Seminar Paper No. 674

COLLUSION-PROOF YARDSTICK COMPETITION

by

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Collusion-proof yardstick competition[□]

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Abstract

This paper analyses the incentives for collusion when an industry is regulated by means of yardstick competition. The central assumption is that firms must write collusive side contracts before the revelation of private information and are unable to communicate later. It is shown that optimal collusion-proof regulation demands more high-powered (low-powered) incentives to high-productivity (low-productivity) firms than prescribed by the second-best contract. Collusion is costly to society also when correlation of private information is near perfect. This contrasts with the result by Laffont and Martimort (1998b), that the cost of collusion vanishes in the limit.

JEL Classification: L51.

Keywords: Yardstick competition, collusion, regulation.

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1. Introduction

Regulated industries such as telecommunications, electricity distribution, water supply and health care consist of multiple firms. Costs typically covary across firms since they produce under similar conditions. Correlation of costs gives the regulatory authority the possibility to establish industry standards against which to measure the performance of each individual firm. High (low) performance firms are rewarded (punished) accordingly. This is known as yardstick competition or relative performance evaluation and is a powerful tool to extract rents and increase production efficiency.¹

Due to its attractive features, Laffont and Tirole (1993) predict "an increased use of yardstick competition in segments of regulated industries such as water and electricity distribution" (p.86). Examples of current applications of yardstick competition include the UK water industry (Cowan, 1997), Norwegian electricity distribution (Dalen, Moen and Riis, 1998), the Japanese railway industry (Mizutani, 1997) and the operation of Swedish motor-vehicle inspections (Ylvinger, 1998). The best known example of yardstick competition is probably Medicare's reimbursement of hospital costs in the US, see Shleifer (1985) for a description. Although this paper focuses on the application to regulation, yardstick competition extends beyond performance comparisons of firms. Many labour contracts have elements of relative performance evaluation (Lazear, 1995), and Rappaport (1999) argues that manager compensation should be related to how the firm performs relative to a "peer index". It has been suggested that public agencies could be divided into subunits in order to facilitate efficiency comparisons. The Review

¹For example, the regulator is able to extract all surplus from firms and reach full efficiency if technologies are perfectly correlated. See Baiman and Demski (1982), Holmström (1982), Nalebuff and Stiglitz (1983), Demski and Sappington (1984) for general treatments and Shleifer (1985), Auriol and Laffont (1992), Auriol (1993), Dalen (1998) and Sobel (1999) for applications to regulation.

of Commonwealth/State Service Provision (RCSSP) in Australia publishes since 1995 performance indicators on a number of government services such as education, health and justice. One of the intentions is to "foster yardstick competition by promoting greater debate about comparative performance" (RCSSP, 1999, p. 5). Further, Yaisawarng and Puthuchearry (1997) sketch how, within public agencies in New South Wales, resources could be allocated among different operation units as a function of their relative efficiency.

The problem with yardstick competition, as with other forms of competition, is that it creates incentives for collusion. When regulated firms realise that they are played out against each other, they can be expected to take precautionary measures - to collude. The regulator may be forced to compensate firms for not colluding, which reduces the social value of yardstick competition. This paper studies optimal yardstick competition under the threat of collusion. As such, it adds to the mechanism design literature that emphasises collusion among agents as a source of inefficiency.² The paper that lies the closest to this essay is Laffont and Martimort (1998b), henceforth abbreviated LM. LM consider, just as I do, collusion among agents with private, correlated information. The key difference is that LM assume agents to have private information when they write collusive side contracts, whereas firms, in my setting, must form their cartel before the arrival of private information. Further, I assume that producers are unable to renegotiate the side contracts. Thus LM analyse collusion under asymmetric information, I study collusion under symmetric information.

The assumptions maintained here, are justified on the following grounds. The purpose of yardstick schemes such as those in UK water supply and Norwegian electricity distribution, is to increase efficiency (reduce slack) in production. This

²Recent contributions include a sequence of papers by Laffont and Martimort (1997, 1998a, 1998b). See also the references cited therein.

means that collusion involves collective decisions about the level of efficiency to uphold in each firm. As slack cannot be changed ex post (after the period is over), firms must meet ex ante (in the beginning of the period) to decide on collusion. The running of a firm is a continuous process, which means that firms do not know for sure what their future costs are going to be when they form the cartel. Changes in factor prices, break-down of machinery and other factors that affect production cost, occur regularly. Theoretically, firms could meet every time costs change and renegotiate their collusive contracts. However, this is cumbersome and increases the probability of detection. It therefore seems realistic to assume that collusion takes place in the anticipation that private information will arrive in the future and that this eventuality must be incorporated in the collusive side contract today.

I utilize a framework in which firm productivity is private information and consists of a firm-specific and an industry-specific part (Auriol and Laffont, 1992). The regulator applies yardstick competition to filter out the common, industry-specific productivity parameter. Firms with high industry-specific productivity collude so as to restore informational rents. The anti-competitive effect of collusion creates a trade-off between efficiency and rent-extraction. In the third-best, collusion-proof contract (i) efficiency of low-productivity producers is distorted below the second-best (yardstick competition) level; (ii) high-productivity firms produce more efficiently than under second-best regulation. The first effect reflects the possibility to increase rent-extraction from high-productivity firms by reducing the efficiency of low-productivity firms. The second appears because nobody mimics a high-productivity firm under collusion, hence there is not much scope for distortions.

Collusion under asymmetric information involves the sharing of private information within the cartel. LM show how the regulator is sometimes able to exploit

internal incentive problems. In particular, the regulator can set transfers so as to make collusion very expensive for the cartel when correlation of information is high. When correlation becomes near perfect, the regulator extracts almost all surplus from firms at infinitesimal cost. The social cost of collusion vanishes in the limit. Here, firms do not exchange information, hence there are no incentive problems to be exploited. Contrary to the findings of LM, the welfare loss of collusion persists in the almost perfectly correlated environment. In fact, the regulator is unable to extract any surplus at all. Collusion allows firms to behave as a merged entity; which enables them to fully offset the effect of yardstick competition. The result suggests that cartel-formation with information-sharing may not be the best collusive arrangement for regulated firms. Firms that cannot credibly transmit information to each other are better off not exchanging information at all, but rather applying rules of the kind discussed in this paper.

The remainder of this paper is organised as follows: Section 2 formulates the model. In section 3 I present two benchmark cases: in the first firms are regulated as separate entities, in the second yardstick competition is applied under the assumption that firms are unable to collude. Section 4 studies the incentives for collusion. Collusion-proof regulation is characterized in section 5. Lastly, section 6 concludes. Tedious proofs are collected in the appendix.

2. The model

2.1. Technology and preferences

In order to illustrate the assumptions of the model, I shall assume that the regulated industry is the water industry. The water industry consists of a number of regional natural monopolies that utilize a standardized technology for purifying drinking water and treating sewerage. The fact that firms use similar technolo-

gies, plus a minimal scope for direct competition between the firms for customers, makes the industry a suitable candidate for yardstick competition (Armstrong Cowan and Vickers, 1994). There are two regions ($i = 1; 2$), each with an inelastic demand for $S=2$ litres of water.³ Each region is served by a local water purifying plant that supplies the demanded water at cost:

$$C_i = \tau_i + e_i. \quad (2.1)$$

Cost depends on an exogenous parameter τ_i and effort $e_i \in \underline{e}$ exerted by management. Management's disutility of effort is

$$\tilde{A}(e_i) \text{ with } \tilde{A}(\underline{e}) \leq 0, \tilde{A}' > 0, \tilde{A}'' > 0, \tilde{A}''' \leq 0. \quad (2.2)$$

Disutility of effort is always non-negative, it is increasing in effort at an increasing rate. Non-negativity of the third derivative is sufficient for concavity of the social planner's problem. The regulator only observes each producer's aggregate cost C_i and cannot disaggregate τ_i and e_i without an appropriate incentive contract. Water is purified and sewerage is treated using a standardized technology. Hence, production cost depends in part on factors common to both firms. For example, a change in prices for chemicals for treating sewerage or a change in the cost of billing customers, should have the same impact on both producers' cost. Production cost is influenced also by factors specific to each region or firm, such as local pollution. When pollution increases, it becomes more costly to purify water. Local pollution is uncorrelated, therefore cost depends also on firm specific factors. I capture these effects by adopting the stochastic structure introduced by Auriol and Laroont (1992). The cost or productivity parameter τ_i consists of an industry specific part m (factor prices) and a firm specific part μ_i (local pollution). Industry specific

³The assumptions of inelastic demand and monopoly production are inconsequential to our analysis if firms produce at constant marginal cost. In that case the appropriate incentive contracts are independent of the pricing rule, see ch. 3 in Laroont and Tirole (1993) - in particular their proposition 3.4.

