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Abstract

The regulator chooses for either a monopolist producing two complementary inputs in fixed proportion, or two independent firms producing one input each. The optimal regulatory choice depends on the correlation between the input production costs, and on the producers' liability structure. Full rent extraction is possible for independent firms with unlimited liability when costs are correlated. Under limited liability monopolistic input supply gives a higher expected welfare whenever the correlation coefficient is sufficiently small and nonnegative. For higher correlation coefficients independent input supply is chosen, and the regulatory scheme is non-monotonic in total costs.

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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. The railways industry requires both network and cargo services. 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. Traditionally, final output was supplied by a regulated monopolist that produced both inputs. In the 1980s and 1990s, some 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 divided between local monopolies. The new AT&T provides long-distance services and several Baby Bells serve the local markets.

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 its incentives. A 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 suppliers, the regulator has to pay them socially costly informational rents. 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.

Dana (1993) studies this problem in a model were the goods supplied are substitutes. 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 the schemes are quite different from those 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. Although the regulatory schemes differ, they implement a similar optimal organization of input supply. The optimal regulatory scheme under independent input supply also 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.

There are two conflicting effects at work. 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 makes the monopolist less willing 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.

The occurance of the yardstick competition effect depends on the regulator's possibility of punishing producers for sending unlikely (and unfavourable) cost messages. The regulator punishes a producer by making 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. 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.[1] He does this by punishing both producers severely in unlikely cost states. Under monopolistic input supply, 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 more severe ex post losses, the smaller the correlation between the costs. When producers are protected by limited liability, they cannot be forced to bear 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.[2]

Under limited liability and in a model with substitutible products Dana (1993) 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. In this paper we show that a similar result holds true for an industry with perfectly complementary goods. The regulatory scheme that underpins the optimal organization of input supply,

[1] 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 Auriol and Laffont (1992). In their model the first-best is not reached for intermediate degrees of correlation because their model contains besides a correlated, also an independently distributed cost component.

[2] 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.

however, is quite different from that in Dana (1993).

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 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 requires the supply of one unit of input 1 and one unit of input 2. The cost of producing input i, c_i $(i = 1, 2)$, can be either high, $\bar{c}$, or low, $\underline{c}$, with $\underline{c} < \bar{c}$. 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 independent input supply, and the subgame for monopolistic input supply. These subgames are defined in the remainder of this section.

In the *independent input supply* (IIS) subgame, the regulator sets a transfer scheme $(t^1, t^2) : \{\underline{c}, \bar{c}\} \times \{\underline{c}, \bar{c}\} \rightarrow \Re \times \Re$ with transfers from the regulator to the producer of input 1 and 2, respectively. Furthermore he randomizes between production of the good and no production by choosing a probability of production $Q^I : \{\underline{c}, \bar{c}\} \times \{\underline{c}, \bar{c}\} \rightarrow 0, 1$.[3] Producers receive a transfer irrespective of whether or not they produce.

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 the following table:

c_2 \ c_1	$\underline{c}$	$\bar{c}$
$\underline{c}$	p^l	q
$\bar{c}$	q	p^h

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

[3] In a model with divisible output, choosing $Q^I(.)$ 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.

the distribution. When $q = 0$ there is perfect positive correlation between the production costs of the inputs. We assume that $\rho \geq 0$, or $0 \leq q \leq \sqrt{p^l p^h}$. Each producer is privately informed about his own cost, and communication between the two input producers about their costs is not possible.

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 input producers send a message about their costs in the fourth stage of the game. Input producer i sends message $\tilde{c}_i$ for $i = 1, 2$, and the regulator's instruments are a function of these messages, $\{t^1(\tilde{c}), t^2(\tilde{c}), Q^I(\tilde{c})\}$, where $\tilde{c} = (\tilde{c}_1, \tilde{c}_2)$.

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 liabilty. 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.

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

$$W^I(\tilde{c}, c) = VQ^I(\tilde{c}) - (1 + \lambda)\, t^1(\tilde{c}) + t^2(\tilde{c}) \; + \; \pi_1(\tilde{c}, c) + \pi_2(\tilde{c}, c) \;,$$

where V is the social value of the produced output, λ represents the social cost of public funds,[4] and firm i's expected profit is

$$\pi_i(\tilde{c}, c) = t^i(\tilde{c}) - c_i Q^I(\tilde{c}), \text{ with } c = (c_1, c_2) \text{ and } i = 1, 2.$$

In the *monopolistic input supply* (MIS) subgame, the regulator sets a transfer scheme $T : \{2\underline{c}, \underline{c} + \bar{c}, 2\bar{c}\} \to \Re$, and lets production occur with probability $Q^M : \{2\underline{c}, \underline{c} + \bar{c}, 2\bar{c}\} \to 0, 1$. The input production costs under monopolistic input supply are drawn from the same distribution as under independent input supply. The monopolist learns the production costs of both inputs, (c_1, c_2), and sends a cost message, $\tilde{C} = \tilde{c}_1 + \tilde{c}_2$, to the regulator. The regulator's instruments are a function of this message, $\{T(\tilde{C}), Q^M(\tilde{C})\}$. Given these instruments and his cost

[4] 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 specification gives similar qualitative results.

message, the monopolist decides whether or not to participate in the regulatory scheme. 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. Social welfare is then defined as

$$\begin{aligned} W^M(\tilde{C}, C) &= VQ^M(\tilde{C}) - (1+\lambda)T(\tilde{C}) + \Pi(\tilde{C}, C), \text{ and} \\ \Pi(\tilde{C}, C) &= T(\tilde{C}) - CQ^M(\tilde{C}) \end{aligned}$$

is the monopolist's expected profit ($C = c_1 + c_2$).

