For $q \geq q^M$ we set $\hat{s}^{H|L} = 0$, which gives dual solution:

$$\begin{aligned}\hat{s}_Q^L &= \max\{0, p^L w^M(2\underline{\theta})\}\\ \hat{s}_Q^m &= \max\{0, 2qw^M(\underline{\theta}+\overline{\theta})\}\\ \hat{s}_Q^H &= \max\{0, p^H w^M(2\overline{\theta})\}.\end{aligned}$$

Then the primal solution of lemmas 1 and 2 is feasible, since it satisfies the complementary slackness conditions. And it implements the optimal dual value $\hat{s}_Q^L + \hat{s}_Q^m + \hat{s}_Q^H$. From the duality theorem we can conclude that this scheme is optimal.

For $q < q^M$ we take $\hat{s}^{H|L} > 0$. This implies from the complementary slackness conditions that $Q^M(2\overline{\theta}) = Q^M(\underline{\theta}+\overline{\theta})$. Then the following slack variables solve the reduced dual problem:

$$\begin{aligned}\hat{s}_Q^L &= \max\{0, p^L w^M(2\underline{\theta})\}\\ \hat{s}_Q^m + \hat{s}_Q^H &= \max\{0, 2qw^M(\underline{\theta}+\overline{\theta}) + p^H w^M(2\overline{\theta})\}.\end{aligned}$$

Then the scheme of lemmas 1 and 3 is feasible, since it satisfies the complementary slackness conditions. And it implements $\hat{s}_Q^L + \hat{s}_Q^m + \hat{s}_Q^H$. It follows from the duality theorem that this scheme is optimal.

This completes the proof of lemmas 1, 2 and 3.

## 6.2 IIS: Proofs

### 6.2.1 Optimal Schemes: Proof of Propositions 1, 3 and 5

Under IIS, the welfare optimization problem is a linear programming problem. Observe that the schemes under propositions 5 and proposition 1 or 3 give feasible variables to this problem. Make firms' incentive compatibility constraint for overstating costs binding, and set the slack variable $\hat{s}_i^{H|L} = \lambda$. Also make the high-cost firms' participation constraint binding by choosing slack variables $\hat{s}_1^{HL} = \lambda(p^L + q)$ and $\hat{s}_1^{HH} = \lambda(q + p^H)$, and similar slack variables for firm 2. Set all remaining slack variables for incentive compatibility and participation constraints equal to 0. Choose the slack variables for the feasibility of probability of production as follows:

$$\begin{aligned} s_Q^{LL} &= \max\{0, p^L[V-(1+\lambda)2\underline{\theta}]\} \\ s_Q^{HL} = s_Q^{LH} &= \max\left\{0, q[V-(1+\lambda)(\underline{\theta}+\overline{\theta}) - \lambda\frac{p^L}{q}(\overline{\theta}-\underline{\theta})]\right\} \\ s_Q^{HH} &= \max\left\{0, p^H[V-(1+\lambda)2\overline{\theta} - \lambda\frac{2q}{p^H}(\overline{\theta}-\underline{\theta})]\right\}. \end{aligned}$$

Consequently, for $q \geq q^I$ the regulatory scheme from propositions 1 and 5 satisfies the complementary slackness condition and equalizes the primal and dual values. Therefore this scheme is optimal. For $q < q^I$ the regulatory scheme from propositions 3 and 5 satisfies the complementary slackness condition and it equalizes dual and primal values. It follows from the duality theorem that the regulatory schemes are optimal. This completes the proof to propositions 1, 3 and 5.