(IS) productivity m is high ($m = \underline{m}$) with probability v and low ($m = \bar{m}$) with probability $1 - v$. Firm specific (FS) productivity ϵ_i is continuously distributed on the interval $[\underline{\epsilon}; \bar{\epsilon}]$ with strictly positive density $g(\epsilon)$ and cumulative distribution $G(\epsilon)$. The hazard rate G/g is assumed to be increasing, and I assume further that m , ϵ_1 and ϵ_2 are all stochastically independent. Total productivity is given by the weighted average:

$$\tau_i = \theta m + (1 - \theta) \epsilon_i. \quad (2.3)$$

The weight $\theta \in [0, 1]$ is common knowledge. Correlation of productivity is increasing in θ and perfect at $\theta = 1$. I make the simplifying assumption that

$$\theta = \frac{\bar{\epsilon} - \underline{\epsilon} + \bar{A}^{0,1}(1)}{\bar{m} - \underline{m} + \bar{\epsilon} - \underline{\epsilon}}. \quad (2.4)$$

(2.3) and (2.4) imply that τ_i is distributed over two disjoint intervals $A_1 = [\underline{\tau}; a^-]$ and $A_2 = [a^+; \bar{\tau}]$, where $\underline{\tau} = \theta \underline{m} + (1 - \theta) \underline{\epsilon}$, $a^- = \theta \underline{m} + (1 - \theta) \bar{\epsilon}$, $a^+ = \theta \bar{m} + (1 - \theta) \underline{\epsilon}$ and $\bar{\tau} = \theta \bar{m} + (1 - \theta) \bar{\epsilon}$.⁴

Figure 1

Both firms have productivity in A_1 if IS productivity is high ($m = \underline{m}$) and A_2 if IS productivity is low ($m = \bar{m}$). The regulator can use this information to filter out the realization of the common parameter m . If firm 2 (1) were to operate at a cost that would imply a cost parameter somewhere in A_1 (A_2), the regulator would know that one of them were manipulating its cost. It can punish firms for making such incompatible cost reports, which then leads both firms to report cost in the correct interval (unless they are colluding). The analysis with overlapping

⁴The second purpose of assumption (2.4) is to ensure that production cost C_i be increasing in τ_i . It is further assumed that $\bar{m} - \underline{m} > \bar{A}^{0,1}(1)$ to keep the set of θ 's non-degenerate. For example, the condition is satisfied for all $\bar{m} > \underline{m}$ if $\bar{A}(e) > \exp(e)$.

intervals A_1 and A_2 is complicated and therefore skipped.⁵ Denote by $A = A_1 \cup A_2$ the support of θ_i . Subscripts i and j used to identify firms, is dropped in some of the analysis that follows. The reason is that firms are identical ex ante, hence are given identical regulatory contracts in equilibrium. Sometimes, I shall let θ denote the type of a firm and θ^0 the type of the "other" firm. Write $F(\theta)$ the cumulative marginal distribution of θ and $f(\theta)$ the corresponding density function. The hazard rate F/f is a function of G and g and restrictions are put on G sufficient to guarantee that even F/f be increasing.⁶ The distribution of θ^0 conditional on θ , $F(\theta^0|\theta)$, is equal to $G(\theta^0)$, where $G(\theta^0) = G(\frac{\theta^0 - \underline{\theta}_i}{\theta_i - \underline{\theta}_i})$ with $m = \underline{m}$ for $\theta \in A_1$ and $m = \overline{m}$ for $\theta \in A_2$. Density $f(\theta^0|\theta) = g(\theta^0)$ is defined correspondingly.

The firm is fully compensated for its production cost C_i and receives in addition a net transfer t_i for serving its market. Hence firm i 's rent is given by

$$U_i = t_i - \tilde{A}(e_i). \quad (2.5)$$

Welfare equals

$$W = S + \sum_i U_i - (1 + \lambda) \sum_i (t_i + C_i), \quad (2.6)$$

consumer surplus S plus the sum of firm rent U_i minus the social cost of the gross transfer $(t_i + C_i)$ to each firm. λ is the positive shadow price on public funds. As is now standard (2.1), (2.5) and (2.6) are manipulated to yield

$$W = S - (1 + \lambda) \sum_i (\theta_i - e_i + \tilde{A}(e_i)) - \sum_i U_i. \quad (2.7)$$

2.2. The regulatory contract

The regulator proposes a direct revelation mechanism $D = (t; C_g)$ that specifies a vector $t = (t_1(b); t_2(b))$ of transfers to firms and a vector of cost targets

⁵This is due to complicated second-order conditions of incentive compatibility constraints. But see Auriol (1993) for an analysis without collusion.

⁶See Auriol and Laffont (1992) for the details.

$C = (C_1(b); C_2(b))$ as a function of reported productivity $b = (b_1; b_2)$.⁷

2.3. The side contract

A side contract $\phi = f^\circ; t^g$ between firms consists of a set of mappings $\phi = (\phi_1(\cdot); \phi_2(\cdot))$ that specifies which productivity ϕ_i firm i should to report as a function of its realized productivity θ_i , plus a vector of inter-firm transfers $t = (t_1(b); t_2(b))$ that depends on the vector of reported productivity b . Colluding firms agree on a rule that prescribes how each of them should report productivity, plus a set of side payments. The role of these side payments is to discipline firms to stick with the rule agreed upon. For simplicity, I impose a balanced budget constraint $t_1(b) = -t_2(b)$. Define

$$Z_i(b_i; \theta_i) = \int_A [U(b_i; \theta_i; \phi_j(\theta_j)) + t_i(b_i; \phi_j(\theta_j))] dF(\theta_j | \theta_i),$$

firm i 's expected utility of reporting b_i contingent on productivity θ_i and firm j reporting $\phi_j(\cdot)$. Two natural restrictions are imposed on the set of admissible side contracts: feasibility and optimality.

Definition 2.1. A side contract is said to be feasible if it satisfies:

$$Z_i(\theta_i) = Z_i(\phi_i(\theta_i); \theta_i) \geq Z_i(b_i; \theta_i) \quad \forall b_i \in A^2, i = 1, 2 \quad (2.8)$$

Feasibility is equivalent to incentive compatibility. Sticking with the side contract must be firm i 's optimal strategy if it thinks that firm j will report according to $\phi_j(\cdot)$. Feasibility thus requires that firms cannot write contracts they are going to abandon later. Let Φ be the set of feasible side contracts, ϕ and ψ two specific contracts in Φ , and denote by $S_i(\cdot)$ i 's expected surplus when both firms abide by

⁷This is equivalent to a regulatory contract that specifies transfers as a function of realized cost if cost target C_i is strictly increasing in θ_i (Laffont and Tirole, 1993). It is easy to check that all the derived contracts in this paper have this property.

the side contract Φ . The second requirement is that the selected side contract be optimal.

Definition 2.2. A feasible side contract Φ is said to be optimal if it satisfies:

$$\int_{\mathcal{A}} Z_i(\theta_i) dF(\theta_i) \geq \int_{\mathcal{A}} Z_i(\theta_i) dF(\theta_i) \quad \forall \Phi \in \mathcal{F} \quad (2.9)$$

The optimality requirement is quite obvious. It states that firms are going to write a particular side contract only if it is incentive compatible and maximises expected industry profits.

2.4. Timing

I study a static game in which there is production only once. First, the regulator proposes the regulatory contract D . Second, each firm accepts or rejects; rejection leaves a firm with reservation utility 0. If both firms agree to produce, they may write a side contract Φ . Third, productivity is revealed and is the private information of each firm. Even at this stage firms have the opportunity to turn down both the regulatory and the side contract. Fourth, productivity is reported, transfers are paid out as specified by the regulatory contract, and firms meet their corresponding cost target. Finally, side transfers, if any, are made.

The interim participation constraint of each firm is made for the sake of realism. Normally firms have limited liability; owners are not liable for more than they have put into the firm. Consequently, an owner cannot be prevented from shutting down her firm if she finds production unprofitable. I assume that consumer surplus S is sufficiently high to guarantee that the regulator always finds it socially optimal to offer a contract that satisfies this constraint. Enforceability of side transfers is normally justified by a dynamic argument; firms who fail to comply are punished in subsequent periods. In the static setting there are no

subsequent periods, hence side payments may not be possible. I study collusion under two alternative assumptions about the ability to commit to side payments: (i) firms do not have access to side payments at all; (ii) firms can commit to unlimited side payments. Firms' unlimited access to side payments can be considered a worst-case scenario, and it defines an upper bound on what firms can achieve by colluding.