A scetch of the game's timing is depicted in the appendix. In the next section we solve this game up to the regulator's divesture decision.

3. Solving the Subgames

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 equilibrium strategies under monopolistic input supply. The second subsection characterizes the equilibrium strategies 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.

$$\max_{\{T(.),Q^M(.)\}} E_C\{W^M(C, C)\}$$

s.t.

$$\Pi(C, C) \geq \Pi(\tilde{C}, C) \tag{3.1}$$

$$\Pi(C, C) \geq 0, \text{ for all } C, \tilde{C} \in \{2\underline{c}, \underline{c} + \bar{c}, 2\bar{c}\} \tag{3.2}$$

Inequality (3.1) is the incentive compatibility constraint, which states that it is optimal for the monopolist to reveal its true costs. Inequality (3.2) is the monopolist's participation constraint. A regulatory scheme that satisfies both (3.1) and (3.2), is called feasible. It is well-known that 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., $0 \leq Q^M(2\bar{c}) \leq Q^M(\underline{c} + \bar{c}) \leq Q^M(2\underline{c}) \leq 1$.

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

Proposition 3.1. *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:*

$$T(C) = CQ^M(C) + (\bar{c} - \underline{c}) \sum_{\tilde{C}>C} Q^M(\tilde{C}), \text{ for } C \in \{2\underline{c}, \underline{c} + \bar{c}, 2\bar{c}\}$$

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

$$\max_{\{Q^M(.)\}} \{Q^M(2\bar{c}) \cdot p^h w^M(2\bar{c}) + Q^M(\underline{c} + \bar{c}) \cdot 2q w^M(\underline{c} + \bar{c}) + Q^M(2\underline{c}) \cdot p^l w^M(2\underline{c})\}$$
$$\text{s.t. } 0 \le Q^M(2\bar{c}) \le Q^M(\underline{c} + \bar{c}) \le Q^M(2\underline{c}) \le 1,$$

with

$$w^M(C) = V - (1 + \lambda)C - \lambda \frac{\Pr c_1 + c_2 < C}{\Pr c_1 + c_2 = C}(\bar{c} - \underline{c}), \text{ for } C \in \{2\underline{c}, \underline{c} + \bar{c}, 2\bar{c}\},$$

the "virtual value" of welfare at cost C, 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.

The "virtual value" of social 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 value" of social welfare is non-negative, which gives a non-increasing probability scheme. This is stated in the following proposition.

Proposition 3.2. *For $q \ge q^M$, production takes place with certainty whenever the "virtual value" of welfare is positive, and there is no production otherwise:*

$$Q^M(C) = \begin{cases} 1, & \text{if } w^M(C) \ge 0 \\ 0, & \text{otherwise.} \end{cases}, \text{ for } C \in \{2\underline{c}, \underline{c} + \bar{c}, 2\bar{c}\}.$$

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

Proposition 3.3. *For $q < q^M$, (i) if both production units have low costs, production takes place with certainty whenever the "virtual value" of welfare is positive:*

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

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

$$Q^M(\underline{c}+\bar{c}) = Q^M(2\bar{c}) = \begin{cases} 1, & \text{if } 2qw^M(\underline{c}+\bar{c}) + p^h w^M(2\bar{c}) \geq 0 \\ 0, & \text{otherwise} \end{cases}$$

In the next subsection we analyse 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 probabilities of production that do not respect these fixed proportions. Since it is not desirable 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.

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

s.t.

$$E_{c_j}\{\pi_i(c,c)\} \geq E_{c_j}\{\pi_i(\tilde{c}_i, c_j), c\}, \quad \text{for all } i,j=1,2,\ j \neq i, \text{ and } c_i, \tilde{c}_i \in \{\underline{c},\bar{c}\} \tag{3.3}$$

$$\pi_i(c,c) \geq 0, \text{ for all } i=1,2, \text{ and } c_1, c_2 \in \{\underline{c},\bar{c}\} \tag{3.4}$$

Inequalities (3.3) are the input producers' incentive compatibility constraints. The regulatory instruments must induce truthful cost revelation in Bayesian equilibrium. Restriction (3.4) 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.

When the producers have *unlimited* liability and costs are positively correlated, the following transfer scheme implements the first-best expected welfare. The regulator reimburses a producer's expected costs if he has low costs. Both producers receive a positive informational rent if they both send a high cost message. A producer receives less than his expected cost when his production costs are high while the other producer's costs are low. In the remainder of this subsection we show how this scheme is affected by the introduction of limited liability.

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, q^I, value above which the "virtual value" of social welfare is non-increasing in total production costs. The critical value is

$$q^I = \frac{1}{4}\sqrt{p^h}\{\sqrt{p^h(1+\frac{6}{\lambda}+\frac{1}{\lambda^2})+8} - \sqrt{p^h}\frac{1+3\lambda}{\lambda}\},$$

and notice that $q^I \leq \frac{1}{3}(1-p^h)$.[5] For $q \geq q^I$ (relatively low correlation between producers' costs) the transfer scheme is similar to the monopolistic input supply scheme, which is stated in the following proposition.

