A Reexamination of Yardstick Competition

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This paper shows that yardstick competition does not assist a regulator when lump-sum transfers are not costly and the regulator does not care about the distribution of income. Yardstick competition may discourage investment that would make efficient operation possible. The paper characterizes optimal regulatory schemes in a simple model and demonstrates that it may be optimal to limit the amount of information available to the regulator.

1. Introduction

Yardstick regulation arises when a regulator uses information from several similar firms to determine the incentives for each firm. Information acquired from related firms typically enables the regulator to provide better incentives for efficient performance. Yardstick schemes play an important role in Medicare's formulas for reimbursing hospitals (Dranove, 1987), regulation of natural gas and electric power (Joskow and Schmalense, 1986), and telecommunications (FCC, 1994). Similar schemes arise in labor contracts (Lazear, 1995).

I consider a situation in which firms must first decide whether to make an investment that might enable them to use a cost-saving technology in the future. Firms will invest if they expect to earn sufficient rents from cost savings to compensate them for the investment. A regulatory environment that reduces the rents of the firm after it has made its investment could decrease a firm's incentives to make the investment in the first place. This effect creates a trade-off for the regulator. On one hand, using the information available from other firms leads to more efficient regulation once the firms have made their preliminary investment. On the other hand, the information may reduce the firms' incentives to invest. The regulator may wish to limit the amount of information it can use when making regulatory decisions.

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The paper makes two observations about the value of information in a model of regulation. First, I note that using information obtained from other firms improves regulatory outcomes only if it is costly to make transfers from consumers to firms. It is not necessary to use yardstick competition to induce the efficient effort on the part of a firm if the regulator can make transfers without distortion. This observation clarifies the contribution of Shleifer (1985), who presented an early theoretical discussion of yardstick competition in a model where transfers were costless. Second, I point out that when firms make investment decisions prior to regulation, providing the regulator with more information may not be socially beneficial, because it could create incentives adverse to investment. The first result holds because when transfers are costless the regulator is willing to give a firm the residual claim on profits generated by cost-reducing investments. Yardstick competition is beneficial when the firms have correlated information that the regulator lacks and when it is costly to make transfers to the firm. Using information from the other firms reduces the distortion caused by incomplete information, generates higher surplus, and reduces the transfers that need to be made to the firms. The second result holds because increasing the information available to the regulator lowers the rents that a firm might capture if it has access to a good technology. The level of investment decreases because the gains from investment decline.

It is well known that the inability to make commitments can lead to inefficient levels of investment in contracting problems. Underinvestment in my model is a form of Williamson's (1975) holdup problem.[1] Laffont and Tirole (1994, pp. 100–101) discuss the problem in a regulatory framework. This paper demonstrates that increases in the information available to the regulator will increase the magnitude of the holdup problem. Hence I suggest a reason for limiting the number of firms under a single regulatory authority.

Other work has identified different reasons to limit the extent to which performance of others enters into incentive contracts. Baker (1992), Gibbons and Murphy (1990), and Lazear (1995, pp. 33–36) point out that compensation schemes based on relative performance provide incentives for agents to engage in inefficient activities de-

1. Gul (1997) studies a version of the holdup problem in which investment is unobservable. I make the same assumption in this paper. Gul observes that in the presence of asymmetric information the extent of the holdup problem depends on the way the bargaining process is modeled. As is standard in the regulatory design literature, I assume that the regulator holds all of the bargaining power.

signed to reduce the performance of others. In Dranove's (1987) model yardstick regulation could be detrimental because it has the potential to direct customers towards less suitable servers. Possibilities of this sort do not arise in my model, because the markets of individual firms do not overlap. In addition, yardstick competition will not work well if firms are sufficiently heterogeneous.[2]

The trade-off between increasing the scope of a regulator's comparison group and decreasing the incentives to innovate suggests an aspect of organizational design that has received little attention. Maskin et al. (1997) point out that there are advantages to organizing a government (firm) so that yardstick comparisons can be made. Their paper compares the performance of organizations arranged into many independent divisions producing similar products under similar conditions (the multidivision form, or M-form) with that of organizations arranged into specialized, dependent departments (the unitary form, or U-form). They argue that the M-form provides superior incentives if performance across the independent divisions is more highly correlated than performance across the departments. My paper complements their study in that it suggests that the scale at which comparisons are made influences incentives to invest.

The observation that regulators may not prefer to have better information is familiar from other studies. Sappington (1986) points out that information may have negative value to a regulator with limited commitment powers. Dalen (1997) analyzes a dynamic model in which an informed regulator could extract all future rents from the firm. The firm distorts its present actions to avoid this outcome. Dalen observes that improved information could make a regulator with limited commitment power worse off. Riordan (1990) makes a similar observation. Riordan observes that vertical integration makes it easier for a manager to obtain *ex post* information about an agent's private information. This would eliminate *ex post* rents and therefore reduce *ex ante* incentives for cost reduction.

In the basic model, the regulator has the power to set the marginal production cost of the firm, subject to a breakeven constraint. The regulator's problem is nontrivial because the firm has private information about the quality of its technology. In the solution to this problem, the regulator typically allows the firm to choose between a set of production costs and transfers. When the firm has access to a more efficient technology, the optimal regulatory scheme induces the firm to operate at a lower cost.

2. Kridel et al. (1996) assert that heterogeneity is the reason for the limited use of yardstick schemes in telecommunications.

Section 2 describes the model. Section 3 describes the benchmark full-information case and analyzes the optimal regulatory mechanism of a single firm that has already made an investment decision. It demonstrates that the regulator can obtain the full-information solution when transfers are not costly.

In Section 4, I assume that there are many firms and that the probabilities that they have access to the more efficient technology are correlated. I make the familiar observation that the regulator gains from using information about other firms' technology. When transfers are costly, social welfare increases when the regulatory policy applied to one firm depends nontrivially on the behavior of other firms. One detail that appears from the analysis is that the regulator gains useful information not only from knowing a firm's technology, but also from knowing whether the firm made an investment to improve its technology.

Sections 5, 6, and 7 study regulatory schemes in the model in which firms must make an investment that determines (stochastically) the quality of their technology. Section 5 concentrates on the case in which the regulatory scheme is independent. Sections 6 and 7 allow the regulator to use yardstick regulation. Section 6 characterizes the optimal regulatory scheme when the regulator can commit to a mechanism prior to the firms' investment decisions. If investment success is not independent, commitment ability allows the regulator to implement the full-information incentive scheme. Section 7 discusses yardstick regulation when the regulator cannot commit to a mechanism prior to the firms' investment decisions. I demonstrate that the regulator's inability to observe the technology of the firm reduces the incentives to invest. This effect is stronger the more information the regulator has about the technologies of other firms.

Section 8 makes the point that, when the decision to invest in technological improvement is endogenous, yardstick competition may be inferior to independent regulation. Section 9 contains concluding comments.

2. The Model

Initially, each firm first must decide whether or not to make an investment. Denote the investment decision by τ, where $\tau = 1$ means that there has been investment, and $\tau = 0$ means that there has been no investment. $C > 0$ is the opportunity cost of making an investment. The investment is successful with probability $\rho \in (0, 1)$. The investment determines the type of the firm. I denote the type of the firm by θ and assume that there are two possible types of firm.