3. Regulation in the absence of collusion

In this section I derive a few regulatory contracts that will serve as benchmarks against which to evaluate the effects of collusion. The regulator maximizes expected welfare (subscript i is skipped throughout this section since both firms are identical ex ante and are given identical regulatory contracts):

$$\max_{f(e); g(e)} S = 2 \int_{A^2} [(1 + \beta)(-j - e(-) + \tilde{A}(e(-))) + \beta U(-)] d\mathbf{b}(-) \quad (3.1)$$

subject to the incentive compatibility (IC) constraint:

$$V(-), \int_A U(-) dF(-^0 | j^-) \geq V(b; -), \int_A U(b; -) dF(-^0 | j^-) \geq \int_A U(b; -) dF(-^0 | j^-) \quad (3.2)$$

and the interim participation (IR) constraint:

$$\int_A U(-) dF(-^0 | j^-) \geq 0 \quad (3.3)$$

$\mathbf{b}(-)$ is the joint cumulative distribution of $-$, where $- = (-; -^0)$ is the vector of cost parameters. The IC constraint (3.2) requires that truth-telling maximize expected rents conditional on the firm's belief that the other firm report its true type too. The IR constraint (3.3) requires that all firms be willing to produce in equilibrium. Let $\underline{(-)}$ respective $\overline{(-)}$ denote the lower respective upper boundary of A_k for $- \in A_k$, and write A_k^c the complement of A_k , $k = 1, 2$. I sometimes refer

to a regulatory contract that meets the IC constraint as a truthful mechanism. It is straightforward to verify that a contract is a truthful mechanism if and only if:

$$V(\bar{\theta}) = \int_{\underline{\theta}(\bar{\theta})}^{\bar{\theta}(\bar{\theta})} \tilde{A}^0(e(x; \bar{\theta})) dx dG(\bar{\theta}^0) + V(\bar{\theta}(\bar{\theta})) \quad (3.4)$$

$$V(\bar{\theta}) \geq V(b_i; \bar{\theta}), \quad \forall (b_i; \bar{\theta}) \in A_k \in A_k^c \quad (3.5)$$

$$C(\bar{\theta}) \text{ non-decreasing in } \bar{\theta} \geq \int_{\underline{\theta}(\bar{\theta})}^{\bar{\theta}(\bar{\theta})} [\bar{\theta}(\bar{\theta}) - \bar{\theta}(\bar{\theta})]^2. \quad (3.6)$$

Note that expected rents are locally decreasing in $\bar{\theta}$ so $V(a^i) \geq 0$ and $V(\bar{\theta}) \geq 0$ are necessary and sufficient for (3.3) to be satisfied.

3.1. Individual regulation of firms

This section considers individual regulation of firms. Collusion is of no concern under this regime because each firm's rent is independent of the other firm's performance. The maximization of (3.1) subject to (3.4)-(3.6) and (3.3), becomes:

$$\max_{U(\bar{\theta}); e(\bar{\theta})} \int_{\underline{\theta}(\bar{\theta})}^{\bar{\theta}(\bar{\theta})} \frac{S}{2} \int_A [(1 + \gamma)(\bar{\theta} - e(\bar{\theta}) + \tilde{A}(e(\bar{\theta}))) + \gamma U(\bar{\theta})] dF(\bar{\theta}) \quad (3.7)$$

subject to the incentive compatibility (IC) constraints:

$$U(\bar{\theta}) = \int_{\underline{\theta}(\bar{\theta})}^{\bar{\theta}(\bar{\theta})} \tilde{A}^0(e(x)) dx + U(\bar{\theta}(\bar{\theta})) \text{ and } U(a^i) \geq U(a^+; a^i) \quad (3.8)$$

$$C(\bar{\theta}) \text{ non-decreasing in } \bar{\theta} \geq \int_{\underline{\theta}(\bar{\theta})}^{\bar{\theta}(\bar{\theta})} [\bar{\theta}(\bar{\theta}) - \bar{\theta}(\bar{\theta})]. \quad (3.9)$$

and the interim participation (IR) constraint:

$$U(\bar{\theta}) \geq 0. \quad (3.10)$$

The last restriction in (3.8) does not appear in the standard analysis. It enters explicitly here due to non-convexity of A . Straightforward maximization of (3.7) subject to (3.8)-(3.10) yields optimal effort $e^s(\bar{\theta})$ implicitly defined by:

$$\tilde{A}^0(e^s(\bar{\theta})) = 1 + \frac{\gamma}{1 + \gamma} \frac{F(\bar{\theta})}{f(\bar{\theta})} \tilde{A}^0(e^s(\bar{\theta})) \geq \int_{\underline{\theta}(\bar{\theta})}^{\bar{\theta}(\bar{\theta})} [\bar{\theta}(\bar{\theta}) - a^i] [1 - e^s(\bar{\theta})]. \quad (3.11)$$

This is the standard solution. Note however, that, due to non-convexity of A , there is some bunching at the optimum, i.e. all firms of type $\theta \in [a^+; \theta^s)$ meet the same cost target $C^s(\theta^s)$. Thus⁸

$$e^s(\theta) = e^s(\theta^s) + \theta - a^+ \quad \theta \in [a^+; \theta^s). \quad (3.12)$$

3.2. Yardstick competition

Yardstick competition allows the regulator to costlessly filter out the industry-specific (IS) parameter m . m is perfectly correlated across firms so productivity θ is either in A_1 ($m = \underline{m}$) for both producers or A_2 ($m = \bar{m}$) for both producers. The two firms know this and so does the regulator. The only way a firm is going to enjoy rents for high IS productivity is by mimicking a low IS producer, i.e. by reporting $\theta \in A_2$. In this standard, non-collusive setting each firm trusts the other to truthfully reveal its type $\theta \in A_1$. Therefore, a deviation is expected to lead to incompatible productivity reports, $\theta \in A_2$ and $\theta \in A_1$. The regulator can costlessly remove this incentive by refusing to pay any transfers in case of incompatible reports. Dalen (1998) shows that optimal effort $e^{yc}(\theta)$ under yardstick competition is the solution to:⁹

$$\tilde{A}^0(e^{yc}(\theta)) = 1 - \frac{\theta}{1 + \theta} \frac{F(\theta) - IF(a)}{f(\theta)} \tilde{A}^0(e^{yc}(\theta)) \quad \theta \in A. \quad (3.13)$$

I is an indicator function that takes on the value 1 for $\theta \in A_1$ and zero otherwise. A comparison of effort levels under individual regulation and yardstick competition shows:

Proposition 3.1. (Dalen, 1998) Optimal contracts are characterized by (i) $e^s(\theta) = e^{yc}(\theta)$ for all $\theta \in A_1$ and; (ii) $e^s(\theta) < e^{yc}(\theta)$ for all $\theta \in A_2$.

⁸See appendix A.1 for a derivation of the optimal contract and optimal level of bunching θ^s .

⁹See also AL for the derivation of a similar expression.

Effort is distorted below first best in order to extract rents from high productivity firms. Rents must be given up to firms with high industry-specific productivity under individual regulation so as to prevent them from understating productivity and reporting $\tau \geq A_2$. This is not necessary under yardstick competition. Hence, the marginal rent extraction is larger under individual regulation than under yardstick competition. This calls for larger distortions of effort in the former than latter case.

4. Collusion

The socially optimal effort level $e^{yc}(\tau)$ is attained under the assumption that each firm believes the other to truthfully report productivity. This allows the regulator to costlessly extract information about industry-specific (IS) productivity by punishing firms for delivering incompatible productivity reports. It is evident that firms may have an incentive to coordinate on compatible reports so as to get around yardstick competition. Suppose that firms have agreed to pretend they have low IS productivity and maximum firm-specific productivity whenever they in reality have high IS productivity, i.e. report $a^+ = \bar{m} + (1 - \tau)z$ for all $\tau \geq A_1$. The rent is $U^{yc}(a^+; \tau) = t^{yc}(a^+) - \tilde{A}(\tau - C^{yc}(a^+))$ for the firm of type $\tau \geq A_1$ under the collusive agreement. The expected rent when both firms truthfully reveal productivity is $U^{yc}(\tau) = t^{yc}(\tau) - \tilde{A}(e^{yc}(\tau))$. The difference is:

$$U^{yc}(a^+; \tau) - U^{yc}(\tau) = [t^{yc}(a^+) - t^{yc}(\tau)] + [\tilde{A}(\tau - C^{yc}(\tau)) - \tilde{A}(\tau - C^{yc}(a^+))]. \quad (4.1)$$

When both firms understate productivity, transfers and cost targets change. The first term in (4.1) is the transfer effect. It is non-negative. An a^+ firm has the highest possible FS productivity and thus exerts the highest effort in equilibrium (equation (3.13)). Therefore it must receive the maximum transfer in order to be

willing to produce at all.¹⁰ Furthermore, producers are able to credibly inflate costs from $C^{yc}(\bar{e})$ to $C^{yc}(a^+)$ (shirk) under collusion.¹¹ The second term, the cost effect, is thus strictly positive. To summarize; low firms that coordinate reports on a^+ instead of telling the truth, receive more money for less work. This indicates that the regulator is going to have a problem with firms with high IS productivity collectively acting as if they have low IS productivity. Moreover, it is not difficult to show that high firms never have an incentive to overstate productivity (report $b \geq A_1$). They would then have to satisfy more ambitious cost targets, the disutility of which would never be compensated by the extra transfers they might receive.