Proposition 3.4. *For $q \geq q^I$ the optimal transfers are such that they reimburse the producers' expected costs and they give an informational rent to each low-cost producer:*

$$t^1(c_1, c_2) = c_1 Q^I(c_1, c_2) + (\bar{c} - \underline{c}) \sum_{\tilde{c}_1 > c_1} Q^I(\tilde{c}_1, c_2), \text{ for } c_1, c_2 \in \{\underline{c}, \bar{c}\}.$$

Producer 2 receives similar transfers.

These transfers do not implement truth-telling in a unique Bayesian equilibrium. For each producer with low cost, $\underline{c}$, the transfer scheme makes him

[5] Since q^I increases in λ, 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 $q < p^l$.

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 3.5. *For $q \geq q^I$ 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.*
Increase $t^1(\underline{c},\underline{c})$, $t^1(\underline{c},\bar{c})$ $t^2(\underline{c},\underline{c})$ and $t^2(\bar{c},\underline{c})$ with $\varepsilon > 0$, and take $\delta > 0$.
(i) If $Q^I(.) = 0$, choose $Q^I(\underline{c},\underline{c}) = 2(\frac{\varepsilon}{\Delta c} + \delta)$ and $Q^I(\underline{c},\bar{c}) = Q^I(\bar{c},\underline{c}) = \frac{\varepsilon}{\Delta c} + \delta$.
(ii) If only $Q^I(\underline{c},\underline{c}) = 1$, choose $Q^I(\underline{c},\bar{c}) = Q^I(\bar{c},\underline{c}) = \frac{\varepsilon}{\Delta c} + \delta$.
(iii) If only $Q^I(\bar{c},\bar{c}) = 0$, choose $Q^I(\underline{c},\bar{c}) = Q^I(\bar{c},\underline{c}) = 1 - (\frac{\varepsilon}{\Delta c} + \delta)$.
(iv) If $Q^I(.) = 1$, choose $Q^I(\underline{c},\bar{c}) = Q^I(\bar{c},\underline{c}) = 1 - (\frac{\varepsilon}{\Delta c} + \delta)$ and $Q^I(\bar{c},\bar{c}) = 1 - 2(\frac{\varepsilon}{\Delta c} + \delta)$.

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 by the following proposition.

Proposition 3.6. *For $q < q^I$ the optimal transfers reimburse each producer's expected cost and give an informational rent only if both producers report low production costs:*

$$\begin{aligned} t^1(\underline{c},\underline{c}) &= \underline{c}Q^I(\underline{c},\underline{c}) + (\bar{c}-\underline{c})\, Q^I(\bar{c},\underline{c}) + \frac{q}{p^l} Q^I(\bar{c},\bar{c}) \\ t^1(c_1,c_2) &= c_1 Q^I(c_1,c_2), \text{ for } (c_1,c_2) \neq (\underline{c},\underline{c}). \end{aligned}$$

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

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 3.5 and 3.7 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 $Q^I(\underline{c},\bar{c})$ and $Q^I(\bar{c},\underline{c})$, we obtain the following optimization problem.

$$\max_{\{Q^I(.)\}} \{Q^I(2\bar{c})p^h w^I(\bar{c},\bar{c}) + Q^I(\underline{c}+\bar{c})q\, w^I(\underline{c},\bar{c}) + w^I(\bar{c},\underline{c}) \;+ Q^I(2\underline{c})w^I(\underline{c},\underline{c})\}$$
$$\text{s.t. } 0 \leq Q^I(c_1+c_2) \leq 1, \text{ for } c_1, c_2 \in \{\underline{c},\bar{c}\},$$

where

$$w^I(\tilde{c}) = V - (1+\lambda)(\tilde{c}_1+\tilde{c}_2) - \lambda\frac{\sum_{i=1}^{2} \Pr c_i < \tilde{c}_i, c_j = \tilde{c}_j}{\Pr c = \tilde{c}}(\bar{c}-\underline{c})$$

is the "virtual value" of welfare at costs $(\tilde{c}_1, \tilde{c}_2)$ under independent input supply. Due to symmetry $w^I(\underline{c},\bar{c}) = w^I(\bar{c},\underline{c})$, which makes $w^I(.)$ a function of total costs only. Given the optimal transfer scheme of independent input supply, incentive constraints do not put any restriction upon the probabilities of production. Under monopolistic input supply the probability scheme was required to be non-increasing in total costs.

It is easy to check that the following proposition holds.

Proposition 3.8. *The optimal probabilities of production are such that production takes place with certainty whenever the virtual value of welfare is positive:*

$$Q^I(c_1+c_2) = \begin{cases} 1, \text{ if } w^I(c_1+c_2) \geq 0 \\ 0, \text{ otherwise} \end{cases}, \text{ for } c_1, c_2 \in \{\underline{c},\bar{c}\}$$

For small values of q ($q < q^I$, 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 $Q^I(\underline{c}+\bar{c})$ smaller than $Q^I(2\bar{c})$ 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 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 ($q < q^I$), by shifting all informational rents to the $(\underline{c}, \underline{c})$ state of nature, which does not happen in Dana (1993).

4. The Regulator's Optimal Divesture Decision

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 proposition'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 is smaller than the expected total transfers under IIS, $E_c\{t^1(c) + t^2(c)\}$. In state $(\underline{c}, \underline{c})$ the regulator needs to give both independent input suppliers an incentive not to overstate their costs. A monopolistic input supplier with costs $(\underline{c}, \underline{c})$ must effectively only be induced not to say that he has intermediate cost $\underline{c}+\bar{c}$. 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.