#### 6.2.2 Dominant Strategy Equilibrium: Proofs of Propositions 2 and 4

Suppose that producer 2 chooses mixed strategy $p_2(\theta_2) = \Pr(\widetilde{\theta} = \underline{\theta}|\theta_2)$ in the message sending stage. Given this strategy, producer 1 assigns the following probability to a low cost message:

$$\Pr(\widetilde{\theta}_2 = \underline{\theta}|\theta_1, p_2(.)) = \Pr(\theta_2 = \underline{\theta}|\theta_1)p_2(\underline{\theta}) + \Pr(\theta_2 = \overline{\theta}|\theta_1)p_2(\overline{\theta}).$$

The expected profit for producer 1 from stating low costs is

$$\begin{aligned} &E_{\theta_2}\{\pi_1(p_1(\theta_1) = 1, p_2(\theta_2)|\theta_1)\} = \\ &\Pr(\widetilde{\theta}_2 = \underline{\theta}|\theta_1, p_2)\left[t^1(\underline{\theta},\underline{\theta}) - \underline{\theta}Q^I(\underline{\theta},\underline{\theta})\right] + \\ &+\left(1 - \Pr(\widetilde{\theta}_2 = \underline{\theta}|\theta_1, p_2)\right)\left[t^1(\underline{\theta},\overline{\theta}) - \underline{\theta}Q^I(\underline{\theta},\overline{\theta})\right], \end{aligned}$$

and he obtains the following from stating high costs:

$$\begin{aligned} &E_{\theta_2}\{\pi_1(p_1(\theta_1) = 0, p_2(\theta_2)|\theta_1)\} = \\ &\Pr(\widetilde{\theta}_2 = \underline{\theta}|\theta_1, p_2)\left[t^1(\overline{\theta},\underline{\theta}) - \underline{\theta}Q^I(\overline{\theta},\underline{\theta})\right] + \\ &+\left(1 - \Pr(\widetilde{\theta}_2 = \underline{\theta}|\theta_1, p_2)\right)\left[t^1(\overline{\theta},\overline{\theta}) - \underline{\theta}Q^I(\overline{\theta},\overline{\theta})\right]. \end{aligned}$$

Substituting the modified regulatory transfer scheme from proposition 2 into the expected profit functions proves this proposition immediately.

The proof to proposition 4 is given in the remainder of this subsection. A Bayesian equilibrium in interim dominant strategies cannot be obtained for arbitrary small changes to proposition 3's transfer scheme and the optimal probabilities of production. If one producer always states high costs, i.e. $p_i(\theta_i) = 0$ for all $\theta_i \in \{\underline{\theta}, \overline{\theta}\}$, the other producer has a strict preference to overstate his cost, whenever $Q^I(\overline{\theta}, \overline{\theta}) > 0$. This proves proposition 4.

### 6.3 MIS vs IIS: Proof of Theorem 1

In this subsection we compare the expected optimal welfare level under MIS with that under IIS. Define $\Delta\theta = \overline{\theta} - \underline{\theta}$ and $\Delta W = E_\theta\{W^I(\theta)\} - E_\Theta\{W^M(\Theta)\}$.

We first show how the critical values are ordered. It is obvious that $q^M \leq \bar{q}^2$. Furthermore, $q^M \leq \bar{q}^1$, because this gives:

$$\frac{\sqrt{p^H}\left[(p^H + \lambda(1+p^H))\sqrt{4\lambda^2 + p^H(4\lambda+1)} - \sqrt{p^H}(4\lambda^2 + \lambda + (3\lambda+1)p^H)\right]}{4\lambda(p^H + \lambda(1+p^H))} \geq 0,$$

which is equivalent to:

$$(p^H + \lambda(1+p^H))^2(4\lambda^2 + p^H(4\lambda+1)) \geq p^H(4\lambda^2 + \lambda + (3\lambda+1)p^H)^2,$$

and this is equivalent to $4\lambda^3(1-p^H)^2(\lambda + p^H) \geq 0$, which obviously holds always.

The inequality $\bar{q}^2 \leq q^I$ always holds, because it gives:

$$(p^H + \lambda(1+2p^H))\sqrt{\lambda^2(p^H+8) + p^H(6\lambda+1)} \geq \sqrt{p^H}(\lambda^2(7+2p^H) + \lambda + (5\lambda+1)p^H),$$

which is equivalent to $8\lambda^3(1-p^H)^2(\lambda+p^H)^2 \geq 0$, which obviously holds always.