5. Collusion-proof regulation

In the previous section I argued that firms have an incentive to collude by collectively understating productivity. This section analyses the regulator's optimal response to collusion. Attention is restricted to the class of collusion-proof mechanisms. Define the truthful side contract to be the side contract in which no side payments are made and firms agree on truthful revelation of productivity. A regulatory contract is said to be collusion-proof if it induces firms to select the truthful side contract. Under collusion-proof regulation, the regulator faces the following maximization problem (again subscript i is dropped on the regulatory contracts to save on notation):

$$\max_{f(U(\bar{e}); e(\bar{e}))g} S = 2 \int_{A^2} [(1 + \beta)(\bar{e} - e(\bar{e}) + \tilde{A}(e(\bar{e}))) + \beta U(\bar{e})] d\mu(\bar{e}) \quad (5.1)$$

$$\text{s.t. } V(\bar{e}) \geq V(b_i; \bar{e}) \geq 8(b_i; \bar{e}) \geq A^2, \quad (5.2)$$

¹⁰ $t^{yc}(\bar{e}) = U^{yc}(\bar{e}) + \tilde{A}(e^{yc}(\bar{e}))$. Moreover $U^{yc}(\bar{e}) = \int_{\bar{e}}^{\bar{R}(\bar{e})} \tilde{A}^0(e^{yc}(x)) dx$. Therefore $t^{yc}(\bar{e}) = \int_{\bar{e}}^{\bar{R}(\bar{e})} (1 - e^{yc}(\bar{e})) \tilde{A}^0(e^{yc}(x)) dx < 0$. Symmetry of contracts imply $t^{yc}(\bar{e}) = t^{yc}(a^+)$, which establishes $t^{yc}(a^+)$ as the global maximum.

¹¹ See appendix A.2 for a formal proof that cost is strictly increasing in $\bar{e}$ under regular yardstick competition.

$$\int_A V(\bar{\theta}_i) dF(\bar{\theta}_i) \geq \int_A V(\bar{\theta}_i) dF(\bar{\theta}_i) \quad (5.3)$$

$$\int_A V(\bar{\theta}_i) dF(\bar{\theta}_i) \geq \int_A V(\bar{\theta}_i) dF(\bar{\theta}_i) \quad (5.4)$$

Expected welfare is maximised under the conditions that the truthful side contract be feasible (constraint (5.2)), that all firms be willing to produce under truthful revelation of productivity (constraint (5.3)) and that the truthful side contract maximise expected industry profits under all feasible side contracts (constraint (5.4)).

Our interest in collusion-proof regulation stems from the fact that the welfare maximizing regulatory contract can be rewritten as a collusion-proof contract. The intuition behind this Collusion-proofness Principle is the same as that underlying the Revelation Principle. Given her knowledge about the collusive agreement, the regulator can tailor transfers and cost targets so as to construct an incentive compatible, truthful side contract that is identical to the optimal collusive side contract, hence generates the same expected industry profits. Effort and rents are the same under the new collusion-proof contract as under the original contract, hence expected welfare is the same. Formally:¹²

Proposition 5.1. Assume that firms can write and enforce collusive side contracts of the form discussed in section 2.3. For every welfare maximising regulatory contract, there exists a collusion-proof regulatory contract that generates the same expected welfare.

Proof. Write $D^* = (t^*, C^*)$ the welfare maximising mechanism and $S^* = (f^*, g^*)$ the corresponding optimal side contract. Define the regulatory contract $D = (t, C)$ with $t_i(b) = t_i^*(\theta_i^*(b_i); \theta_j^*(b_j)) + f^*(\theta_i^*(b_i); \theta_j^*(b_j))$ and $C_i(b) = C_i^*(\theta_i^*(b_i); \theta_j^*(b_j))$. Suppose that j reports its true type. $V_i(b_i; \bar{\theta}_i) = Z_i^*(\theta_i^*(b_i); \bar{\theta}_i)$

¹²Confer Laffont and Martimort (1997 and 1998b) for proofs of the Collusion-proofness Principle in different contexts.

implies $V_i(\bar{b}_i) = \max V_i(b_i; \bar{b}_{-i})$ by feasibility of $\bar{b}$. This implies that the truthful side contract is feasible under D. $V_i(\bar{b}_i) = Z_i^a(\bar{b}_i) - 2A$ implies collusion-proofness of D by the assumption that $\bar{b}$ is optimal. It further implies that individual rationality is met. Finally, $C_i(\bar{b}) = C_i^a(\bar{b})$, $U_i(\bar{b}) = U_i^a(\bar{b})$ and $t_1(\bar{b}) + t_2(\bar{b}) = t_1^a(\bar{b}) + t_2^a(\bar{b}) + \bar{b}_i - \bar{b}_i^a$ imply that welfare is unchanged. ■

Two restrictions have been put on the admissible side contract: i) that it be feasible, i.e. it must be in each firm's best interest to adhere to the side contract if it believes that the other firm will do so; ii) that it be optimal, i.e. firms pick the side contract that maximises expected industry profits. This means that the regulator can ward off collusion either by rendering every collusive side contract infeasible, or by reassuring that the most profitable side contract be the truthful one. As we shall see, the optimal strategy depends on firms' access to side payments. Two cases are considered. First, I assume that firms cannot commit to side payments at all. This could be relevant, since the model considered here is a one-shot game. This is the best-case scenario, as access to side payments facilitates collusion. At the other extreme is the worst-case scenario where firms can commit to unlimited side payments. This case is studied in section 5.2.

5.1. The best-case scenario: no access to side payments

The discussion in section 4 showed that high productivity firms want to coordinate on a side contract that understates productivity. But is it sufficient that firms agree to coordinate on productivity reports? In other words, is it possible to uphold collusive agreements in the absence of side payments? The answer is no. Firms cannot collude unless they can commit to side payments.¹³ The reason is that the regulator can break any collusive agreement by the appropriate design

¹³However, the absence of observed transfers cannot be taken as evidence that collusion is impossible. In the model side transfers are used as a punishment mechanism to discipline firms. Non-existence of side transfers could imply that firms cannot collude, but it could equally well be explained by disciplined collusive behaviour.

of sticks and carrots. Suppose that the regulator offers a huge bonus to the high productivity producer in case of incompatible reports. Most yardstick competition schemes have the property that a high-performance firm receives a higher payment than a low-performance firm. It is easy to see that there exists a carrot sufficiently big to break every collusive agreement to report low productivity (see appendix A.2 for an example of such a contract). By offering a sufficiently big carrot to the deviator, the regulator can costlessly prevent collusion. Bonuses are not paid out in equilibrium, hence welfare is not diminished by the restriction that regulation be collusion-proof:

Proposition 5.2. Assume that firms do not have access to side payments. Then there exists a regulatory contract that implements second-best effort $e^{yc}(\tau)$ as a unique Bayesian Nash equilibrium (BNE). It has the additional property that truth-telling is a strictly dominating strategy for all $\tau \in [\underline{\tau}; \bar{\tau}]$.

Proof. See appendix A.2.

Without inter-firm transfers, collusion must be of the form that firms coordinate on a particular BNE. However, the only BNE is in truth-telling strategies, hence collusion is impossible.

5.2. The worst-case scenario: unlimited access to side payments

If firms can pay transfers to each other, collusion is a serious concern, simply because any sticks and carrots offered by the regulator can be neutralised by firms' choice of side payments:

Proposition 5.3. Assume that firms have access to unlimited side payments and that the regulator offers the second-best contract. In that case, there exists a feasible collusive side contract that yields strictly higher expected industry profits than the truthful side contract.