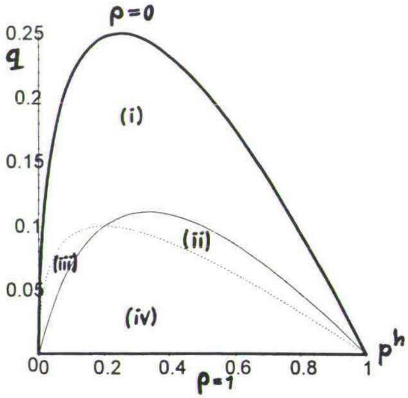
For low values of q (high correlation coefficients) the incentive constraints for the probabilities of production under MIS become binding. Because the optimal production probabilities under IIS do not obey these monotonicity constraints, they are not feasible for the monopolistic input supply problem. 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, independent input supply yields higher expected welfare than monopolistic supply for low q.

The following proposition shows how the optimal organizational structure depends on q. Define the critical values

$$\bar{q}^1 = \frac{1}{4}\sqrt{p^h}\sqrt{p^h(\frac{4}{\lambda} + \frac{1}{\lambda^2}) + 4} - \sqrt{p^h}(\frac{1 + 2\lambda}{\lambda}), \quad \bar{q}^2 = \frac{p^h(1-p^h)}{p^h(\frac{1+2\lambda}{\lambda}) + 1}, \text{ and}$$

$$\bar{v} = \frac{p^h}{p^h - 2q}(1 + \lambda)2\bar{c} + \lambda\frac{2q}{p^h}(\bar{c} - \underline{c}) - \frac{2q}{p^h - 2q}(1 + \lambda)(\underline{c} + \bar{c}) + \lambda\frac{p^l}{2q}(\bar{c} - \underline{c}) \, .$$

Proposition 4.1. *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]

Figure 1 illustrates regions (i) until (iv) for $\lambda = 1$. From the proposition we conclude that for big enough q the regulator's choice for 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 unfavourable 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 depends on the liability structure of input producers, 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 duopolistic 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 unfavourable 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.

This implies that complementary activities with highly correlated costs, such as local telephony services in separate regions, are best regulated by creating two separate firms each providing local services in only one region. In contrast, complementary activities with low cost correlation, such as local and long-distance telephony, are best regulated by having one firm that performs both activities.

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

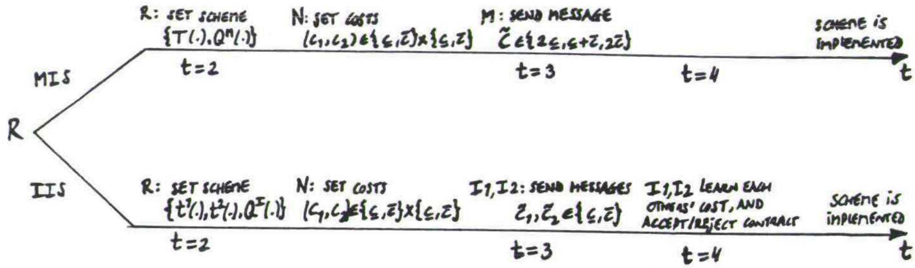
In our model the choice between monopolistic and independent input supply is made before costs are reported, and are therefore, in a sense, exogenous. Endogenizing the organizational choice of the regulator by procuring the control over input production between two bidders could give interesting new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

It could also be worthwile 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 goods 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

In the first subsection of this appendix the game tree is depicted. The second subsection contains the proof to propositions 3.1, 3.2 and 3.3, which concern monopolistic input supply. The third subsection gives the proof to propositions 3.4, 3.6 and 3.8, and to 3.5 and 3.7 which concern independent input supply. Subsection 4 proves proposition 4.1, which concerns the optimal organisation of input supply.

6.1. Game Tree



6.2. MIS: Proof of Propositions 3.1, 3.2 and 3.3

Note that the welfare optimization problem under MIS is a linear programming problem.

$$\max_{T,Q^M \geq 0} E_C\{W^M(C)\}$$

$$\text{s.t.} \begin{bmatrix} -1 & 1 & 0 & 2\underline{c} & -2\underline{c} & 0 \\ -1 & 0 & 1 & 2\underline{c} & 0 & -2\underline{c} \\ 0 & -1 & 1 & 0 & (\underline{c}+\bar{c}) & -(\underline{c}+\bar{c}) \\ 1 & -1 & 0 & -(\underline{c}+\bar{c}) & (\underline{c}+\bar{c}) & 0 \\ 1 & 0 & -1 & -2c & 0 & 2\bar{c} \\ 0 & 1 & -1 & 0 & -2\bar{c} & 2\bar{c} \\ -1 & 0 & 0 & 2 & 0 & 0 \\ 0 & -1 & 0 & 0 & (\underline{c}+\bar{c}) & 0 \\ 0 & 0 & -1 & 0 & 0 & 2\bar{c} \\ 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} T(2\underline{c}) \\ T(\underline{c}+\bar{c}) \\ T(2\bar{c}) \\ Q^M(2\bar{c}) \\ Q^M(\underline{c}+\bar{c}) \\ Q^M(2\bar{c}) \end{bmatrix} \leq \begin{bmatrix} 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 1 \\ 1 \\ 1 \end{bmatrix}$$