The superior ($\theta = 1$) type of firm has access to a technology that enables it to operate more efficiently at lower costs. When the firm has the inferior technology ($\theta = 0$), its optimal cost is higher. Whether or not a firm makes an investment, the firm is characterized by a net revenue function $R(c, \theta)$. Assume that (denoting partial derivatives by subscripts) $R_{cc}(c, \theta) < 0$. The function that determines the gains from having the efficient technology is $S(c) = R(c, 1) - R(c, 0)$. Assume that this function is positive, decreasing, and convex over the range of costs relevant to the regulator. These assumptions guarantee that firms with the superior technology are better able to reduce costs.

Profits of a firm are given by $\pi = R(c, \theta) + T - \tau C$, where T is a lump-sum transfer to the firm. There is a cost associated with raising money for transfers. It costs $1 + \lambda$ dollars to raise 1 dollar to transfer to a firm. Assume $\lambda \geq 0$. The objective of the regulator is to maximize the sum of consumer surplus $[CS(c)]$ and profits: $CS - (1 + \lambda)T + \pi$. Assume that $CS(\cdot)$ is concave.

c is a one-dimensional variable that I call cost. The analysis of the paper applies when the regulator controls any number of variables. Only the concavity conditions needed to describe the qualitative properties of the solution need to be modified.[3] The simplest interpretation of $R(\cdot)$ is that it represents the revenue of the firm net of production costs under the assumption that prices are exogenously fixed and the firm must produce to meet demand. Under this interpretation, c represents the production costs of the firm. The assumptions on $R(\cdot)$ guarantee that $\theta = 1$ is the superior technology. More generally, $R(\cdot)$ could represent an optimal value function obtained when the firm selects prices to maximize profits given the regulator's choice of operating cost.

There are two interpretations of the investment decision. The most natural specification is that C is a research and development expense. A firm that pays C operates a research enterprise that could lead to lower production costs. An alternative assumption is that C represents the cost of undertaking a careful review of the organization of the firm. With positive probability, a review will uncover systematic inefficiencies in the way that the firm operates. Correcting these problems provides access to an improved technology. In both of these cases, it is natural to assume that the firm is better informed about its cost structure than the regulator.

3. An earlier version assumed that the regulator controlled both price and cost.

The paper will analyze several games. The games differ along three dimensions: whether the investment decision is endogenous; whether the regulator uses a joint or an independent regulatory mechanism; and whether the regulator can commit to a mechanism prior to the investment decisions of the firm. In the next section I discuss independent regulatory schemes constructed after a firm has made an investment decision. That is, the regulator designs the mechanism knowing the probability that the firm has access to the good technology. Given this mechanism, the firm responds by reporting its type. This report determines the firm's required production cost and the transfer that it receives (see Fig. 1). The regulator is able to observe the cost selected by the firm (but not the firm's type θ).[4] The scheme is independent in the sense that what the regulator requires of a firm does not depend on the reports of other firms.

Section 4 analyzes joint regulatory schemes constructed after the firm has made its investment decision. The regulator designs a mechanism that responds to the reported investment decisions and outcomes of all firms. Specifically, the regulator knows the probability that each firm invests and the conditional probability of successful investment. The regulatory mechanism asks each firm to report whether it invested and, if it invested, whether it has acquired a good technology (the information that the regulator receives is denoted by ν). These reports determine a firm's required production cost and the transfer that it receives (see Fig. 2). The difference between the analysis in this section and the analysis in Section 4 is that in Section 4 the regulator is able to use information obtained from the investment decision and outcome of one firm to regulate other firms. When investment success is correlated, this information is useful to the regulator.

Section 5 returns to independent schemes, but assumes that the investment decision is endogenous. In the limited-commitment case (Fig. 3), first the firm decides whether to invest, then the regulator,

4. One can show that even if the regulator cannot observe the actual cost of the firm, the mechanisms of this paper will still solve the regulator's optimization problem.

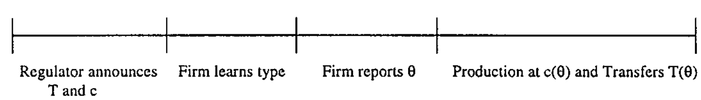

FIGURE 1. INDEPENDENT REGULATION AFTER THE INVESTMENT DECISION (SECTION 3)

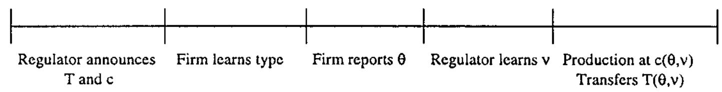

FIGURE 2. JOINT REGULATION AFTER THE INVESTMENT DECISION (SECTION 4)

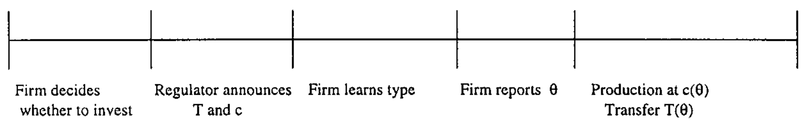

FIGURE 3. INDEPENDENT REGULATION PRIOR TO THE INVESTMENT DECISION: LIMITED COMMITMENT (SECTION 5)

knowing the firm's strategy but not the outcome of the investment, determines a regulatory scheme, and then the game proceeds as in Figure 1. In the commitment case (Fig. 4), the regulator announces a regulatory scheme prior to the firm's investment.

Section 6 discusses joint schemes in which the regulator has full commitment ability. The regulator announces a scheme, and firms make their investment decisions and report the results. The regulator is able to use information obtained by one firm to regulate others (see Fig. 5).

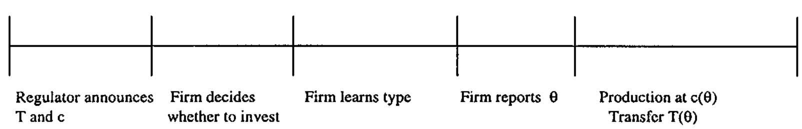

FIGURE 4. INDEPENDENT REGULATION PRIOR TO THE INVESTMENT DECISION: FULL COMMITMENT (SECTION 5)

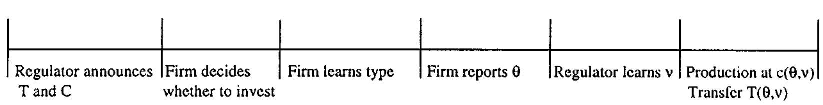

FIGURE 5. JOINT REGULATION PRIOR TO THE INVESTMENT DECISION: FULL COMMITMENT (SECTION 6)

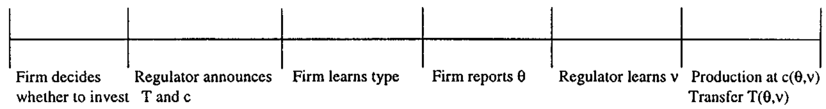

FIGURE 6. JOINT REGULATION PRIOR TO THE INVESTMENT DECISION: LIMITED COMMITMENT (SECTION 7)

Finally, Section 7 describes the game in which the regulator cannot commit to a mechanism until after firms have made their investment choices (Fig. 6).

3. Independent Regulation

This section describes the solution to the regulator's problem under two assumptions that are relaxed later. First, it is assumed that the regulator controls each firm independently. That is, the regulator does not use information it might gain from observing one firm to modify another firm's compensation scheme. Second, it is assumed that the decision whether to invest has already been made, and that the regulator believes that $h(\theta)$ is the probability that the firm is type θ.