Proof. Yardstick competition is a truthful mechanism. This implies, by lemma A.2 in the appendix, that there exists a feasible side contract $\$$ with the properties $\phi^*(\bar{\theta}) = a^+ - \frac{1}{2} A_1$ and $\phi^*(\bar{\theta}) = \bar{\theta}$ otherwise. $Z(\bar{\theta}) = V(\bar{\theta}) - \frac{1}{2} A_2$ and $Z(\bar{\theta}) = U^{yc}(a^+; \bar{\theta}) - \frac{1}{2} A_1$ imply that $\$$ strictly outperforms truth-telling because $U^{yc}(a^+; \bar{\theta}) > U^{yc}(\bar{\theta}) = V(\bar{\theta}) - \frac{1}{2} A_1$, as shown in section 4. ■

Proposition 5.3 states that there exists no collusion-proof regulatory contract that implements second-best effort. Thus, the regulator is forced give up rents to firms in order to implement collusion-proof regulation. This creates a trade-off between efficiency and rent-extraction. I show in appendix A.3 that the binding collusive incentive constraint is:

$$\int_{\bar{\theta}}^{\bar{\theta}^+} V(\bar{\theta}) dF(\bar{\theta}) = \int_{\bar{\theta}}^{\bar{\theta}^+} (t^+ - \tilde{A}(\bar{\theta} - C^+)) dF(\bar{\theta}), \quad (5.5)$$

where t^+ is the transfer to each firm if they both report a^+ , and C^+ is the corresponding cost-target. Collusion-proof regulation requires that expected industry profits under truth-telling equal expected industry profits of a side contract in which firms report their true type whenever they have low industry-specific (IS) productivity ($\bar{\theta} \leq [a^+; \bar{\theta}^+]$) and a^+ otherwise. This is what I hinted at in section 4: the fundamental problem with collusion is that firms with high IS productivity have an incentive to collusively pretend they have low IS productivity and simultaneously high firm-specific (FS) productivity (report $b = a^+$). This strategy maximises transfers while allowing a generous cost target.

Equation (5.5) shows that the social cost of collusion, i.e. firm rents, is defined entirely by transfers to and cost targets for producers with low IS productivity. This has two implications. First, it increases the marginal value of efficiency distortions for low productivity firms. Suppose that an a^+ firm is allowed a slightly more generous cost target than under second-best regulation. This implies that the transfer to the a^+ firm can also be reduced to keep the firm indifferent between

the new and the old contract. Due to convexity of the disutility function $\tilde{A}$, it is more valuable to a low productivity firm than to a high productivity firm to be allowed to inflate costs. A reduction in transfers that keeps a low productivity firm equally well off as before, has the implication that collusion becomes less valuable because the reduction in transfers more than offsets the value of the inflated cost target for the firm with high IS productivity. The implication is that marginal distortion of effort below its second-best level for low-type firms increases rent-extraction from high-type firms. Second, collusion reduces the marginal value of efficiency distortions for high IS productivity firms. The problem with collusion is not that low productivity firms pretend that they have high productivity; it is the opposite. There is little to gain in terms of rent extraction by distorting efficiency of high-productivity firms. This means that collusion-proof regulation demands stronger incentives for cost reduction than the second-best contract for firms with high IS productivity. The analysis below provides the formal solution to the regulator's problem.

Appendix A.3 shows that the maximization problem (5.1)-(5.4) can be rewritten as:

$$\max_{e(\cdot)} \frac{S}{2} \int_{\underline{a}}^{\underline{a}^+} (1 + \frac{R}{A}(-; e(-) + \tilde{A}(e(-)))dF(-) + \int_{\underline{a}^+}^{\underline{a}^+} \tilde{A}^0(e(-)) \frac{F(-)}{f(-)} dF(-) + \int_{\underline{a}}^{\underline{a}^+} \tilde{A}^0(-; a^+ + e(a^+)) \frac{F(-)}{f(-)} dF(-) + \int_{\underline{a}^+}^{\underline{a}^+} \tilde{A}^0(x; a^+ + e(a^+)) dx F(a)] \quad (5.6)$$

$$\text{s.t. } C(-) \text{ non-decreasing on } \mathbb{R}^2 [\underline{C}(-); \overline{C}(-)], \quad (5.7)$$

$$\text{and } \int_{\underline{a}}^{\underline{a}^+} (t^+; \tilde{A}(-; C^+))dF(-) \leq \int_{\underline{a}}^{\underline{a}^+} \tilde{A}^0(e(-)) \frac{F(-)}{f(-)} dF(-). \quad (5.8)$$

The second term in (5.6) is the social cost of production, and the long term in brackets is the expected rent. The constraint (5.8) is the participation constraint of the firm with productivity a^+ (see appendix A.3). Not too surprisingly it shows that the harder high-productivity firms must work, the less likely it is that the

constraint be satisfied. The standard procedure to derive the socially optimal amount of effort would be to solve (5.6) as an unconstrained problem and verify ex post that (5.7) and (5.8) were met. This is not possible here because (5.7) is binding. Just like in the case with separate regulation of firms, there is some bunching at the optimum. Further, (5.8) may be binding too. Let $\bar{e}^{cp}$ denote the optimal level of bunching, that is let all firms with productivity in $[a^+; \bar{e}^{cp})$ be given the cost target $C(\bar{e}^{cp})$.¹⁴ Denote by $W^{cp}(\bar{e})$ expected welfare (5.6) under collusion-proof regulation and form the Lagrangian:

$$L = W^{cp} + \lambda \int_{a^+}^{\bar{e}^{cp}} (t^+ - \tilde{A}(\bar{e} - C^+) - \tilde{A}^0(e(\bar{e})) \frac{F(\bar{e})}{f(\bar{e})}) dF(\bar{e}) \quad (5.9)$$

λ is the Lagrange multiplier. Maximizing over effort gives the following first-order conditions:

$$\tilde{A}^0(e^{cp}(\bar{e})) = 1 - \frac{1}{1 + \lambda} \frac{F(\bar{e})}{f(\bar{e})} \tilde{A}^{00}(e^{cp}(\bar{e})) \delta^{-2} [\bar{e}; a^+], \quad (5.10)$$

$$\tilde{A}^0(e^{cp}(\bar{e})) = 1 - \frac{\lambda}{1 + \lambda} \frac{F(\bar{e})}{f(\bar{e})} \tilde{A}^{00}(e^{cp}(\bar{e})) \delta^{-2} [\bar{e}^{cp}; \bar{e}], \quad (5.11)$$

where $e^{cp}(\bar{e})$ denotes optimal level of effort under collusion-proof regulation. As already mentioned, all firms with productivity in $[a^+; \bar{e}^{cp})$ produce at the same cost. Consequently, effort equals

$$e^{cp}(\bar{e}) = e^{cp}(\bar{e}^{cp}) + \bar{e} - \bar{e}^{cp} \delta^{-2} [a^+; \bar{e}^{cp}). \quad (5.12)$$

A comparison of optimal effort (5.10)-(5.12) under collusion-proof regulation with optimal effort (3.13) under regular yardstick competition confirms our expectations:

Proposition 5.4. Third best, collusion-proof regulation entails more (less) distortion of effort for firms with low (high) industry-specific productivity than second-best regulation.

¹⁴The optimal level of bunching under collusion-proof regulation is derived in appendix A.4.

Proof. See appendix A.4.

An central proposition in Laffont and Martimort (1998) (LM) states that the social cost of collusion vanishes in the limit when correlation of information becomes near perfect. The reason is that the regulator is able to exploit informational asymmetries within the cartel to extract almost all rents. Here, firms never share information. Therefore there are no informational asymmetries for the regulator to exploit. As we shall see, the welfare implication is fundamentally different.

To see what happens when correlation of information changes, subtract expected welfare W^S when firms are regulated on an individual basis (equation (A.3) in appendix A.1) from expected welfare W^{CP} under collusion-proof regulation to obtain:

$$W^{CP} - W^S = B, \quad \text{where } B = \int_{\underline{a}}^{\bar{a}} [\tilde{A}^0(e(\theta)) - \tilde{A}^0(\theta - C(a^+))] F(\theta) d\theta. \quad (5.13)$$

B is the benefit of yardstick competition. Under individual regulation a firm with high IS productivity ($\theta = \bar{\theta}$) can credibly mimic a firm with low IS productivity ($\theta = \underline{\theta}$). This means that every firm with high IS productivity must be compensated for not understating productivity to a^+ under separate regulation. Under collusion-proof yardstick competition, an $\bar{\theta}$ firm cannot credibly pretend to be an $\underline{\theta}$ firm. It would involve incompatible reports, for which they are punished. However, the regulator must pay firms ex ante for not agreeing to manipulate reports. A deviation must be unprofitable in expectation. In a sense one can say that yardstick competition allows the regulator to switch from an ex post to an ex ante incentive constraint for $\bar{\theta}$ firms. B measures the social value of the reduction in expected transfers attributed to the change from the ex post to the ex ante incentive constraint.

Proposition 5.5. The benefit (B) of yardstick competition vanishes when correlation of private information (measured by ρ) becomes perfect.