For later use we prove the following lemma.

**Lemma 4** $\bar{q}^1 \geq \bar{q}^2 \Leftrightarrow p^H \leq 2q$.

**Proof.** Take $p^H = \frac{\delta\lambda}{4\lambda+1}$, with $0 \leq \delta \leq 4 + \frac{1}{\lambda}$. Then:

$$\bar{q}^1 - \bar{q}^2 = \frac{(1 + 4\lambda + \delta(1 + 2\lambda))\sqrt{\frac{\delta(4\lambda+\delta)}{4\lambda+1}} - \delta(1 + 6\lambda + \delta)}{4(1 + 4\lambda + \delta(1 + 2\lambda))}.$$

Therefore, $\bar{q}^1 \geq \bar{q}^2$ is equivalent to:

$$\delta(1 + 4\lambda + \delta(1 + 2\lambda))^2(4\lambda + \delta) \geq \delta^2(1 + 6\lambda + \delta)^2(4\lambda + 1),$$

which gives:

$$4\delta\lambda(1 - \delta)(1 + (4 - \delta)\lambda)(1 + \delta + 4\lambda) \geq 0.$$

This holds whenever $\delta \leq 1$. Finally, note that for $\delta = 1$ we obtain $\bar{q}^1 = \bar{q}^2 = \frac{\delta\lambda}{2(4\lambda+1)} = \frac{1}{2}p^H$, which proves the lemma.□

Note that for $Q^M(2\underline{\theta}) = Q^M(\underline{\theta} + \overline{\theta}) = 0, Q^M(2\overline{\theta}) = 1$, and $Q^I(2\underline{\theta}) = 1, Q^I(\underline{\theta} + \overline{\theta}) = 0, Q^I(2\overline{\theta}) = 1$ we have:

$$\Delta W = p^H \left( V - (1 + \lambda)2\overline{\theta} - \lambda \frac{2q}{p^H}\Delta\theta \right) - 2q \left( V - (1 + \lambda)(\underline{\theta} + \overline{\theta}) - \lambda \frac{p^L}{2q}\Delta\theta \right). \tag{5}$$

For $q \leq q^M$ and $q \geq q^I$ the expected welfare comparison is straightforward, resulting in a preference for independent and monopolistic input supply, respectively. For $q^M < q < q^I$ we distinguish four cases, that are analyzed in the following four cases.

**(i)** For $\max\{\bar{q}^1, \bar{q}^2\} \leq q \leq q^I$ we have the following parameter ordering:

$$\begin{aligned} (1 + \lambda)(\underline{\theta} + \overline{\theta}) + \lambda \frac{p^L}{2q}\Delta\theta \quad &< \quad (1 + \lambda)2\overline{\theta} + \lambda \frac{2q}{p^H}\Delta\theta < \\ &< \quad (1 + \lambda)(\underline{\theta} + \overline{\theta}) + \lambda \frac{p^L}{q}\Delta\theta \leq (1 + \lambda)2\overline{\theta} + \lambda \frac{1 - p^H}{p^H}\Delta\theta. \end{aligned} \tag{6}$$

The welfare comparison is straightforward, except for the case in which:

$$(1 + \lambda)2\overline{\theta} + \lambda \frac{2q}{p^H}\Delta\theta < V < (1 + \lambda)(\underline{\theta} + \overline{\theta}) + \lambda \frac{p^L}{q}\Delta\theta. \tag{7}$$

