Chapter 24

DESIGN OF REGULATORY MECHANISMS AND INSTITUTIONS

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Contents

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1. Introduction

Regulation involves government intervention in markets in response to some combination of normative objectives and private interests reflected through politics. Whatever objective regulation is intended to achieve, the regulator must choose policies tailored to the particular regulatory setting and to the characteristics of the firms subject to its authority. In choosing those policies, the regulator must take into account the strategies the firm might employ in response to those policies. The focus of this chapter is the design of regulatory policies that take into account the opportunities for strategic behavior provided by incomplete information and limited observability on the part of the regulator.

Dupuit (1952) was perhaps the first to address the regulatory design issue when he considered the pricing policy for a bridge that requires a fixed expenditure for its construction but has no incremental cost for a crossing. He concluded that the first-best pricing policy was to set a price of zero for each crossing and to levy a fixed charge to cover the costs of construction. Dupuit reached this conclusion under the assumptions that (1) the designer has complete information about the construction cost of the bridge, (2) the costs are not a function of actions taken during construction or operation, and (3) the costs remain the same over time. The design of regulatory mechanisms is straightforward, albeit complex, in such a case where the regulator or mechanism designer has the same information as the regulated firm, can observe the actions taken by the firm, and has the authority to exercise control.[1]

The focus of this chapter is the design of regulatory mechanisms and institutions in settings in which the regulator has incomplete information and limited ability to observe the actions of the firms under its jurisdiction. Incomplete information and limited observability create opportunities for strategic behavior on the part of both the regulator and the regulated. The mechanisms considered in this chapter are reflections of that strategic behavior and will be characterized as equilibria of a game whose structure corresponds to the authority granted to the regulator. Regulatory policies are thus viewed as endogenous responses to informational asymmetries and limited observability rather than as exogenously-specified mechanisms descriptive of actual regulatory arrangements. Although the mechanisms may thus be weak in their descriptive power, they reflect the incentives present in regulatory relationships and take into account how the parties involved respond to those incentives.

[1] The optimal regulatory policies for this setting are characterized in Chapter 23 of this Handbook.

This chapter is not intended to provide a complete survey of the many contributions to this literature but rather is intended to provide a unified approach to the design of mechanisms progressing from a simple setting such as that studied by Dupuit and to more complex settings involving dynamics and multiple parties. Surveys of this literature have recently been provided by Caillaud, Guesnerie, Rey and Tirole (1988), Sappington and Stiglitz (1986), and Besanko and Sappington (1987). In addition, Romer and Rosenthal (1985) have surveyed the political dimension of regulatory research, and Hart and Holmstrom (1987) present an overview of contracting theory under symmetric information with a focus on cases in which performance is not verifiable by the participants.

The context in which the theory of regulatory mechanisms will be developed in this chapter is the regulation of a franchise monopolist in an industry characterized by decreasing average costs. This simple setting permits a focus on mechanism design without the complication of strategic competition among suppliers. The approaches developed here are applicable to a variety of other regulatory and nonregulatory settings including defense procurement, the control of bureaucracies and government-owned firms, and labor-managed firms.[2]

To motivate the setting to be considered, it is useful to consider a number of features of regulation in the United States. In the United States regulation is applied to firms owned by private investors, so at least in principle regulated firms have the same objectives as any other firm.[3] The firms considered here will thus be represented as profit-maximizers and will be assumed to take whatever actions are permitted within the regulatory framework to maximize their profits. The regulator, however, has broader objectives, so the regulatory relationship involves a conflict of objectives that is resolved endogenously through the strategies chosen by the regulator and the firm.

The objective of the regulator is generally not unambiguous and depends on a variety of normative and positive factors. From a normative perspective the regulator might be charged with maximizing total surplus or might be assigned distributional objectives such as maximizing the surplus of consumers. From a positive perspective regulation may be a response to competing interests of consumers and firms as intermediated by a legislature. Although some regulatory commissions are publicly-elected and others are appointed, in either case the legislature is responsible for the budget of the regulator and for monitoring the

[2] The models presented here can be directly applied to the case of the provision of goods by public agencies either through procurement from privately-owned firms or through a bureaucracy. Niskanen (1971) was the first to pose formally the question of the control of a bureaucracy that has private information about the cost of production.

[3] An exception is cooperatives which, for a variety of reasons including favorable tax treatment and antitrust exemptions, have grown to some importance in the United States in certain regulated industries such as electricity. Cooperatives can be considered in the framework developed here using a model related to that of a labor-managed firm. Guesnerie and Laffont (1984) develop the theory of a labor-managed firm in the context of the information and observability problems considered here.

performance of the regulator. The electoral relationship, directly between voters and regulators or indirectly through executive officers and legislators, suggests the possibility, if not the likelihood, that regulatory objectives reflect interests manifested through an electoral connection. Consequently, the design of regulatory mechanisms will be parameterized by the weight assigned to various interests.