Proof. $0 \leq B \leq \int_{\underline{a}}^{\bar{a}} \frac{R^{ai}}{\Delta} \tilde{A}^0(e(\cdot)) F(\cdot) d\cdot - \int_{\underline{a}}^{\bar{a}} \frac{R^{ai}}{\Delta} F(\cdot) d\cdot - \int_{\underline{a}}^{\bar{a}} (a_i - \underline{a}) F(a) = \int_{\underline{a}}^{\bar{a}} (1 - \rho)(\bar{a} - \underline{a}) v$. The first inequality follows from monotonicity of C , the second from $\tilde{A}^0 > 0$, the third from $\tilde{A}^0(e(\cdot)) \leq 1$ and the fourth from $F^0 > 0$. It is evident that $B \rightarrow 0$ when $\rho \rightarrow 1$. ■

Proposition 5.5 combined with expression (5.13) shows that collusion-proof regulation converges to individual regulation of firms when correlation becomes high. Contrary to the LM case, firms recover all their losses in a perfectly correlated environment, when collusion is possible. Collusion allows producers to act as a merged entity, thereby fully countervailing the rent-extraction effect of yardstick competition. The result suggests that cartel-formation with information-sharing may not be the best collusive arrangement for regulated firms. Highly similar firms who cannot credibly transmit information to each other, are better off not exchanging information, but rather applying rules of the kind discussed in this paper.¹⁵ The explanation for the result lies in the restrictions the different modes of collusion puts on side transfers. In the LM model the two agents report their true type to a third party that uses the information to manipulate the social planner's mechanism. This puts a lot of restrictions on the side payments. A massive side transfer may be required in order to induce agent 1 to truthfully reveal his type, but the huge side transfer may have the implication that it becomes unprofitable for agent 2 to reveal his type or even participate in the cartel. What LM show, is that although the stakes of collusion increase when correlation of types becomes stronger, there is no way the agents can set up side transfer schemes to reap the benefits. Not so in this model. Here, the value of side transfers is measured solely by the pain it inflicts on the potential deviator. The value does not matter to the

¹⁵This presupposes that the regulator knows the mode of collusion.

recipient since firms do not share information in the first place. Thus firms are able to neutralise any sticks and carrots offered by the regulator, irrespective of the degree of collusion

Finally, a word on collateral. The first-best regulatory contract is to give each firm a fixed-price contract, which maximises efficiency in production, and pay out transfers sufficient to guarantee that firms' ex ante participation constraint is just met. This is even collusion-proof since each firm is regulated on an individual basis. However, the contract implies that some low-productivity firms run a deficit ex post, hence shut down. The interim participation constraint can be relaxed by the use of collateral. If firms put up sufficient collateral, they are willing to produce at all levels of productivity even with a fixed-price contract. The problem is that firms realise that rents are decreasing in the amount of collateral they put up. Consequently, they have no incentive to provide it. A potential method for raising collateral is by means of an auction where the right to produce goes to the firm with the highest collateral. However, the set of potential bidders may be small and their access to collateral limited. Therefore, the regulator may be forced to use yardstick competition in regulation. Collateral must be in the form of lump sum payments, in order to preserve truth-telling incentives. It can have no effect on firms' joint efforts to manipulate incentive contracts because they retrieve their collateral whether they collude or not as long as they keep producing. The conclusion is that the use of collateral can be used as an instrument to increase efficiency in production, but not to prevent collusion - unless firms are willing to put up significant amounts of it.

6. Conclusion

This paper has studied the nature of collusion and characterized collusion-proof regulation when firms are regulated by means of yardstick competition and have the opportunity to write collusive side contracts prior to the revelation of private, correlated information. High productivity firms collectively pretend to have low productivity in order to circumvent the effects of yardstick competition. They must be compensated for not colluding, which creates a trade-off between rent-extraction and efficiency. Collusion-proof yardstick competition demands less (more) cost efficient production for low (high) productivity firms than prescribed by regular (second-best) yardstick competition. It has been shown that colluding firms are able to recover almost all rents when correlation of information is near perfect. This contrasts with the result by Laffont and Martimort (1998b), that firms are able to recover almost no rents when information is highly correlated. The divergent welfare implications stem from assumptions about timing. Firms collude after the revelation of private information in the Laffont and Martimort framework, whereas they form the cartel prior to the revelation of private information in my setting. This suggests that regulated firms may want to commit to not exchanging information when they form cartels.

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A. Appendix

I first prove some intermediary results. Write $b = (b; b^0)$, and let $t(b)$, $U(b)$, $C(b)$ and $e(b)$ denote respectively transfer, rent, cost-target and effort level that accrues to a firm that reports b when the other firm reports b^0 . Let $\bar{b} = (\bar{b}; \bar{b}^0)$ be the vector of true types.

Lemma A.1. A mechanism is truthful only if:

$$t(\bar{b}) = \int_{\bar{b}^0}^{\bar{b}^0} \bar{A}^0(e(x; \bar{b}^0)) dx + U(\bar{b}; \bar{b}^0) + \bar{A}(e(\bar{b})) - 2A_1^2 - A_2^2. \quad (A.1)$$

Proof. By definition $V(b; \bar{b}^0) = E_0[t(b; \bar{b}^0)] - E_0[\bar{A}(\bar{b} - C(b; \bar{b}^0))]$. $E_0[t(\bar{b})]$ is expected transfer and $E_0[\bar{A}(e(\bar{b}))]$ is expected disutility of effort, conditional on the other firm telling the truth and on $\bar{b}$. $E_0[\bar{b}]$ is independent of $\bar{b}$ because the conditional distribution $f(\bar{b}^0 | \bar{b}) = g(\bar{b}^0)$ is independent of $\bar{b}$. Thus $V(b; \bar{b}^0) = V(\bar{b}) + E_0[\bar{A}(e(b; \bar{b}^0))] - E_0[\bar{A}^0(\bar{b} - C(b; \bar{b}^0))]$. Use (3.4) and differentiate to obtain:

$$\frac{\partial V(b; \bar{b}^0)}{\partial b} = \int_{\bar{b}^0}^{\bar{b}^0} \bar{A}^0(x - C(b; \bar{b}^0)) dx \frac{\partial C(b; \bar{b}^0)}{\partial b} dG(\bar{b}^0) - 2A_k^2.$$

We see that $\partial U(b; \bar{b}^0) / \partial b = 0$ is met at the optimum $b = \bar{b}$ for all realizations of $\bar{b}^0$, hence indirect utility satisfies $\partial U(\bar{b}) / \partial \bar{b} = -\bar{A}^0(e(\bar{b}))$. Use this and $U(\bar{b}) = t(\bar{b}) - \bar{A}(e(\bar{b}))$ to obtain (A.1). ■

Lemma A.2. The side contract $\phi = \phi^0; \phi^1$ defined below is feasible under every truthful mechanism.

$$\phi^0(\bar{b}) = \begin{cases} \frac{1}{2} a^+ - \frac{1}{2} A_1 & \text{if } \bar{b} \in A_1 \\ \frac{1}{2} a^+ - \frac{1}{2} A_2 & \text{otherwise} \end{cases}, \quad \phi^1(b) = \begin{cases} \frac{1}{2} Z(a^1) - t(b) & \text{if } (b; \bar{b}^0) \in A_1^2, b^0 \in A_2 \\ 0 & \text{otherwise} \end{cases}. \quad (A.2)$$

Proof. Feasibility of $\bar{b}$ is obvious for $\bar{b} \geq A_2$ because there is no collusion in that case. Suppose therefore that $\bar{b} \geq A_1$. $Z(b; \bar{b}) = Z(a^+) - \int_{a^+}^{\bar{b}} \tilde{A}(\bar{b} - C(b; a^+)) \cdot Z'(\bar{b}) - \tilde{A}(a^+ - C(a^+; a^+)) \cdot Z'(\bar{b}) \geq 0$. The inequality follows from $Z'(\bar{b}) = - \int_{a^+}^{\bar{b}} \tilde{A}'(\bar{b} - C(a^+; a^+)) < 0$ and $\tilde{A}' \geq 0$. $Z(b; \bar{b}) = t(b; a^+) - \int_{a^+}^{\bar{b}} \tilde{A}(\bar{b} - C(b; a^+)) - \tilde{A}(a^+ - C(a^+; a^+)) \geq 0$ for $\bar{b} \geq A_2 \in A_1$. Use (A.1) and differentiate to get:

$$\frac{\partial Z(b; \bar{b})}{\partial b} = - \int_{a^+}^{\bar{b}} \tilde{A}''(x - C(b; a^+)) dx \frac{\partial C(b; a^+)}{\partial b} \leq 0 \text{ for } \bar{b} \geq A_2 \in A_1.$$