As a benchmark, I describe the solution to the regulator's problem under complete information. The regulator will choose transfers so that each type of firm earns zero profits and then selects costs $c^*(\theta)$ to maximize $CS(c(\theta)) + (1 + \lambda)R(c(\theta), \theta)$. The solution will satisfy

$$CS'(c^*(\theta)) + (1 + \lambda)R_c(c^*(\theta), \theta) = 0. \tag{3.1}$$

The solution to (3.1) is the *efficient regulatory scheme*.

When the regulator lacks information about θ, the problem is a familiar incentive problem. I will describe the features of the solution of the problem. The details are available in standard sources [for example, Laffont and Tirole (1994)[5]]. The regulator operates by asking the firm to report its cost type. It constructs its regulatory regime to induce the firm to report its type truthfully and to guarantee the firm nonnegative profit. The requirement that the firm report honestly is without loss of generality. I assume that the regulator does

5. In Laffont and Tirole's model, firms can take on more than two types. My specification of costs is more general.

not use random schemes. Standard arguments demonstrate that randomization does not benefit the regulator in this setting.

The problem of the regulator is to find $c(\theta)$ and $T(\theta)$ to maximize surplus subject to individual rationality and incentive compatibility constraints. That is, in response to the firm's reported technology, the regulator sets the firm's production cost (c) and the transfer that the firm will receive (T). The individual rationality constraint guarantees that the firm earns nonnegative profits. The incentive compatibility constraint guarantees that it is optimal for the firm to report its type honestly to the regulator.[6] In the solution, the individual rationality constraint that requires the firm to earn zero profit when it has an inferior technology and the incentive compatibility condition that states that the firm truthfully reveals that it has the superior technology (rather than claim $\theta = 0$) must bind. From these observations, one can solve for the optimal transfers, and substitute for T in the objective function to obtain an objective function for the regulator:

$$\max \sum_{\theta=0}^{1} [CS(c(\theta)) + (1 + \lambda)R(c(\theta), \theta)]h(\theta) - \lambda S(c(0))h(1), \quad (3.2)$$

where

$$T(0) = -R(c(0), 0) \quad \text{and} \quad T(1) = -R(c(1), 1) + S(c(0)) \quad (3.3)$$

The remaining incentive condition will hold if and only if $c(0) \geq c(1)$ in the solution to (3.2).

The first-order conditions for (3.2) are

$$(1 + \lambda)R_c(c(0), 0) + CS'(c(0)) = \lambda S'(c(0))h(1)/h(0) \quad (3.4)$$

and

$$(1 + \lambda)R_c(c(1), 1) + CS'(c(1)) = 0. \quad (3.5)$$

When (3.4) and (3.5) can be solved uniquely for $c(\theta)$ for $\theta = 0$ and 1 such that $c(1) \leq c(0)$, the conditions characterize a solution to (3.2).[7] In order to guarantee that $c(1) < c(0)$, it is sufficient that

6. If the regulator can observe output and cost, then it can force a firm that reports type θ to produce at the cost $c(\theta)$. Hence the incentive constraint requires that a type-θ firm prefer to report θ and produce at $c(\theta)$ rather than report $\theta' \neq \theta$ and produce at $c(\theta')$.

7. A sufficient set of conditions for (3.4) and (3.5) to have unique solutions is $\lim_{c \to 0}[(1 + \lambda)R_c(c, \theta) + CS'(\theta)] = \infty$ and $\lim_{c \to \infty}[(1 + \lambda)R_c(c, \theta) + CS'(\theta)] = 0$ for $\theta = 0$ and 1.

$S''(c) > 0$. When $S(\cdot)$ is not convex, the solution to (3.2) may involve both types of firm operating at the same cost level.

Proposition 3.1 summarizes the solution to the regulator's problem.

Proposition 3.1: *The solution to the problem of regulating a single firm is the solution to the problem of maximizing* (3.2). *When* $\lambda = 0$, *the solution to this problem is efficient*: $c(\theta) = c^*(\theta)$ *for* $\theta = 0$ *and* 1. *When* $\lambda > 0$, *the type-*$\theta = 1$ *firm operates efficiently* ($c(1) = c^*(1)$) *while the type-*$\theta = 0$ *firm produces at a higher than efficient cost* ($c(0) > c^*(0)$).

The regulator is able to induce the firm to operate at an efficient level when lump-sum transfers are costless and the regulator cares only about total surplus (and not the distribution of income). In this case ($\lambda = 0$), the regulator is able to make the firm the residual claimant of profit. The firm has the correct incentives to reduce cost to the efficient level. The firm always produces at the efficient cost given its technology. When the firm has private information about its costs, it earns a strictly positive amount. The regulator must give informational rents to the firm (when $\theta = 1$) in order to encourage it to operate efficiently. It follows from (3.3) that these rents are equal to $S(c(0))$.

The observation that the optimal regulatory scheme is efficient is absolutely standard in a pure moral-hazard model. In general, efficient schemes are feasible in models of adverse selection and moral hazard provided that transfers are costless and a technical condition holds. Baron and Myerson (1982, pp. 923–924) make the point in a pure adverse-selection model. It is implicit in the construction of Laffont and Tirole (1994), pp. 84–86). When transfers are free, the principal can induce an agent with private information to behave efficiently by appropriately varying the transfers. The intuition that adverse selection leads to inefficiency even when parties are risk-neutral is strong. Consequently, one might incorrectly think that yardstick competition is necessary to obtain efficient performance even when transfers are not costly.[8]

8. Shleifer (1985) assumes that transfers can be made without cost and that the regulator can observe the realized marginal cost. He does not explicitly model any uncertainty the regulator may have about the firm's technology. He assumes that if the firm earns the same profit at two different marginal costs, then it will choose to operate at the higher (due to unmodeled costs of managerial effort). Under these conditions Shleifer's independent regulatory scheme will hold the firm's profits to zero no matter what its choice of marginal cost. Consequently the firm does not reduce its cost. This solution suggests that the regulator is unable to commit to a regulatory scheme prior to the firm's choice of c. Even so, since transfers are costless in Shleifer's model, it is not clear why the regulator does not provide the incentives needed to induce the manager of the firm to select an efficient cost level.

When $c^*(1) > c^*(0)$ [which is possible if $S(\cdot)$ is not convex] and $\lambda = 0$, the firm may not produce at the efficient marginal cost. Instead, both types of firm operate at the same level of marginal cost, which is implicitly defined as the solution to $h(0)R_c(c,0) + h(1)R_c(c,1) + CS'(c) = 0$. In this case the results of the next section demonstrate that yardstick competition does increase total surplus.

Subsequent sections identify a firm's incentives to make an investment given that it will be regulated as above. Investing makes it possible for the firm to become efficient. Investment is costly. Therefore, a firm will only choose to invest if it stands to earn enough to pay for the investment. The rents earned when the firm has the superior technology are equal to $S(c(0)) = R(c(0),1) - R(c(0),0)$. Since $S'(c) < 0$, a parameter change that increases the marginal cost selected by the type-$\theta = 0$ firm will lower the rent obtained by the type-$\theta = 1$ firm. Using (3.4), differentiation demonstrates that an increase in the probability that $\theta = 1$ increases $c(0)$. Therefore an increase in probability that a firm has the lower-cost technology lowers the rent received by the $\theta = 1$ firm.