Then $\Delta W$ is as in (5). This means that for $p^H > 2q$, $\Delta W < 0 \Leftrightarrow V < \bar{v} \Leftrightarrow$

$$\begin{aligned} V &< (1+\lambda)(\underline{\theta}+\overline{\theta}) + \lambda\frac{p^L}{q}\Delta\theta + \\ &+\frac{p^H}{p^H-2q}\left([(1+\lambda)2\overline{\theta}+\lambda\frac{1-p^H}{p^H}\Delta\theta] - [(1+\lambda)(\underline{\theta}+\overline{\theta})+\lambda\frac{p^L}{q}\Delta\theta]\right) \end{aligned}$$

which holds given (6) and (7). For $p^H = 2q$, $\Delta W < 0$ is a direct consequence of (6). Finally, for $p^H < 2q$, $\Delta W < 0 \Leftrightarrow V > \bar{v} \Leftrightarrow$

$$\begin{aligned} V &> (1+\lambda)2\overline{\theta} + \lambda\frac{2q}{p^H}\Delta\theta + \\ &+\frac{2q}{p^H-2q}\left([(1+\lambda)2\overline{\theta}+\lambda\frac{2q}{p^H}\Delta\theta] - [(1+\lambda)(\underline{\theta}+\overline{\theta})+\lambda\frac{p^L}{2q}\Delta\theta]\right) \end{aligned}$$

which holds given (6) and (7).

**(ii)** Due to the lemma 4, $\bar{q}^1 < q < \bar{q}^2$ gives $p^H > 2q$, and:

$$\begin{aligned} (1+\lambda)(\underline{\theta}+\overline{\theta}) + \lambda\frac{p^L}{2q}\Delta\theta &< (1+\lambda)2\overline{\theta} + \lambda\frac{2q}{p^H}\Delta\theta < \\ &< (1+\lambda)2\overline{\theta} + \lambda\frac{1-p^H}{p^H}\Delta\theta < (1+\lambda)(\underline{\theta}+\overline{\theta}) + \lambda\frac{p^L}{q}\Delta\theta. \end{aligned} \tag{8}$$

The welfare comparison is straightforward, except for:

$$(1+\lambda)2\overline{\theta} + \lambda\frac{2q}{p^H}\Delta\theta < V < (1+\lambda)2\overline{\theta} + \lambda\frac{1-p^H}{p^H}\Delta\theta.$$

Then $\Delta W$ is as in (5), and $\Delta W > 0$ whenever $V > \bar{v}$. It suffices to note that, due to (8),

$$(1+\lambda)2\overline{\theta} + \lambda\frac{2q}{p^H}\Delta\theta < \bar{v} < (1+\lambda)2\overline{\theta} + \lambda\frac{1-p^H}{p^H}\Delta\theta,$$

since rewriting gives:

$$\begin{aligned} \bar{v} &= (1+\lambda)2\overline{\theta} + \lambda\frac{2q}{p^H}\Delta\theta + \\ &-\frac{2q}{p^H-2q}\left([(1+\lambda)(\underline{\theta}+\overline{\theta})+\lambda\frac{p^L}{2q}\Delta\theta] - [(1+\lambda)2\overline{\theta}+\lambda\frac{2q}{p^H}\Delta\theta]\right), \end{aligned}$$

and

$$\begin{aligned} \bar{v} &= (1+\lambda)2\overline{\theta} + \lambda\frac{2q}{p^H}\Delta\theta + \\ &-\frac{2q}{p^H-2q}\left([(1+\lambda)(\underline{\theta}+\overline{\theta})+\lambda\frac{p^L}{q}\Delta\theta] - [(1+\lambda)2\overline{\theta}+\lambda\frac{1-p^H}{p^H}\Delta\theta]\right). \end{aligned}$$

**(iii)** From lemma 4, $\bar{q}^2 < q < \bar{q}^1$ implies that $p^H < 2q$, and:

$$\begin{aligned}(1+\lambda)2\overline{\theta} + \lambda\frac{2q}{p^H}\Delta\theta &< (1+\lambda)(\underline{\theta}+\overline{\theta}) + \lambda\frac{p^L}{2q}\Delta\theta < \\ &< (1+\lambda)(\underline{\theta}+\overline{\theta}) + \lambda\frac{p^L}{q}\Delta\theta < (1+\lambda)2\overline{\theta} + \lambda\frac{1-p^H}{p^H}\Delta\theta.\end{aligned} \tag{9}$$