Observe that proposition 3.1 in combination with either proposition 3.2 or 3.3 gives a feasible primal solution. In matrix notation the primal problem is denoted as $\max_{x\geq 0}.$ $\{p\cdot x|Ax\leq r\}$, with

$$p=\begin{bmatrix} -\lambda p^l \\ -\lambda 2q \\ -\lambda p^h \\ p^l[V-2\underline{c}] \\ 2q[V-(\underline{c}+\bar{c})] \\ p^h[V-(2\bar{c})] \end{bmatrix}$$

The corresponding dual problem is $\min_{s\geq 0}.$ $\{r\cdot s|A^T s\geq p\}$, with slack variables

$$s^T=\begin{bmatrix} s^{m|l} & s^{h|l} & s^{h|m} & s^{l|m} & s^{l|h} & s^{m|h} & s^l & s^m & s^h & s^l_Q & s^m_Q & s^h_Q \end{bmatrix}.$$

Take $\hat{s}^{m|l}=\lambda p^l$, $\hat{s}^{h|m}=\lambda(1-p^h)$, $\hat{s}^{l|m}=\hat{s}^{l|h}=\hat{s}^{m|h}=\hat{s}^l=\hat{s}^m=0$, and $\hat{s}^h=\lambda$. This reduces the problem to

$$\min_{s\geq 0}.\ \{s^l_Q+s^m_Q+s^h_Q\}$$
$$\text{s.t.}\begin{cases} s^l_Q\geq p^l[V-(1+\lambda)2\underline{c}] \\ s^m_Q-(\bar{c}-\underline{c})s^{h|l}\geq 2q[V-(1+\lambda)(\underline{c}+\bar{c})-\lambda\frac{p^l}{q}(\bar{c}-\underline{c})] \\ s^h_Q+(\bar{c}-\underline{c})s^{h|l}\geq p^h[V-(1+\lambda)2\bar{c}-\lambda\frac{1-p^h}{p^h}(\bar{c}-\underline{c})] \end{cases}$$

If $\hat{s}^{h|l}=0$, then

$$\begin{aligned} \hat{s}^l_Q &= \max\{0,p^l w^M(2\underline{c})\} \\ \hat{s}^m_Q &= \max\{0,2qw^M(\underline{c}+\bar{c})\} \\ \hat{s}^h_Q &= \max\{0,p^h w^M(2\bar{c})\} \end{aligned}$$

solves the dual problem. For $q\geq q^M$ the primal solution from propositions 3.1 and 3.2 satisfies the complementary slackness conditions and implements $r\cdot\hat{s}$. From the duality theorem we can conclude that this scheme is optimal. If $\hat{s}^{h|l}>0$, which implies that $Q^M(2\bar{c})=Q^M(\underline{c}+\bar{c})$ from the complementary slackness conditions, then

$$\begin{aligned} \hat{s}^l_Q &= \max\{p^l w^M(2\underline{c})\} \\ \hat{s}^m_Q+\hat{s}^h_Q &= \max\{0,2qw^M(\underline{c}+\bar{c})+p^h w^M(2\bar{c})\} \end{aligned}$$

solves the dual problem, and for $q>q^M$ the complementary slackness condition is satisfied and the dual value $r\cdot\hat{s}$ implemented by the scheme from propositions 3.1 and 3.3. Then it follows from the duality theorem that this scheme is optimal.

This completes the proof of propositions 3.1, 3.2 and 3.3.□

6.3. IIS: Proofs

6.3.1. Optimality: Proof of propositions 3.4, 3.6 and 3.8

Under IIS, the welfare optimization problem is linear programming problem $\max_{x\geq 0}.\ \{p\cdot x|Ax\leq r\}$, with

$$A=\begin{bmatrix} -p^l & -q & p^l & q & 0 & 0 & 0 & 0 & p^l\underline{c} & q\underline{c} & -p^l\underline{c} & -q\underline{c} \\ 0 & 0 & 0 & 0 & -p^l & -q & p^l & q & p^l\underline{c} & -p^l\underline{c} & q\underline{c} & -q\underline{c} \\ q & p^h & -q & -p^h & 0 & 0 & 0 & 0 & -q\bar{c} & p^h\bar{c} & q\bar{c} & p^h\bar{c} \\ 0 & 0 & 0 & 0 & q & p^h & -q & -p^h & -q\bar{c} & q\bar{c} & -p^h\bar{c} & p^h\bar{c} \\ -1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \underline{c} & 0 & 0 & 0 \\ 0 & -1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \underline{c} & 0 & 0 \\ 0 & 0 & -1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \bar{c} & 0 \\ 0 & 0 & 0 & -1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \bar{c} \\ 0 & 0 & 0 & 0 & -1 & 0 & 0 & 0 & \underline{c} & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & -1 & 0 & 0 & 0 & 0 & \underline{c} & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & -1 & 0 & 0 & \bar{c} & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & -1 & 0 & 0 & 0 & \bar{c} \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 \end{bmatrix}$$