4. Joint Regulation

The regulator can improve upon the scheme identified in the previous section using information obtained by observing similar firms. Baiman and Demski (1980), Green and Stokey (1983), Holmström (1982), Lazear and Rosen (1981), Nalebuff and Stiglitz (1983a, b), and Shleifer (1985) make this observation in related contexts. I assume that gaining access to the efficient technology requires two things: first, the firm must make an investment to have an opportunity to obtain the technology; second, the investment must succeed. Firms independently decide whether to invest. The basic results require only that the outcome of the investment be correlated across firms.

This section studies the behavior of the regulator towards a single firm under the assumption that the regulator uses information it obtains from similar firms. When the regulator selects the cost and transfer for a particular firm, it does so based on the reports of all of the firms. The regulator will construct a regulatory scheme so that all firms make honest reports. From the point of view of a representative firm, the regulator learns how many of the other firms have attempted to improve their technology, and how many of these firms have succeeded. Assume that the probability that at least one of the other firms has tried to improve its technology is $A \in (0,1)$. In Section 7, A will be determined endogenously by the investment strategies of the firms. It will typically depend upon the number of firms.

In a direct mechanism, the regulator asks each firm to report one of three things: whether it tried to acquire the superior technology and, if it tried, whether it succeeded. Abusing terminology, let $\theta = 1$ denote a firm that has gained access to the superior technology $R(\cdot, 1)$; let $\theta = 0$ denote a firm that has not tried to improve its technology; and let $\theta = -1$ denote a firm that has tried but failed to acquire the technology $R(\cdot, 1)$. Note that $R(\cdot, -1) = R(\cdot, 0)$.

Given A and ρ, the problem of the regulator is to find functions $c(\theta, \nu)$ and $T(\theta, \nu)$ to solve

$$\max \sum_{\theta=-1}^{1} \sum_{\nu} [CS(c(\theta, \nu)) + R(c(\theta, \nu), \theta) - \lambda T(\theta, \nu)] H(\theta; \nu)$$

subject to individual rationality and incentive compatibility. In this objective function, θ represents the type of the firm. The incentive constraints guarantee that the firm makes an honest report. $\nu = (\alpha, \beta)$ represents the information of the firm; β denotes the number of the other firms that report that they have made an investment; α denotes the number of firms that report that they have access to a low-cost technology $(0 \leq \alpha \leq \beta)$. $H(\theta; \nu)$ denotes the probability that the regulator's information is ν and the report is θ; it is a function of the probability that one of the other firms invest (A), the probability that the firm invests (r), and the correlation between investments. Note that for all ν,

$$H(0; \nu) = (1 - r) \sum_{\theta=-1}^{1} H(\theta; \nu). \tag{4.1}$$

$\sum_{\theta=-1}^{1} H(\theta; \nu)$ is simply the probability that the regulator receives the information ν. Hence (4.1) states that the regulator does not learn anything about the success of one firm's investment from the information that another firm has not invested. Assume that there is a nontrivial correlation between the success of investments across firms. This means that the conditional distribution $\mu(\theta, \nu) = H(\theta, \nu)/\sum_{\theta'=-1}^{1} H(\theta'; \nu)$ depends nontrivially on ν, or

$$\text{there exists} \quad \nu \neq (0, 0) \quad \text{such that} \quad \mu(\cdot; \nu) \neq \mu(\cdot; 0, 0). \tag{4.2}$$

This condition does not state whether the correlation is positive or negative.

The next proposition characterizes the solution to the regulator's problem. The Appendix constructs the solution to the regulator's optimization problem.

Proposition 4.1: *If the regulator learns with probability $A > 0$ that another firm has made an investment, then the optimal regulatory scheme requires a firm that invests to operate at the efficient cost. A firm that does not invest operates at a cost that is above the efficient level. When $\lambda > 0$, the social surplus under yardstick regulation is greater than under independent regulation and is a strictly increasing function of the regulator's information, A.*

The proof of the proposition constructs the solution to a direct revelation game. It may be more intuitive to imagine that the regulator offers each firm a choice of three possible kinds of regulation (level of transfer and cost of production). These plans differ depending on whether the firm obtained the efficient technology, tried and failed to obtain the efficient technology, or did not try. The firm decides which of the three plans it prefers. The plans depend upon the behavior of other firms. If a firm accepts the plan designed for a firm that did not attempt to improve its technology, then its cost and transfer will depend on whether any of the other firms succeeded in improving its technology. The scheme involves yardstick regulation because what the firm is allowed to do depends on the decisions of other firms.

Proposition 4.1 contrasts a bit with results that suggest that full-rent extraction is possible in mechanism design problems with correlated information [for example, Crémer and McLean (1985) and McAfee and Reny (1992)]. The main difference between these results is that my model imposes a constraint on the form of the correlation (4.1) that is violated in the more general analyses. Nevertheless, Proposition 6.1 demonstrates that full rent extraction is possible if the regulator is able to commit to a mechanism before the firms make their investment decisions.

The total surplus obtained from a single firm increases with the probability that the regulator obtains information from other firms. This observation strengthens the obvious point that information is beneficial to the regulator. The regulatory scheme described in the previous section is still feasible when the regulator has other information. Since the optimal regulatory scheme uses additional information when available, it must lead to a strict increase in surplus.

5. Single-Firm Regulation with an Investment Decision

The technology of the firm was assumed to be fixed in Section 3. This section investigates the effect of regulation when firms must make a costly investment to acquire the superior technology. First firms make a decision whether to invest. If they make an investment, then with probability $\rho \in (0, 1)$ the firm acquires the superior technology $(\theta = 1)$. If the firm does not make an investment or if it makes an investment but the investment is not successful, then the firm is type $\theta = 0$. The regulator cannot observe whether the firm made an investment, nor whether the investment was successful. Furthermore, the regulator cannot commit to a specific price and transfer rule until after the investment has been made.

The nature of the equilibrium of this model depends on how the surplus given to the $\theta = 1$ type varies with the probability that the regulator places on the firm having the superior technology. Let $h = h(1)/h(0)$, and denote the value of $c(0)$ that solves the system (3.4) by $\tilde{c}(h)$. It is straightforward to verify that $\tilde{c}(h)$ is increasing. Therefore, the surplus available to the type-$\theta = 1$ type firm, $\tilde{S}(h) = R(\tilde{c}(h), 1) - R(\tilde{c}(h), 0)$, is decreasing.

It follows that there are three qualitatively different equilibria depending on parameter values.