For this case the welfare is straightforward except for:

$$(1+\lambda)(\underline{\theta}+\overline{\theta}) + \lambda\frac{p^L}{2q}\Delta\theta < V < (1+\lambda)(\underline{\theta}+\overline{\theta}) + \lambda\frac{p^L}{q}\Delta\theta.$$

Then $\Delta W$ is as in (5), and $\Delta W > 0$ whenever $V < \bar{v}$. Again it suffices to note that, due to (9),

$$(1+\lambda)(\underline{\theta}+\overline{\theta}) + \lambda\frac{p^L}{2q}\Delta\theta < \bar{v} < (1+\lambda)(\underline{\theta}+\overline{\theta}) + \lambda\frac{p^L}{q}\Delta\theta,$$

since rewriting gives:

$$\begin{aligned}\bar{v} &= (1+\lambda)(\underline{\theta}+\overline{\theta}) + \lambda\frac{p^L}{2q}\Delta\theta + \\ &\quad -\frac{p^H}{p^H-2q}\left([(1+\lambda)(\underline{\theta}+\overline{\theta}) + \lambda\frac{p^L}{2q}\Delta\theta] - [(1+\lambda)2\overline{\theta} + \lambda\frac{2q}{p^H}\Delta\theta]\right),\end{aligned}$$

and

$$\begin{aligned}\bar{v} &= (1+\lambda)(\underline{\theta}+\overline{\theta}) + \lambda\frac{p^L}{q}\Delta\theta + \\ &\quad -\frac{p^H}{p^H-2q}\left([(1+\lambda)(\underline{\theta}+\overline{\theta}) + \lambda\frac{p^L}{q}\Delta\theta] - [(1+\lambda)2\overline{\theta} + \lambda\frac{1-p^H}{p^H}\Delta\theta]\right).\end{aligned}$$

**(iv)** Finally, for $q^M < q \leq \min\{\bar{q}^1, \bar{q}^2\}$ the parameters are ordered as follows:

$$\begin{aligned}(1+\lambda)2\overline{\theta} + \lambda\frac{2q}{p^H}\Delta\theta &< (1+\lambda)(\underline{\theta}+\overline{\theta}) + \lambda\frac{p^L}{2q}\Delta\theta < \\ &< (1+\lambda)2\overline{\theta} + \lambda\frac{1-p^H}{p^H}\Delta\theta < (1+\lambda)(\underline{\theta}+\overline{\theta}) + \lambda\frac{p^L}{q}\Delta\theta.\end{aligned} \tag{10}$$

The welfare is not straightforward for the case in which:

$$(1+\lambda)(\underline{\theta}+\overline{\theta}) + \lambda\frac{p^L}{2q}\Delta\theta < V < (1+\lambda)2\overline{\theta} + \lambda\frac{1-p^H}{p^H}\Delta\theta. \tag{11}$$

This means that for $p^H > 2q$, $\Delta W > 0$ is equivalent to:

$$\begin{aligned} V &> (1+\lambda)(\underline{\theta}+\overline{\theta}) + \lambda\frac{p^L}{2q}\Delta\theta + \\ &+\frac{p^H}{p^H-2q}\left([(1+\lambda)2\overline{\theta}+\lambda\frac{2q}{p^H}\Delta\theta] - [(1+\lambda)(\underline{\theta}+\overline{\theta})+\lambda\frac{p^L}{2q}\Delta\theta]\right) \end{aligned}$$

which holds given (10) and (11). For $p^H = 2q$, $\Delta W > 0$ is a direct consequence of (10). And, finally, for $p^H < 2q$, $\Delta W > 0$ is equivalent to:

$$\begin{aligned} V &< (1+\lambda)2\overline{\theta} + \lambda\frac{1-p^H}{p^H}\Delta\theta + \\ &+\frac{2q}{p^H-2q}\left([(1+\lambda)2\overline{\theta}+\lambda\frac{1-p^H}{p^H}\Delta\theta] - [(1+\lambda)(\underline{\theta}+\overline{\theta})+\lambda\frac{p^L}{q}\Delta\theta]\right) \end{aligned}$$

This completes the proof of theorem 1.

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