In furthering its objective the regulator is bound by the limits of the authority delegated to it.[4] In the case of a franchise monopoly, regulatory authority generally includes control over prices and profits and often extends to the approval of investment and financing plans. The regulator may also have the authority to command certain information from the firm and to monitor its performance. That authority, however, generally does not include the power to impose taxes on the firm or to subsidize it from public funds.[5] Consequently, the revenue received by the firm comes from consumers and not from the state. Since property rights must be respected, regulatory authority is also constrained by procedural requirements derived from constitutional protections including due process, just compensation in the form of a fair return on invested capital, administrative requirements specified in the Administrative Practices Act and in the regulator's mandating legislation, and procedures established by the regulatory body itself. The regulator may, however, be allowed to impose certain limited penalties on the firm.

To indicate the difference between exogenously-specified and endogenous regulatory mechanisms, a model, presented by Averch and Johnson (1962), of an exogenously-specified regulatory mechanism is considered in the next section. In Section 3 endogenous mechanisms are introduced, and an equilibrium mechanism is characterized in Section 4 for a static model in which the firm has private information about its marginal cost. The regulatory setting in that section is based on the assumption that the regulator is unable to observe the performance of the firm, so in Section 5 the regulator is assumed to be able to observe, perhaps imperfectly and at a cost, the actual cost incurred by the firm. In Section 6 the models are extended to a dynamic setting with an emphasis on the ability of the regulator to commit to a multiperiod policy. The models considered in these sections involve a regulator and firm that has already been selected to be the supplier, and in Section 7 mechanisms are introduced that incorporate both the selection of the firm and the policy to regulate the selected firm. The selection of the regulated firm is a form of ex ante competition that improves the efficiency of

[4]The capture theory of regulation as developed by political scientists argues that the regulators adopt the objectives of the firms they regulate either because the initial legislation establishing the regulation reflects those interests or because the firm induced the regulator to share its goals. Those political forces will not be considered here.

[5]The authority to impose taxes is generally restricted to representative bodies elected by the citizenry. In addition, regulatory agencies are seldom granted appropriations to be used to subsidize either the firm or consumers. Cross-subsidization among consumers, however, is a frequently observed characteristic of regulation.

regulation, and in Section 8 ex post competition is considered. Section 9 considers the case in which the regulator also has private information that may be revealed by the mechanism it chooses. The mechanisms considered in these sections are Bayesian in the sense that they are based on a probabilistic representation of the information available to the parties. In Section 10 non-Bayesian mechanisms are considered in which the regulator bases its policy in each period on the observation of performance in previous periods. Extensions are considered in Section 11, and directions for future research are considered in the final section.

2. Exogenous regulatory mechanisms: The Averch–Johnson model

Early research on regulatory mechanisms focused on models representing stylized descriptions of actual regulatory processes. For example, the regulation of public utilities can be viewed as a grant of a franchise monopoly to a firm and the subsequent setting of prices that generate sufficient revenue from customers to cover the total costs of the firm including a fair return on the capital employed. This "revenue requirements" perspective is characterized by Robichek (1978) and Breyer (1982) and may be thought of as focusing on cash and noncash costs. Since cash costs are measured by accounting systems that are audited on a regular basis, attention often centers on noncash costs such as the required return to equity capital.[6] The model formulated by Averch and Johnson thus ostensibly focuses on controlling monopoly profits with a regulatory mechanism that establishes the rate-of-return on equity that the firm is allowed to earn.[7]

An alternative interpretation of the Averch–Johnson model is as a mechanism employed in response to incomplete information about characteristics of the firm's costs or demand. Averch and Johnson assume that the profit, or the cash flow, and the capital stock of the firm are observable and thus base the regulatory mechanism on those two variables. With those observables, it is natural to view the regulator as directly controlling profit as a function of the capital the firm employs, or equivalently indirectly controlling profit through the rate-of-return the firm is allowed to earn. Both pricing and factor input decisions are thus delegated to the firm. A sufficient condition for the firm to participate in this regulatory arrangement is thus that the allowed rate-of-return is at least as great as the cost of capital to the firm.

The model is formulated with the firm choosing its capital κ and labor L inputs with the price set to equate demand to the resulting output q. The

[6] Regulation may also focus on cash costs as in the case of fuel adjustment clauses.

[7] Comprehensive analysis of the implications of the Averch–Johnson model are provided by Baumol and Klevorick (1970) and Bailey (1973). A number of models including Bailey and Coleman (1971) extend the Averch–Johnson framework to multiperiod settings to investigate the consequences of regulatory lag on the efficiency of input choices.

production function $q = G(\kappa, L, \theta)$ may be specified as incorporating a technology parameter θ about which the firm is informed and the regulator is not. The profit π of the firm is

$$\pi = R(q) - wL - r\kappa, \tag{2.1}$$

where $R(q)$ is the resulting revenue, w is the factor price of labor, and r is the cost of capital. In the Averch–Johnson formulation, the revenue is given by $R(q) = P(q)q$, where $P(q)$ is the inverse demand function. With this price structure, regulation cannot achieve first-best efficiency if the technology is characterized by increasing returns to scale. Second-best efficiency is thus the relevant efficiency standard for the Averch–Johnson model.