Proposition 5.1: *There is a unique equilibrium to the investment game with independent regulation. If $\tilde{S}(0) \leq C/\rho$, then a firm will not make an investment. If $C/\rho \in (\tilde{S}(\rho/(1-\rho)), \tilde{S}(0))$, then the firm must follow a mixed investment strategy in which it invests with the probability r that solves the equation $\tilde{S}(r\rho/(1-r\rho)) = C/\rho$. If $C/\rho < \tilde{S}(\rho/(1-\rho))$, then the firm invests with probability one. The firm's expected profit is zero if $C/\rho \geq \tilde{S}(\rho/(1-\rho))$ and positive otherwise.*

When $\tilde{S}(0) < C/\rho$, there is no investment. The regulator has complete information, and the firm earns no profit. If all firms invest, then the regulator will think that the probability that $\theta = 1$ is ρ. Consequently, $\tilde{S}(\rho/(1-\rho))$ is the surplus that a firm receives when it succeeds in acquiring the superior technology. Hence the firm earns positive rent when $C/\rho < \tilde{S}(\rho/(1-\rho))$. Finally, in the intermediate case, the firm randomizes. The monotonicity of $\tilde{S}(\cdot)$ guarantees that the equation

$$\tilde{S}\left(\frac{r\rho}{1-r\rho}\right) = \frac{C}{\rho} \tag{5.1}$$

has a unique solution $r \in (0, 1)$ when $C/\rho \in (\tilde{S}(\rho/(1-\rho)), \tilde{S}(0))$. When (5.1) holds, the firm earns zero profit.

Since the firm has no informational advantage *ex ante*, it is not surprising that it obtains limited surplus in equilibrium. The level of investment will be inefficiently low relative to what would be possible if the regulator had complete information. Relative to the best that the regulator could do without investment, encouraging investment would save at least $(1 + \lambda)\rho\tilde{S}(0)$, which is the amount that it would gain by operating at cost $c(0)$ even if it had access to the superior technology. Therefore, a sufficient condition for the informed regulator to encourage investment is $(1 + \lambda)\tilde{S}(0) \geq C/\rho$. Since $\tilde{S}(\cdot)$ is nonincreasing and $\lambda \geq 0$, whenever the equilibrium involves investment with positive probability, the complete information solution involves investment with probability one. It follows that incomplete information lowers the level of investment.

The incentive scheme induces two different kinds of inefficiency. First, the firm may undertake an inefficient level of investment because it will not be permitted to keep returns associated with its effort to reduce the cost of production. Second, as in Section 3, the solution to the regulator's postinvestment problem requires the firm to operate at an inefficiently high cost when it has the inferior technology.

The regulator's inability to commit to a regulatory scheme also leads to a reduction in investment. The regulatory scheme described in this section leads to underinvestment. The regulator can encourage investment by increasing the surplus obtained by a firm that gains access to the superior technology. By committing to a scheme that transfers more to firms that claim to have access to the superior technology (by reporting $\theta = 1$), the regulator can induce higher levels of investment. Small changes of this kind will not violate incentive compatibility.[9] Commitment power is good for the regulator and will encourage more investment.

6. Joint Regulation with Investment: Commitment

Section 4 contains the elements of an analysis of the model in which the regulator can commit to a scheme prior to the original investment decision of the firms. In this section assume that the regulator can commit to a scheme consisting of transfer function $T(\theta, \nu)$ and a cost function $c(\theta, \nu)$. The regulator requests the firm to make an investment with probability r. The firm then decides whether to invest and reports the outcome of its investment decision to the regulator. The regulator receives information from other firms (summarized by ν) and decides on a transfer and a cost for the firm on the basis of its

9. The constraint that guarantees that type $\theta = 0$ does not want to report $\theta = 1$ is not binding in the solution of Section 3.

information and the firm's report. In this situation, the regulator can obtain the full-information solution provided that $A > 0$ and that there is some correlation between firms [that is, (4.2) holds].

The result depends on two observations. First, if the regulator knows that the firm invested in developing a new technology, then the regulator can induce the firm to report honestly without distorting the cost decisions. The analysis in Section 4 establishes this point. Second, when the firm operates at the efficient cost given its technology, the firm's gain from investing when the regulator does not request investment is no greater than the gain in total surplus due to investment. Hence, the regulator can encourage investment whenever it is optimal by compensating the firm for its investment decision if and only if it reports that it has access to the good technology.

The following proposition summarizes the result; the Appendix contains a proof.

Proposition 6.1: *Assume that the regulator learns with probability $A > 0$ that another firm has made an investment, and that investment success is correlated across firms. Assume that firms make investment decisions prior to selecting their operating cost. If the regulator has full commitment power, then it can implement the full-information optimal mechanism.*

7. Joint Regulation with Investment: Limited Commitment

This section studies the game in which firms simultaneously make an investment decision. After the investment decision they are regulated by yardstick competition. The structure of the problem is similar to the one analyzed in Section 5. The difference is that now the level of information that the regulator obtains from other firms can sharpen its postinvestment incentive scheme. This may lower the surplus available to a firm that succeeds in acquiring the superior technology. The principal result in this section is that yardstick competition will lower the incentives to invest. In any equilibrium to the investment game, the probability that a firm will invest will be no greater than it was in the equilibrium in Section 5. The difference between the analysis of this section and the analysis in Section 6 is the solution concept. In this section the regulator cannot make a commitment to a regulatory scheme until after firms have made their investment decisions.

Fix the probability A that the regulator learns something from the other firms. To simplify the discussion, I describe outcome of a game when investment results are perfectly correlated. Under this assumption, the investment of a given firm improves its technology if and only if all firms that make an investment obtain the superior technology. The qualitative results of this section and the next one continue to hold when there is imperfect correlation. I discuss the robustness of the results at the end of Section 8. If $A > 0$ and the firm invests with probability r, then the firm will obtain positive surplus only when the investment improves its technology. In the event of successful investment, expected surplus is zero if $r = 1$ and

$$A\tilde{S}\left(\frac{r}{1-r}\right) + (1-A)\tilde{S}\left(\frac{\rho r}{1-r}\right)$$

otherwise.[10] For fixed r expected surplus is decreasing in A. If $\tilde{S}(0) \leq C/\rho$, then it is optimal for the firm not to invest. If $\tilde{S}(0) > C/\rho$, then there is a unique $r^* \in (0, 1)$ such that

$$A\tilde{S}\left(\frac{r^*}{1-r^*}\right) + (1-A)\tilde{S}\left(\frac{\rho r^*}{1-r^*}\right) = \frac{C}{\rho}. \tag{7.1}$$

If the regulator expects the firm to invest with probability r^*, then (7.1) guarantees that the firm will be indifferent between investing and not investing.

Proposition 7.1: *Assume that firms make investment decisions prior to selecting their operating cost. If the regulator has limited commitment power, then the equilibrium probability of investment under yardstick competition is no greater than the probability that a firm invests under independent regulation. If $\tilde{S}(0) \leq C/\rho$, then on firm invests. If $\tilde{S}(0) > C/\rho$, then all firms invest with a probability strictly between zero and one. If the probability that at least one of the other firms makes an investment is A, then the firm invests with probability r^*, where r^* solves the equation* (7.1).

The proposition does not completely characterize the equilibrium of the game, since it does not determine the value of A. The game in which firms independently make investment decisions and then are regulated using yardstick competition may not have a unique equilibrium. Intuitively, the more information the regulator has, the lower are the incentives for an individual firm to make an

10. $r/(1-r)$ is the ratio of the probability $\theta = 1$ to the probability $\theta = -1$ when the regulator learns that at least one of the other firms has made an investment; $\rho r/(1-r)$ is that ratio when no other firm claims to have made an investment.

investment. It is possible to construct examples in which one firm invests with a high probability and another with a low probability. Nevertheless, even though equilibrium is not unique, it is possible to compare the investment obtained under yardstick competition with that obtained under the independent regulatory scheme described in Section 5.