The inequality is implied by monotonicity of C in b and $b > \bar{b}$. ■

A.1. Individual regulation of firms

Rents are minimized if $U(a^+) = U(a^+; a^+)$. $U(a^+; a^+) = U(a^+) + \tilde{A}(e(a^+)) - \int_{a^+}^{\bar{b}} \tilde{A}(a^+ - C(a^+; a^+))$. Substitute this into (3.8) to get an expression for $U(\bar{b})$ that depends entirely on effort and $U(\bar{b})$. $U(\bar{b})$ is decreasing, hence (3.10) is met if $U(\bar{b}) = 0$. Substitute the new expression for $U(\bar{b})$ into (3.7) and do an integration by parts to get:

$$\max_{e(\cdot)} \int_{a^+}^{\bar{b}} \frac{1}{2} \int_{a^+}^{\bar{b}} [(1 + \lambda)(\bar{b} - e(\bar{b}) + \tilde{A}(e(\bar{b}))) + \lambda \tilde{A}'(e(\bar{b})) \frac{F(\bar{b})}{f(\bar{b})}] dF(\bar{b}) - \int_{a^+}^{\bar{b}} \tilde{A}''(x - a^+ + e(a^+)) dx F(a) \quad (A.3)$$

$$\text{s.t. } C(\bar{b}) \text{ increasing on } A. \quad (A.4)$$

Denote expected welfare (A.3) by W^S . The last term in (A.3) enters due to non-convexity of A . Pointwise maximization of W^S violates the monotonicity requirement (A.4). Therefore there is some bunching at the optimum. $\bar{b}^S$ is found by substituting optimal levels of effort (3.11) and (3.12) back into W^S and differentiating wrt $\bar{b}^S$. This renders a first order condition for optimal bunching:

$$\int_{a^+}^{\bar{b}^S} \tilde{A}''(x - C^S(\bar{b}^S)) dx F(a) - \int_{a^+}^{\bar{b}^S} [(1 + \lambda)(1 - \tilde{A}'(e^S(\bar{b}^S))) + \lambda \frac{F(\bar{b}^S)}{f(\bar{b}^S)} \tilde{A}''(e^S(\bar{b}^S))] dF(\bar{b}) = 0. \quad (A.5)$$

W^S is concave at the interior solution. Note that $\bar{b}^S > a^+$ unless $a^+ = a^+$, in which case there is no bunching. The equality is strict when $\bar{b}^S < \bar{b}$, but the possibility of a corner solution at $\bar{b}$ is not ruled out.

A.2. Proof of proposition 5.2

Consider the regulatory contract $D^{yc} = ft^{yc}; C^{yc}g$ with cost target $C^{yc}(b) = C^{yc}(b) = b_i - e^{yc}(b)$ for all $b \in A^2$ and with transfers:

$$t^{yc}(b) = \begin{cases} < r^{yc}(b) & b \in A_k^2, k = 1; 2 \\ r^{yc}(b) + r & b \in A_1; b^0 \in A_2 \\ \tilde{A}^0(a_i - C^{yc}(b)) \pm \epsilon & b \in A_2; b^0 \in A_1 \end{cases}, \quad (A.6)$$

where

$$r^{yc}(b) = \int_b^{\mathbf{Z}^{-(b)}} \tilde{A}^0(e^{yc}(x))dx + \tilde{A}(e^{yc}(b)); \quad (A.7)$$

$r, r^{yc}(a^+), \tilde{A}(a_i - C^{yc}(a^+))$ and $\pm \epsilon > 0$ is a small number. It is shown below that truth-telling is the unique BNE when the regulator proposes D^{yc} . This implies that both firms meet the cost target $C^{yc}(\cdot) = \cdot - e^{yc}(\cdot)$, hence the social choice function $e^{yc}(\cdot)$ is implemented as a unique BNE.

First, strict monotonicity of C^{yc} is proved: $C^{yc}(\cdot) = 1 - e^{yc}(\cdot) > 0$ on $\cdot \in [\underline{\cdot}(\cdot); \bar{\cdot}(\cdot)]$ by $e^{yc}(\cdot) < 0$. C^{yc} is globally strictly increasing if $C^{yc}(a_i) < C^{yc}(a^+)$. This is equivalent to $a^+ - a_i > \tilde{A}^{0-1}(1) - e^{yc}(a_i)$ since $\tilde{A}^0(e^{yc}(a^+)) = 1$. $a^+ - a_i > \tilde{A}^{0-1}(1)$ holds for all θ that satisfy (2.4).

Denote by $4U$ a firm of type $\cdot$'s net benefit of truthfully reporting $\cdot$ over b when the other firm reports b^0 . By invoking (A.6) and (A.7), it is straightforward to show that

$$4U = \int_b^{\mathbf{Z}^{-(b)}} \int_{C^{yc}(x)}^{\mathbf{Z}^{-(b)}} \tilde{A}^{00}(x - y)dydx - \int_{C^{yc}(x)}^{\mathbf{Z}^{-(b)}} \tilde{A}^{00}(x - y)dydx \quad 8(b; \cdot) \in A_1 \in A \in A_1, \quad (A.8)$$

where $b = (b; b^0)$. Strict monotonicity of C^{yc} implies that (A.8) is strictly positive unless $b = \cdot$, in which case $4U = 0$. Next,

$$4U = \int_{a_i}^{a^+} \int_{C^{yc}(x)}^{\mathbf{Z}^{-(b)}} \tilde{A}^{00}(x - y)dydx + \int_{a_i}^{a^+} \int_{C^{yc}(a^+)}^{\mathbf{Z}^{-(b)}} \tilde{A}^{00}(x - y)dydx + \int_{a_i}^{a^+} \int_{C^{yc}(x)}^{\mathbf{Z}^{-(b)}} \tilde{A}^{00}(x - y)dydx + (1 - I) \pm 8(b; \cdot) \in A_2 \in A \in A_1, \quad (A.9)$$

where I is an indicator function that takes on the value 1 for $b^0 \in A_2$ and zero otherwise. (A.9) is strictly positive for all $\cdot < a_i$ and non-negative for $\cdot = a_i$.

Thus, truth-telling is a strictly dominating strategy for all $\bar{c} < a^i$ and a weakly dominating strategy for $\bar{c} = a^i$. In equilibrium $b^0 = \bar{c}^0$ for all $\bar{c} < a^i$, hence $I = 0$ for almost every b . The firm's expected loss of reporting $b \in A_2$ is therefore $\pm > 0$ for $\bar{c} = a^i$. Hence, truth-telling is the unique BNE for all $\bar{c} \in A_1$.

Consider next the case with $\bar{c} \in A_2$. Proceed in a similar fashion as before to obtain:

$$4U = \int_b^{a^i} \int_{C^{yc}(b)}^{C^{yc}(x)} \tilde{A}^{00}(x; y) dy dx + \int_{a^i}^{\bar{c}} \int_{C^{yc}(b)}^{C^{yc}(a^+)} \tilde{A}^{00}(x; y) dy dx \pm 8(b; \bar{c}) \in A_1^2 \in A_2$$

$$4U = \int_b^{a^i} \int_{C^{yc}(b)}^{C^{yc}(x)} \tilde{A}^{00}(x; y) dy dx + \int_{a^i}^{a^+} \int_{C^{yc}(b)}^{C^{yc}(a^+)} \tilde{A}^{00}(x; y) dy dx + \int_{a^+}^{\bar{c}} \int_{C^{yc}(x)}^{C^{yc}(b)} \tilde{A}^{00}(x; y) dy dx \pm 8(b; \bar{c}) \in A_1^2 \in A_2^2.$$

The first expression is positive for $\pm$ sufficiently small, the second is always positive. Thus, a firm with $\bar{c} \in A_2$ strictly loses by reporting $b \in A_1$ irrespective of what the other firm reports. Therefore both firms report $b \in A_2$ in equilibrium. We can derive the same expression as in (A.8) to show that truth-telling is the unique best-reply for $\bar{c} \in A_2$ under the constraint $b^0 \in A_2$. Hence, truth-telling is the unique BNE also for all $\bar{c} \in A_2$. ■