$$p=\begin{bmatrix} -\lambda p^l \\ -\lambda q \\ -\lambda q \\ -\lambda p^h \\ -\lambda p^l \\ -\lambda q \\ -\lambda q \\ -\lambda p^h \\ p[V-2\underline{c}] \\ q[V-(\underline{c}+\bar{c})] \\ q[V-(\underline{c}+\bar{c})] \\ p[V-2\bar{c}] \end{bmatrix},\ x=\begin{bmatrix} t^1(\underline{c},\underline{c}) \\ t^1(\underline{c},\bar{c}) \\ t^1(\bar{c},\underline{c}) \\ t^1(\bar{c},\bar{c}) \\ t^2(\underline{c},\underline{c}) \\ t^2(\bar{c},\underline{c}) \\ t^2(\underline{c},\bar{c}) \\ t^2(\bar{c},\bar{c}) \\ Q^I(\underline{c},\underline{c}) \\ Q^I(\underline{c},\bar{c}) \\ Q^I(\bar{c},\underline{c}) \\ Q^I(\bar{c},\bar{c}) \end{bmatrix},\ \text{and } r=\begin{bmatrix} 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 1 \\ 1 \\ 1 \\ 1 \end{bmatrix}.$$

Observe that the scheme of proposition 3.8 and proposition 3.4 or 3.6 is feasible in the primal problem. The corresponding dual problem is $\min_{s\geq 0}\ \{r\cdot s|A^Ts\geq p\}$, with slack variables

$$s^T=\begin{bmatrix} s_1^{h|l} & s_2^{h|l} & s_1^{h|l} & s_2^{h|l} & s_1^{ll} & s_1^{lh} & s_1^{hl} & s_1^{hh} & s_2^{ll} & s_2^{hl} & s_2^{lh} & s_2^{hh} & s_Q^{ll} & s_Q^{lh} & s_Q^{hl} & s_Q^{hh} \end{bmatrix}.$$

Choose

$$\hat{s}_1^{h|l} = \lambda,\ \hat{s}_1^{l|h} = \hat{s}_1^{ll} = \hat{s}_1^{lh} = 0,\ \hat{s}_1^{hl} = \lambda(p^l + q),\ \hat{s}_1^{hh} = \lambda(q + p^h),$$

similar slack variables for producer 2, and

$$\begin{aligned}
\hat{s}_Q^{ll} &= \max.\{0, p^l[V - (1+\lambda)2\underline{c}]\} \\
\hat{s}_Q^{lh} &= \hat{s}_Q^{hl} = \max.\{0, q[V - (1+\lambda)(\underline{c} + \bar{c}) - \lambda\frac{p^l}{q}(\bar{c} - \underline{c})]\} \\
\hat{s}_Q^{hh} &= \max.\{0, p^h[V - (1+\lambda)2\bar{c} - \lambda\frac{2q}{p^h}(\bar{c} - \underline{c})]\}.
\end{aligned}$$

For $q \geq q^I$ the regulatory scheme from proposition 3.4 and 3.8, and for $q > q^I$ the scheme from proposition 3.6 and 3.8 satisfies the complementary slackness conditions and implements value $r \cdot \hat{s}$. Then it follows from the duality theorem that the regulatory schemes are optimal. This completes the proof of propositions 3.4, 3.6 and 3.8.□

6.3.2. Dominant Strategy Equilibrium: Proofs to Propositions 3.5 and 3.7

Assume that producer 2 chooses mixed strategy $p^2(c_2) = \Pr(\tilde{c}_2 = \underline{c}|c_2)$ in the stage of message sending. Given this strategy, producer 1 assigns the following probability to a low cost message:

$$\Pr(\tilde{c}_2 = \underline{c}|c_1, p_2(.)) = \Pr(c_2 = \underline{c}|c_1)p_2(\underline{c}) + \Pr(c_2 = \bar{c}|c_1)p_2(\bar{c}).$$

The expected profit producer 1 from stating low costs is

$$\begin{aligned}
E_{c_2}\{\pi_1(p_1(c_1) &= 1, p_2(c_2)|c_1)\} = \\
\Pr(\tilde{c}_2 &= \underline{c}|c_1, p_2)[t^1(\underline{c},\underline{c}) - \underline{c}Q^I(\underline{c},\underline{c})] + [1 - \Pr(\tilde{c}_2 = \underline{c}|c_1, p_2)][t^1(\underline{c},\bar{c}) - \underline{c}Q^I(\underline{c},\bar{c})],
\end{aligned}$$

and he obtains the following from stating high costs

$$\begin{aligned}
E_{c_2}\{\pi_1(p_1(\underline{c}) &= 0, p_2(c_2))\} = \\
\Pr(\tilde{c}_2 &= \underline{c}|c_1, p_2)[t^1(\bar{c},\underline{c}) - \underline{c}Q^I(\bar{c},\underline{c})] + [1 - \Pr(\tilde{c}_2 = \underline{c}|c_1, p_2)][t^1(\bar{c},\bar{c}) - \underline{c}Q^I(\bar{c},\bar{c})].
\end{aligned}$$

Substituting the modified regulatory schemes from proposition 3.4 in the expected profit functions proves this proposition immediately.□

A Bayesian equilibrium in interim dominant strategies cannot be obtained for arbitrary small changes to proposition 3.6's tranfer scheme and the optimal probabilities of production. If one producer always states high costs, $p_i(c_i) = 0$ for all $c_i \in \{\underline{c}, \bar{c}\}$, the other producer has a strict preference to overstate his cost, whenever $Q^I(\bar{c},\bar{c}) > 0$. This proofs proposition 3.7.□

6.4. MIS vs IIS: Proof to proposition 4.1

In this subsection we compare the expected optimal welfare level under MIS with that under IIS. Define $\Delta c = (\bar{c} - \underline{c})$ and $\Delta W = E_c\{W^I(c)\} - E_C\{W^M(C)\}$.