When $\tilde{S}(0) \leq C/\rho$, firms do not invest whatever the regulatory environment. Otherwise, when the regulator cannot use information from other firms, the probability that a firm invests is the solution to (5.1). Since $\tilde{S}(\cdot)$ is decreasing and $r\rho/(1-r\rho) < r\rho/(1-r) < r/(1-r)$, the solution to (5.1) is greater than the solution to (7.1). Indeed, the highest probability that a firm will invest under yardstick regulation is given by u, where $\tilde{S}(u\rho/(1-u)) = C/\rho$. For the observations in Section 8, it is useful to note that, for fixed $\rho < 1$, u is strictly less than the solution to (5.1). Hence whenever there is any investment, equilibrium investment under yardstick competition is less than what it is under independent regulation. Whatever the regulator learns, it is not attractive for a firm with a superior technology to claim that it made an unsuccessful investment.[11] Hence information reduces the amount of transfers that the regulator needs to make.

I make two other comments about the nature of equilibrium in the investment game followed by yardstick regulation. First, assume that $\tilde{S}(0) > C/\rho$, so that every firm invests with positive probability. It follows from (7.1) and the fact that $\tilde{S}(\cdot)$ is decreasing that there is a strictly positive lower bound to the probability that each firm invests in equilibrium. Specifically, each firm must invest with probability no smaller than l, where $\tilde{S}(l/(1-l)) = C/\rho$. Since $l > 0$, as the number of firms grows to infinity, A must converge to 1. That is, when there are a large number of firms, the regulator will be able to infer whether investment will succeed in improving technology.

Second, while the model of this section has multiple equilibria, it has a unique symmetric equilibrium. In that equilibrium either no firm invests [when $\tilde{S}(0) \leq C/\rho$] or each of the n firms invests with

11. The limit of incentive schemes as A approaches 0 is not the same as the independent regulatory scheme. The reason for the difference is that even when the regulator has a very small probability of obtaining information from other firms, it is able to deter the firm from reporting that $\theta = -1$ when in fact $\theta = 1$. The ability to deter these reports depends on the regulator's ability to levy harsh penalties for "incompatible" reports. Bounding the penalities would complicate the analysis. The result that the type-$\theta = -1$ firm produces at the efficient marginal cost and charges the efficient price is sensitive to the assumption that the regulator can levy arbitrarily harsh penalties. The qualitative results on the value of information do not depend on the assumption.

probability $r \in (0,1)$, where r satisfies (7.1) for $A = 1 - (1-r)^{n-1}$ [when $\tilde{S}(0) > C/\rho$].

8. Comparison

I have demonstrated that increases in the information available to the regulator decrease the incentives to invest. It is not clear whether decreasing the incentive to invest lowers total surplus, however. Yardstick regulation makes it possible to regulate with fewer distortions. In this section I discuss the trade-off between these two effects. I make an observation that follows easily from the previous sections. When firms make their investment decisions based on the regulatory scheme, more information reduces welfare when the costs of transfers are small. The logic behind this result is clear. When λ is close to zero, independent regulation is almost efficient. Hence the potential benefits of yardstick competition are small. On the other hand, yardstick competition lowers the incentives to make investments even when λ is small.[12]

The proof of Proposition 2 computed the change in total surplus resulting from an increase in A. For the case of perfect correlation, this quantity is given by

$$(1-r)\left[\rho P\left(0, \frac{r}{1-r}\right) + (1-\rho)P(0,0) - P\left(0, \frac{\rho r}{1-r}\right)\right],$$

where $P(\theta, \gamma) = \max_c[CS(c) + (1+\lambda)R(c,\theta) - \lambda S(c)\gamma]$. This change is nonnegative, continuous in λ, and equal to zero when $\lambda = 0$. A change in the regulatory procedure may lead to a change in the level of investment. The increase in total surplus from an increase in r is

$$\rho P(1,0) + (1-\rho)P(-1,0) - C - (1-\rho)AP(0,0)$$
$$-(1-A)P\left(0, \frac{\rho r}{1-r}\right) - \rho AP\left(0, \frac{r}{1-r}\right). \tag{8.1}$$

Since $P(1,0) \geq P(-1,0) = P(0,0) \geq P(0,x)$ for $x > 0$, (8.1) is greater than or equal to $\rho[P(1,0) - P(-1,0)] - C$, which itself is greater

12. Section 6 demonstrates that any potential for individual regulation to dominate joint regulation stems from my assumption that the regulator cannot commit to a regulatory policy prior to the initial investment choice. Laffont and Tirole (1994, pp. 86–92) study models with investment choice when the regulator has commitment power.

than or equal to

$$\rho S(c_0) - C. \tag{8.2}$$

It follows that increasing investment by a small amount is guaranteed to raise welfare by at least the savings in cost from using the superior technology (whenever it becomes available) net of the cost of investment. Provided that it is efficient to invest at all, the level of investment under yardstick competition is always discretely lower than under independent regulation. Hence, provided that (8.2) is positive, if λ is sufficiently small, the costs of yardstick competition outweigh the benefits.

One expects that the level of information that the regulator acquires will be an increasing function of the number of similar firms it can observe. This property holds for the symmetric equilibrium. It is also broadly true in the limit, in that as the number of firms goes to infinity, the probability that the regulator obtains information goes to one. When (8.2) is strictly positive and λ is small, it would be to the regulator's advantage to commit to using information from a subset of the firms rather than to base regulation on more detailed information.

The section illustrates that yardstick competition reduces the incentive to invest when the regulator has limited commitment ability. This possibility does not depend on the perfect-correlation assumption. The logic of the result is that if the regulator has superior information, then the firm receives lower surplus and therefore has less incentive to invest. I cannot prove that superior information leads to lower surplus for all values of A when investment success is imperfectly correlated. However, it is not difficult to show that superior information lowers the surplus when A is close to one and that A will converge to one when the number of firms increases to infinity. Consequently the potential for information to lower welfare does not depend on the assumption of perfect correlation.

9. Conclusions

This paper makes two observations about the effectiveness of yardstick competition in a model of regulation with investment. The first point is that yardstick competition is not necessary when firms are risk-neutral and lump-sum transfers are costless. The second point is that when firms make investment decisions prior to regulation, information may have negative value to the regulator. This section discusses the sensitivity of these conclusions to modeling assumptions.

The precise form of the firm's profit function does not play an important role in the analysis. The results continue to hold for general specifications of revenue (in particular, the inclusion of other choice variables like price) provided that concavity assumptions hold. The results would continue to hold if there were more than two technologies available to the firm (although the regularity condition needed in Proposition 3.1 changes).

The construction of the optimal yardstick regulatory schemes uses the assumption that transfers are not necessarily bounded. The characterization of the optimal schemes discussed in Sections 4 and 6 depends on the ability of the regulator to use arbitrary transfers. Imposing no constraints on $T(\cdot)$ makes it possible to completely characterize the optimal regulatory scheme under yardstick regulation. These transfer functions may be implausible if they involve either large bonuses or large penalties for reports that are unexpected given the information that the regulator has received from the other firms. Restrictions on transfers would arise naturally, for example if the firms had limited liability. Constraints of this form would in general bind in the optimal yardstick regulatory scheme. Imposing the constraints would change the details of the optimal contract, but not alter the observation that information may have negative value. On the other hand, Proposition 5, which states that yardstick regulation under full commitment leads to the efficient production, does rely on the particular characterization of the optimal yardstick regulatory scheme identified in Section 3. If there were bounds on the magnitude of transfers, then the regulator might not be able to induce efficient operation costlessly.