A.3. Collusion-proof regulation

The regulator maximizes (5.1) subject to (5.2)-(5.4). From section 3 we know that (5.2)-(5.3) can be replaced by (3.4)-(3.6), $V(a^i) \geq 0$ and $V(\bar{c}) \geq 0$. Set $V(\bar{c}) = 0$ and eliminate (3.5) by setting $t(b) = 0 \ 8b \in A_k \ [A_k^c, k = 1; 2$. The remaining constraints are now (3.4), (3.6), (5.4) and $V(a^i) \geq 0$. The collusion-proof mechanism is truthful. This implies that the side contract $\$$ defined by (A.2) is feasible (lemma A.2). Thus a necessary condition for (5.4) to hold is:

$$\int_{\bar{c}}^{a^i} V(\bar{c}) dF(\bar{c}) = \int_{\bar{c}}^{a^i} (t^+ - \tilde{A}(\bar{c} - C^+)) dF(\bar{c}), \quad (A.10)$$

with t^+ , $t(a^+; a^+)$, e^+ , $e(a^+; a^+)$ and $C^+ = a^+ \downarrow e^+$. (A.10) states that total expected rents are identical under the truthful side contract and under the collusive side contracts $\$$. Assume for the moment that (A.10) is also sufficient and, consequently, strictly binding. Under a truthful mechanism the transfer $t(-)$ is defined by (A.1). Use this to derive an expression for t^+ , substitute it into the binding constraint (A.10) and do an integration by parts to obtain:

$$\int_{-}^{a^+} V(-) dF(-) = \int_{-}^{a^+} \tilde{A}^0(e(-; a^+)) \frac{F(a)}{f(-)} dF(-) + U(-; a^+) F(a) + \int_{-}^{a^+} \tilde{A}^0(x \downarrow C^+) dx F(a) + \int_{-}^{a^+} \tilde{A}^0(- \downarrow C^+) \frac{F(-)}{f(-)} dF(-). \quad (A.11)$$

If (A.10) is the binding collusive incentive compatibility constraint, expected rents to each firm is equal to (A.11) plus

$$\int_{a^+}^{\infty} V(-) dF(-) = \int_{a^+}^{\infty} \tilde{A}^0(e(-)) dG(-) \frac{F(-) \downarrow F(a)}{f(-)} dF(-), \quad (A.12)$$

where I have used (3.4) and $V(-) = 0$ to obtain the expression in (A.12). Clearly, rents to the firm are independent of the type of the other firm 0 , hence $e(-) = e(-)$. In particular, $U(-; a^+) = U(-) = V(-) = 0$ and $e(-; a^+) = e(-) = e(-)$.

I now verify that (A.10) is sufficient for (5.4) to hold. Firms receive no rents if they deliver incompatible cost reports. Thus colluding firms always deliver compatible cost reports in equilibrium. By (A.10), (3.4), independence ($e(-) = e(-)$) and monotonicity of C in $-$, we have $^0(-) = - \delta - 2 A_1$ and $^0(-) = a^i \delta - 2 A_2$ or $^0(-) = - \delta - 2 A_2$ in the optimal side contract. $^0(-) = a^i$ cannot be optimal because $U(a^i; -) = \tilde{A}(e(a^i)) \downarrow \tilde{A}(- \downarrow C(a^i)) < 0 \cdot U(-)$. The first inequality follows from $- > a^i$, the second from individual rationality. Thus (A.10) is sufficient for (5.4) to hold.

Add (A.11) and (A.12) and simplify to get expected firm rents under collusion-proof regulation:

$$\int_{-}^{a^+} U(-) dF(-) = \int_{-}^{a^+} \tilde{A}^0(e(-)) \frac{F(-)}{f(-)} dF(-) + \int_{a^+}^{\infty} \tilde{A}^0(x \downarrow C(a^+)) dx F(a) + \int_{-}^{a^+} \tilde{A}^0(- \downarrow C(a^+)) \frac{F(-)}{f(-)} dF(-). \quad (A.13)$$

Substitute (A.13) into (5.1) to obtain (5.6). The remaining constraints are (3.6) and $V(a^i) \geq 0$. (3.6) and $C(\bar{\omega}) = C(\omega)$ imply (5.7). Use $e(\bar{\omega}) = e(\omega)$ and do an integration by parts on (3.4) to obtain:

$$\int_{\bar{\omega}}^{\omega} V(\bar{\omega}) dF(\bar{\omega}) = \int_{\bar{\omega}}^{\omega} \tilde{A}^0(e(\bar{\omega})) \frac{F(\bar{\omega})}{f(\bar{\omega})} dF(\bar{\omega}) + F(a)V(a^i).$$

Subtract this expression from (A.10), use that ...rms are identical ex ante, and rearrange terms to get:

$$F(a)V(a^i) = \int_{\bar{\omega}}^{\omega} [t^+ - \tilde{A}(\bar{\omega} - C^+) - \tilde{A}^0(e(\bar{\omega})) \frac{F(\bar{\omega})}{f(\bar{\omega})}] dF(\bar{\omega}). \quad (A.14)$$

$V(a^i) \geq 0$ is equivalent to (5.8).

In order to derive the optimal level of bunching under collusion-proof regulation, insert (5.10)-(5.12) into the Lagrangian (5.9) and differentiate wrt. $\bar{\omega}^{cp}$ to get the FOC:

$$\left(\frac{\partial}{\partial \bar{\omega}^{cp}} \right) \left[\int_{a^+}^{\omega} \tilde{A}^0(x - C^{cp}(\bar{\omega}^{cp})) dx F(a) + \int_{\bar{\omega}}^{\omega} \tilde{A}^0(e^{cp}(\bar{\omega})) \frac{F(\bar{\omega})}{f(\bar{\omega})} dF(\bar{\omega}) \right] \geq \int_{a^+}^{\bar{\omega}^{cp}} [(1 + \frac{\partial}{\partial \bar{\omega}^{cp}})(1 - \tilde{A}^0(e^{cp}(\bar{\omega}))) + \tilde{A}^0(e^{cp}(\bar{\omega})) \frac{1}{f(\bar{\omega})} \frac{dF(\bar{\omega})}{d\bar{\omega}}] dF(\bar{\omega}).$$

The LHS is marginal rent-extraction, the RHS is marginal welfare loss from distortion of efficiency.

A.4. Proof of proposition 5.4

$e^{cp}(\bar{\omega}) < e^{yc}(\bar{\omega}) \ 8^{-2} [a^+; \bar{\omega}]$: Compare equations (3.13) and (5.11). Optimal effort is decreasing in the hazard rate by the assumptions on $\tilde{A}$. Thus $e^{cp}(\bar{\omega}) < e^{yc}(\bar{\omega}) \ 8^{-2} [\bar{\omega}^{cp}; \bar{\omega}]$ since $F(\bar{\omega}) = f(\bar{\omega}) < (F(\bar{\omega}) - F(a)) = f(\bar{\omega})$. Further, $e^{cp}(\bar{\omega}) = e^{cp}(\bar{\omega}^{cp}) + \bar{\omega} - \bar{\omega}^{cp} < e^{cp}(\bar{\omega}^{cp}) < e^{yc}(\bar{\omega}^{cp}) < e^{yc}(\bar{\omega}) \ 8^{-2} [a^+; \bar{\omega}^{cp}]$. The first inequality is obvious, the second follows from the first part of this proof, the third from the assumption that $F=f$ is increasing in $\bar{\omega}$ and the fact that e is decreasing in $F=f$. For later reference, observe that $\tilde{A}^0 > 0$ and $e^{cp}(\bar{\omega}) < e^{yc}(\bar{\omega})$ imply

$$V^{cp}(\bar{\omega}) = \int_{\bar{\omega}}^{\omega} \tilde{A}^0(e^{cp}(x)) dx < \int_{\bar{\omega}}^{\omega} \tilde{A}^0(e^{yc}(x)) dx = V^{yc}(\bar{\omega}) \ 8^{-2} [a^+; \bar{\omega}]. \quad (A.15)$$

$e^{cp}(\bar{\omega}) > e^{yc}(\bar{\omega}) - \frac{1}{2}(\bar{\omega} - a^i)$: Second-best regulation is non-collusion-proof, so the regulator must give up rents to firms to prevent collusion, i.e. $E[V^{cp}(\bar{\omega})] > E[V^{yc}(\bar{\omega})]$ in equilibrium. Observe from equation (5.10) that $e^{cp}(\bar{\omega})$ is decreasing in $\bar{\omega}$. Thus for every $\bar{\omega} \in (\bar{\omega} - a^i]$, $e^{cp}(\bar{\omega}) > e^{yc}(\bar{\omega})$, $\bar{\omega} - \frac{1}{2}(\bar{\omega} - a^i) > e^{yc}(\bar{\omega})$ is impossible since it would imply $E[V^{cp}(\bar{\omega})] < E[V^{yc}(\bar{\omega})]$ by (A.15) and

$$V^{cp}(\bar{\omega}) = \int_{\bar{\omega} - a^i}^{\bar{\omega}} \tilde{A}^0(e^{cp}(x))dx > \int_{\bar{\omega} - a^i}^{\bar{\omega}} \tilde{A}^0(e^{yc}(x))dx = V^{yc}(\bar{\omega}) - \frac{1}{2}(\bar{\omega} - a^i). \blacksquare$$

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