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

$$\frac{\sqrt{p^h}\{\sqrt{4\lambda^2 + (4\lambda+1)p^h(p^h + \lambda(1+p^h))} - \sqrt{p^h}(4\lambda^2 + \lambda + (3\lambda+1)p^h)\}}{4\lambda(p^h + \lambda(1+p^h))} \geq 0,$$

which is equivalent to

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

and this is equivalent to

$$4\lambda^3(1-p^h)^2(\lambda + p^h) \geq 0.$$

It is obvious that $\bar{q}^1 \leq q^I$. The inequality $\bar{q}^2 \leq q^I$ also holds, because it gives

$$\frac{\sqrt{p^h}\{\sqrt{\lambda^2(p^h+8) + (6\lambda+1)p^h(p^h + \lambda(1+2p^h))} - \sqrt{p^h}(\lambda^2(7+2p^h) + \lambda + (5\lambda+1)p^h)\}}{4\lambda(p^h + \lambda(1+2p^h))} \geq 0,$$

which is equivalent to

$$8\lambda^3(1-p^h)^2(\lambda + p^h)^2 \geq 0.$$

For later use we proof the following lemma.

Lemma 6.1. $\bar{q}^1 \geq \bar{q}^2 \Leftrightarrow p^h \leq 2q$.

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

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

Thus, $\bar{q}^1 \geq \bar{q}^2$ 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 whever $\delta \leq 1$. 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 $Q^M(2\underline{c}) = Q^M(\underline{c}+\bar{c}) = 0, Q^M(2\bar{c}) = 1$, and $Q^I(2\underline{c}) = 1, Q^I(\underline{c}+\bar{c}) = 0, Q^I(2\bar{c}) = 1$,

$$\Delta W = p^h[V - (1+\lambda)2\bar{c} - \lambda\frac{2q}{p^h}\Delta c] - 2q[V - (1+\lambda)(\underline{c}+\bar{c}) - \lambda\frac{p^l}{2q}\Delta c], \qquad (6.1)$$

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 paragraphs.
(i) For $\max\{\bar{q}^1, \bar{q}^2\} \leq q < q^I$ we have

$$\begin{aligned}(1+\lambda)(\underline{c}+\bar{c}) + \lambda\frac{p^l}{2q}\Delta c &< (1+\lambda)2\bar{c} + \lambda\frac{2q}{p^h}\Delta c < \\ &< (1+\lambda)(\underline{c}+\bar{c}) + \lambda\frac{p^l}{q}\Delta c \leq (1+\lambda)2\bar{c} + \lambda\frac{1-p^h}{p^h}\Delta c.\end{aligned} \qquad (6.2)$$

The welfare comparison is straightforward except for the case in which

$$(1+\lambda)2\bar{c} + \lambda\frac{2q}{p^h}\Delta c < V < (1+\lambda)(\underline{c}+\bar{c}) + \lambda\frac{p^l}{q}\Delta c. \qquad (6.3)$$

Then ΔW is as in (6.1). This means that for $p^h > 2q$, $\Delta W < 0 \Leftrightarrow V < \bar{v} \Leftrightarrow$

$$V < [(1+\lambda)(\underline{c}+\bar{c}) + \lambda\frac{p^l}{q}\Delta c] + \frac{p^h}{p^h - 2q}\{[(1+\lambda)2\bar{c} + \lambda\frac{1-p^h}{p^h}\Delta c] - [(1+\lambda)(\underline{c}+\bar{c}) + \lambda\frac{p^l}{q}\Delta c]\}$$

which holds given (6.2) and (6.3). For $p^h = 2q$, $\Delta W < 0$ is a direct consequence of (6.2). Finally, for $p^h < 2q$, $\Delta W < 0 \Leftrightarrow V > \bar{v} \Leftrightarrow$

$$V > [(1+\lambda)2\bar{c} + \lambda\frac{2q}{p^h}\Delta c] + \frac{2q}{p^h - 2q}\{[(1+\lambda)2\bar{c} + \lambda\frac{2q}{p^h}\Delta c] - [(1+\lambda)(\underline{c}+\bar{c}) + \lambda\frac{p^l}{2q}\Delta c]\}$$

which holds given (6.2) and (6.3).
(ii) Due to lemma 6 1 $\bar{q}^1 < q < \bar{q}^2$ gives $p^h > 2q$, and

$$\begin{aligned}(1+\lambda)(\underline{c}+\bar{c}) + \lambda\frac{p^l}{2q}\Delta c &< (1+\lambda)2\bar{c} + \lambda\frac{2q}{p^h}\Delta c < \\ &< (1+\lambda)2\bar{c} + \lambda\frac{1-p^h}{p^h}\Delta c \leq (1+\lambda)(\underline{c}+\bar{c}) + \lambda\frac{p^l}{q}\Delta c.\end{aligned} \qquad (6.4)$$

The welfare comparison is straightforward except for

$$(1+\lambda)2\bar{c} + \lambda\frac{2q}{p^h}\Delta c < V < (1+\lambda)2\bar{c} + \lambda\frac{1-p^h}{p^h}\Delta c.$$