A contribution of the paper is to note that when the regulator has limited commitment ability, additional information may have negative value because it reduces the incentives firms have to make investments. The conclusion depends on the assumption that the regulator is unable to commit to a regulatory scheme prior to the firms' investment decisions. The assumption that the regulator has partial commitment power suggests an asymmetry between the initial investment decision (whether to invest in research) and the actual choice of operating cost. Such a distinction appears appropriate when investment decisions are infrequent. To the extent that investment decisions are made rarely, the regulator has less incentive to maintain commitments to preserve its reputation. Both the firm and the regulator would gain from renegotiating the regulatory mechanism after the investment phase is over.

It is important that a firm's investment is not directly observable to the regulator. If the investment were observable, then the regulator could condition regulatory policy on a verifiable signal of the amount of investment. The firm could be compensated directly. To some extent the regulator will be able to identify the firm's expenditures on research (by conducting audits or examining tax returns). Gathering and interpreting this information is likely to be expensive, however. At the margin, it is natural to assume that firms maintain an informational advantage. The qualitative results of this paper do not require that the investment cost C be large.

The possibility for collusion exists in my model, as it does in many regulatory schemes that rely on relative performance measures. If firms were able to pool information and coordinate their responses to the regulator, then yardstick competition would be less effective. It is beyond the scope of the paper to give a detailed treatment of the implications of collusion. For simplicity, assume that investment success is perfectly correlated. Under this assumption, firms can be punished severely for making incompatible reports. Collusion would be beneficial only if all firms agreed to collude. If all of the firms did agree, then they would have the potential to gain if they all reported that they made an investment, but failed to acquire the superior technology. If the coalition does not include all of the firms, then the regulator still can implement the optimal scheme. When there are a large number of widely separated firms, it is unlikely that they will be able to coordinate perfectly. Hence the regulatory scheme is not subject to much manipulation under perfect correlation. I do not know the degree to which coalition formation would change results under imperfect correlation.[13]

The model assumed that firms have a discrete (binary) decision to invest. Investment could have been modeled as a continuous variable, with firms selecting the intensity of investment instead of a binary investment decision. In this framework, spending more money on research would increase the probability of acquiring a new technology; specifically, one could assume that an investment of rC would lead to the probability $r\rho$ of acquiring the good technology. This assumption leads to no change in the basic characterization result in Section 4. The qualitative results from Sections 5 through 8 continue to hold. Limited commitment ability of the regulator reduces the incentives to invest. There is no equilibrium in which all firms invest with positive probability, since the regulator can imple-

13. In a related model, Laffont and Martimort [1998] show that imposing a coalition-proof requirement on mechanisms restores continuity between correlated and uncorrelated environments. Coalition-proof mechanisms approach first-best efficiency only when correlation is nearly perfect.

ment the efficient regulatory scheme when it is able to rule out the possibility that a firm has made no investment. Firms therefore would earn zero surplus when transfers are costly and have no incentive to invest.[14]

Appendix

This Appendix contains the proofs of Propositions 4.1 and 6.1.

Proof of Proposition 4.1. Although the regulator's problem has six incentive compatibility constraints [one for each pair (θ, θ') with $\theta, \theta' = -1, 0, 1$ and $\theta \neq \theta'$] and three individual rationality constraints, the proof will first solve a less constrained problem that imposes only two incentive constraints and one individual rationality constraint. The solution to the problem with fewer constraints in fact satisfies all of the constraints. First consider the case $r < 1$. At the end of the proof I will discuss what happens if the firm attempts to improve its technology with probability one.

The relevant incentive compatibility constraints are, for $\theta = -1$ and 1,

$$\begin{aligned}\sum_{\nu} [R(c(\theta,\nu),\theta) + T(\theta,\nu)]H(\theta,\nu) \\ \geq \sum_{\nu} \{[R(c(0,\nu),\theta) + T(0,\nu)] \\ +[R(c(0,\nu),\theta) - R(c(0,\nu),0)]\}H(\theta,\nu). \qquad \text{(A.1)}\end{aligned}$$

These constraints guarantee that a firm that makes an investment would prefer to report the outcome of its investment rather than to conceal its investment from the regulator. The relevant individual rationality condition for the $\theta = 0$ firm is

$$\sum_{\nu} [R(c(0,\nu),0) + T(0,\nu)]H(0,\nu) \geq 0. \qquad \text{(A.2)}$$

Denote by $s(\theta)$ the slack in the incentive constraints (A.1) (for $\theta = -1$ and 1), and by $s(0)$ the slack in the individual rationality constraint (A.2). (The slack is the difference between the left- and right-hand sides of the constraints.) Use these constraints to eliminate $T(\theta, \nu)$

14. Instead the equilibrium to the investment game is asymmetric. Firms divide into two groups; one group invests a positive amount, and the other group does not invest. The expected surplus for both groups is zero.

from the objective function. This first leads to

$$\max \sum_{\theta=-1}^{1} \sum_{\nu} [\mathrm{CS}(c(\theta)) + (1+\lambda) R(c(\theta,\nu),\theta)] H(\theta,\nu)$$
$$+ \lambda \sum_{\theta=-1,1} \sum_{\nu} s(\theta) H(\theta,\nu) - \lambda \sum_{\theta=-1}^{1} \sum_{\nu} [T(0,\nu) + R(c(0,\nu),0)$$
$$+ R(c(0,\nu),\theta) - R(c(0,\nu),0)] H(\theta,\nu). \tag{A.3}$$

By (4.1), this expression simplifies to

$$\max \sum_{\theta=-1}^{1} \sum_{\nu} [CS(c(\theta)) + (1+\lambda) R(c(\theta,\nu),\theta)] H(\theta,\nu)$$
$$- \lambda \sum_{\theta=-1}^{1} \sum_{\nu} [R(c(0,\nu),\theta) - R(c(0,\nu),0) + s(\theta)] H(\theta,\nu). \tag{A.4}$$

Since the slacks must be nonnegative and (A.4) is decreasing in $s(\theta)$ for all θ, constraints (A.2) and (A.1) must bind in the solution to (A.4). I can also set

$$T(0,\nu) = -R(c(0,\nu),0) \tag{A.5}$$

without loss of generality. Using $R(c,-1) = R(c,0)$ for all c, the objective function can be written

$$\max \sum_{\theta=-1}^{1} \sum_{\nu} [CS(c(\theta)) + (1+\lambda) R(c(\theta,\nu),\theta)] H(\theta,\nu)$$
$$- \lambda \sum_{\nu} S(c(0,\nu)) H(1,\nu). \tag{A.6}$$

As in Section 3, the objective function in (A.6) is separable in the choice variables. Provided that the solution satisfies the individual rationality and incentive constraints that I ignored, the solution to the regulator's problem is characterized by the first-order conditions of (A.6). The solution to (A.6) does not specify values for $T(\theta,\nu)$ for $\theta \neq 0$. Using (4.2), it follows that it is possible to find values for $T(\theta,\nu)$ such that the four incentive compatibility constraints involving decisions of types $\theta = -1$ and 1 are binding. [This constraint involves four linear equations in the variables $T(\theta,\nu)$. The system has full rank when (4.2) holds.] For this choice of $T(\cdot)$, the individual rationality conditions follow. Indeed, it follows that types $\theta = -1$ and 0 obtain no surplus [this follows immediately for $\theta = 0$ by (A.5), and for $\theta = -1$ because $\theta = -1$ is indifferent between reporting its type truly and reporting $\theta = 0$]. Since $\theta = 1$ is indifferent between reporting truthfully and reporting $\theta = 0$, this type earns a nonnegative surplus equal to $\sum_\nu S(c(0, \nu), 0)H(1, \nu)$.