Then ΔW is as in (6.1), and $\Delta W > 0$ whenever $V > \bar{v}$. It suffices to note that, due to (6.4),

$$[(1+\lambda)2\bar{c} + \lambda\frac{2q}{p^h}\Delta c] < \bar{v} < [(1+\lambda)2\bar{c} + \lambda\frac{1-p^h}{p^h}\Delta c],$$

since

$$\begin{aligned}
\bar{v} &= [(1+\lambda)2\bar{c} + \lambda\frac{2q}{p^h}\Delta c] - \frac{2q}{p^h - 2q}\{[(1+\lambda)(\underline{c}+\bar{c}) + \lambda\frac{p^l}{2q}\Delta c] - [(1+\lambda)2\bar{c} + \lambda\frac{2q}{p^h}\Delta c]\} \text{ and} \\
\bar{v} &= [(1+\lambda)2\bar{c} + \lambda\frac{2q}{p^h}\Delta c] - \frac{2q}{p^h - 2q}\{[(1+\lambda)(\underline{c}+\bar{c}) + \lambda\frac{p^l}{q}\Delta c] - [(1+\lambda)2\bar{c} + \lambda\frac{1-p^h}{p^h}\Delta c]\}.
\end{aligned}$$

(iii) Through lemma 6.1 $\bar{q}^2 < q < \bar{q}^1$, implies that $p^h < 2q$, and

$$\begin{aligned}
(1+\lambda)2\bar{c} + \lambda\frac{2q}{p^h}\Delta c &< (1+\lambda)(\underline{c}+\bar{c}) + \lambda\frac{p^l}{2q}\Delta c < \\
&< (1+\lambda)(\underline{c}+\bar{c}) + \lambda\frac{p^l}{q}\Delta c \leq (1+\lambda)2\bar{c} + \lambda\frac{1-p^h}{p^h}\Delta c.
\end{aligned} \tag{6.5}$$

The welfare comparison is straightforward except for

$$(1+\lambda)(\underline{c}+\bar{c}) + \lambda\frac{p^l}{2q}\Delta c < V < (1+\lambda)(\underline{c}+\bar{c}) + \lambda\frac{p^l}{q}\Delta c.$$

Then ΔW is as in (6.1), and $\Delta W > 0$ whenever $V < \bar{v}$. It suffices to note that, due to (6.5),

$$[(1+\lambda)(\underline{c}+\bar{c}) + \lambda\frac{p^l}{2q}\Delta c] < \bar{v} < [(1+\lambda)(\underline{c}+\bar{c}) + \lambda\frac{p^l}{q}\Delta c],$$

since

$$\begin{aligned}
\bar{v} &= [(1+\lambda)(\underline{c}+\bar{c}) + \lambda\frac{p^l}{2q}\Delta c] - \frac{p^h}{p^h - 2q}\{[(1+\lambda)(\underline{c}+\bar{c}) + \lambda\frac{p^l}{2q}\Delta c] - [(1+\lambda)2\bar{c} + \lambda\frac{2q}{p^h}\Delta c]\} \text{ and} \\
\bar{v} &= [(1+\lambda)(\underline{c}+\bar{c}) + \lambda\frac{p^l}{q}\Delta c] - \frac{p^h}{p^h - 2q}\{[(1+\lambda)(\underline{c}+\bar{c}) + \lambda\frac{p^l}{q}\Delta c] - [(1+\lambda)2\bar{c} + \lambda\frac{1-p^h}{p^h}\Delta c]\}.
\end{aligned}$$

(iv) For $q^M < q \leq \min\{\bar{q}^1, \bar{q}^2\}$ we have

$$\begin{aligned}
(1+\lambda)2\bar{c} + \lambda\frac{2q}{p^h}\Delta c &< (1+\lambda)(\underline{c}+\bar{c}) + \lambda\frac{p^l}{2q}\Delta c < \\
&< (1+\lambda)2\bar{c} + \lambda\frac{1-p^h}{p^h}\Delta c \leq (1+\lambda)(\underline{c}+\bar{c}) + \lambda\frac{p^l}{q}\Delta c
\end{aligned} \tag{6.6}$$

The welfare comparison is straightforward except for the case in which

$$(1+\lambda)(\underline{c}+\bar{c}) + \lambda\frac{p^l}{2q}\Delta c < V < (1+\lambda)2\bar{c} + \lambda\frac{1-p^h}{p^h}\Delta c. \tag{6.7}$$

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

$$V > [(1+\lambda)(c+\bar{c}) + \lambda \frac{p^l}{2q} \Delta c] + \frac{p^h}{p^h - 2q} \{[(1+\lambda)2\bar{c} + \lambda \frac{2q}{p^h} \Delta c] - [(1+\lambda)(c+\bar{c}) + \lambda \frac{p^l}{2q} \Delta c]\}$$

which holds given (6.6) and (6.7). For $p^h = 2q$, $\Delta W > 0$ is a direct consequence of (6.6). Finally, for $p^h < 2q$, $\Delta W > 0$ is equivalent to

$$V < [(1+\lambda)2\bar{c} + \lambda \frac{1-p^h}{p^h} \Delta c] + \frac{2q}{p^h - 2q} \{[(1+\lambda)2\bar{c} + \lambda \frac{1-p^h}{p^h} \Delta c] - [(1+\lambda)(\underline{c}+\bar{c}) + \lambda \frac{p^l}{q} \Delta c]\}$$

which holds given (6.6) and (6.7).

This completes the proof of proposition 4.1.□

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