In order to complete the proof, it remains to suffices to show that the two remaining incentive compatibility constraints are satisfied. First notice that

$$0 \geq \sum_\nu \{S(c(0, \nu)) - [R(c(-1, \nu); -1) - R(c(-1, \nu); 1)]\}H(1, \nu)$$

$$= \sum_\nu [R(c(-1, \nu), -1) + T(-1, \nu)]H(1, \nu), \tag{A.7}$$

where the inequality comes from $R(c, -1) = R(c, 0)$ and $c(-1, \nu) \leq c(0, \nu)$, and the equation follows because $T(\theta, \nu)$ has been selected to make type $\theta = 1$ indifferent between reporting honestly and reporting $\theta = -1$. Since the utility of the $\theta = -1$ type is equal to zero, it follows from (4.1) and (10.7) that type $\theta = 0$ does not want to report $\theta = -1$. A similar argument shows that type $\theta = 0$ does not want to report $\theta = 1$. It follows that it is possible to construct a solution to the relaxed problem that satisfies all of the constraints of the regulator's problem.

The conditions for optimality are the natural analogs to (3.4) and (3.5). The regulator still lacks perfect information, so the best regulatory scheme differs from the full-information optimum. A firm that does not attempt to improve its technology (type $\theta = 0$) is asked to produce at a larger than optimal marginal cost. This distortion arises for the same reason that it arose earlier: it is the way in which the regulator provides incentives for firms to identify when they have the superior technology. Now the regulator is able to condition its scheme on what it has learned from other firms. The information is useful in two situations. First, if the firm invested but did not improve its technology, then it gains nothing from claiming that it did not invest (in either case it earns no surplus). The regulator does not need to distort the marginal cost of this firm [$c(-1, \nu)$], because a firm with a superior technology will never claim that $\theta = -1$. Second, the regulator can condition its response to a report that $\theta = 0$ based on the reports from other firms. The information permits the regulator to distort the cost less when $\nu = 0$ than when $\nu = 1$.

What happens when $r = 1$? Provided that $A > 0$, the regulator will be able to induce the firm to operate at efficient levels. Firms report their type honestly and operate at the efficient price and marginal cost. They earn zero surplus. A type-$\theta = 1$ firm is unable to gain by reporting that its type is $\theta = 0$ because (when $r = 1$), the regulator knows that $\theta = 0$ is impossible. Hence the regulator can rule out reports of $\theta = 0$ at no cost.

To show that increases in information benefit the regulator, let

$$P(\theta, \gamma) = \max_c [CS(c) + (1 + \lambda)R(c, \theta) - \lambda S(c)\gamma].$$

Set $\gamma(1, \nu) = \gamma(-1, \nu) = 0$ for all ν, $\gamma(0, -1) = 0$, and $\gamma(0, \nu) = H(1; \nu)/H(0; \nu)$ for $\nu = 0$ and 1. Total surplus is equal to $\sum_{\theta=-1}^{1} \sum_{\nu} P(\theta, \gamma(\theta, \nu))H(\theta; \nu)$.

$\sum_{\nu} H(\theta; \nu)$ is just the probability that a firm is type θ, so it does not depend on A. Denote the derivative with respect to A of $H(\theta; \nu)$ by $G(\theta; \nu)$. The envelope theorem implies that changing A leads to a change in total surplus given by

$$\sum_{\nu} P(0, \gamma(0, \nu))G(0; \nu). \tag{A.8}$$

Furthermore, it follows from the definition of $H(\cdot)$ that $H(0; \nu) = A(1 - r)f(\nu)$ and $H(1; \nu) = Ar\rho g(\nu)$ when $\nu \neq (0, 0)$, $H(1; 0, 0) = (1 - A)r\rho$, and $H(0; 0, 0) = (1 - A)(1 - r)$. For example, $H(0; \nu)$, the probability that the regulator receives information ν when the given firm reports $\theta = 0$, is equal to the probability that the firm does not invest $(1 - r)$ times the probability that the regulator receives information (A) times the conditional probability that the firm receives information ν given that a particular firm has not made an investment, which I have denoted by $f(\nu)$. Similar explanations describe the other formula. It follows that $\sum_{\nu \neq (0,0)} \gamma(0, \nu)G(0; \nu) = \alpha(0; 0, 0)$ $G(0; 0, 0)$.

Observe that the function $P(\theta; \gamma)$ is convex in γ, since it is the value function of an optimization problem that is linear in α. Consequently, (A.8) is nonnegative. I can conclude that, for the problem of this section, the regulator benefits from improvements in his information. □

Proof of Proposition 6.1. First note that by linearity, the regulator's problem must have an optimum with $r = 0$ or $r = 1$. Assume for the moment that a firm will invest if and only if the regulator asks it to invest. The arguments in Section 4 demonstrate that the regulator could induce the firm to invest with probability one with no distortion in the costs. If the regulator prefers that the firm does not invest, the regulator will have complete information and can implement the efficient regulatory scheme. Alternatively, the analysis follows the $r = 1$ case, with the modification that firms $T(1, \nu)$ should be increased by C/ρ to compensate for the cost of investment.

Now return to the assumption that firms will invest if and only if the regulator requests investment. When the regulator requests that a firm make an investment, failure to make an investment gains the firm nothing. If the firm does not invest, the best that it can do is report $\theta = -1$, which will lead to no surplus. On the other hand, if the regulator requests that a firm make no investment, then the firm could instead make an investment. In the event the investment succeeds, the firm would earn $S(c^*(0))$. Hence the firm would want to make an investment if

$$\rho S(c^*(0)) > C. \tag{A.9}$$

When (10.9) holds, then it would be in the interest of the regulator to encourage investment. To see this, note that the regulator earns at most

$$CS(c^*(0)) + (1 + \lambda) R(c^*(0), 0) \tag{A.10}$$

when there is no investment, and

$$\begin{aligned}&(1 - \rho)[CS(c^*(0)) + (1 + \lambda) R(c^*(0), 0)] \\ &\qquad + \rho[CS(c^*(1)) + (1 + \lambda) R(c^*(1), 1)] - C\end{aligned} \tag{A.11}$$

when there is investment. By the definition of $c^*(\cdot)$, (A.11) is greater than or equal to

$$CS(c^*(0)) + (1 + \lambda) R(c^*(0), 0) + \rho(1 + \lambda) S(c^*(0)) - C.$$

Hence (A.11) exceeds (A.10) whenever (A.9) holds. It follows that if the regulator requests that firms invest when it is efficient to do so, then firms will obey the regulator's request, because they will only be compensated for investment if they report that they have inefficient technology. □

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