Regulation as represented in the Averch–Johnson model is equivalent to specifying an allowed rate-of-return s which is applied to the capital stock so as to restrict the profit of the firm, i.e.[8]

$$\pi = P(q)q - wL - r\kappa \leq (s - r)\kappa. \tag{2.2}$$

The right-hand side of (2.2) represents the excess return $(s > r)$ allowed by the regulator to enable the firm to access the capital markets.[9]

The incentives created by regulation in the Averch–Johnson model are evident from (2.2). Since the price (or output) and the factor input decisions are delegated to the firm, it will choose them to maximize its profits. To do so, the firm will choose the largest capital stock κ such that it can attain the allowed profit $s\kappa$. Intuitively, the firm would like (a) to have as low an output price as possible so that more capital can be employed and (b) to substitute capital for labor so that more capital can be employed for whatever output is produced. Such substitution increases costs, however, which requires a higher price and that reduces the capital that can be employed.

To determine the optimal factor inputs, it is convenient to rewrite the profit function in terms of the labor requirements function $L(q, \kappa, \theta)$ defined by

$$q \equiv G(\kappa, L(q, \kappa, \theta), \theta). \tag{2.3}$$

The Lagrangian $\mathscr{L}$ for the firm's problem of maximizing π in (2.1) subject

[8]The regulator is assumed to know the cost of capital or at least an upper bound on that cost.

[9]The constraint in (2.2) can be restated in terms of the cash flow $(P(q)q - wL)$ of the firm as

$$P(q)q - wL \leq s\kappa.$$

From this specification, it is clear that the regulator is assumed to be able to observe the cash flow and the capital stock of the firm.

to (2.2) is

$$\mathscr{L} = P(q)q - wL(q,\kappa,\theta) - r\kappa$$
$$+\lambda\left[(s-r)\kappa - \left(P(q)q - wL(q,\kappa,\theta) - r\kappa\right)\right],$$

where λ is a non-negative multiplier. The first-order condition for κ is

$$-(1+\lambda)(wL_\kappa + r) + \lambda(s-r) = 0, \tag{2.4}$$

where L_κ is the partial derivative of L with respect to κ. The multiplier λ is positive when s is below the monopoly rate of return, so

$$L_\kappa = -\frac{r}{w} + \frac{\lambda(s-r)}{1+\lambda} > -\frac{r}{w}. \tag{2.4a}$$

Efficiency requires that $L_\kappa = -r/w$, so the firm employs more capital relative to labor than is efficient given the quantity produced. This is Averch and Johnson's well-known overcapitalization result.

The quantity the firm chooses satisfies the first-order condition:

$$P'(q)q + P(q) - wL_q = 0. \tag{2.5}$$

Thus, q, κ, and λ are determined by (2.4), (2.5), and (2.2) as an equality.[10]

The Averch–Johnson model of regulation predicts both technical and allocative inefficiency. First, the firm employs too much capital relative to labor for the output it produces. Second, because production is inefficient, the required price is too high. These inefficiencies result because the regulator is assumed either only to be able to observe the profit and capital stock of the firm or only to have the authority to restrict profits.

These inefficiencies would not result under a variety of other assumptions. For example, if factor prices and the technology, including θ, were known to the regulator and the regulator had the authority to regulate the price, the regulator could simply specify the price corresponding to the efficient marginal cost. The regulator can determine the efficient marginal cost because it knows the factor prices and the technology. That is, if $L^*(q,\theta)$ and $\kappa^*(q,\theta)$ denote the efficient inputs given the quantity q and the parameter θ, the regulator's problem is

$$\max_q q$$

$$\text{subject to } \pi^*(q) \equiv P(q)q - wL^*(q,\theta) - r\kappa^*(q,\theta) = 0. \tag{2.6}$$

[10]The firm never has an incentive to waste capital or to gold plate, since waste is dominated by substituting capital for labor to reduce the marginal cost in (2.5).

The solution q^* is the quantity that maximizes total surplus subject to the constraint that $\pi^*(q) = 0$.

Since all regulators of public utilities have the authority to regulate prices, Baron and Taggart (1980) interpret the Averch–Johnson model as representing a naive regulator that in effect adjusts price as a function of the cost incurred by the firm. That is, the price can be viewed as a function $p(\kappa)$ chosen to generate revenue sufficient to cover cost. That is, $p(\kappa)$ is defined by

$$p(\kappa)Q(p(\kappa)) \equiv wL(Q(p(\kappa)), \kappa, \theta) + s\kappa,$$

where $Q(\cdot)$ denotes the demand function. The firm then maximizes profit with respect to κ subject to the constraint:

$$p(\kappa)Q(p(\kappa)) - wL(Q(p(\kappa)), \kappa, \theta) - s\kappa \geq 0,$$

which requires that the price $p(\kappa)$ be such that the allowed rate of return can be earned. Baron and Taggart show that this naive regulation results in the Averch–Johnson outcome. Regulatory behavior in the Averch–Johnson model is thus equivalent to the regulator setting the price for the output of the firm in response to the capital input the firm chooses.

As is evident from (2.6), the regulator can act in a sophisticated manner by setting a price p^S taking into account the firm's response to that price. For any price p^S, the firm will choose the efficient inputs $L^*(Q(p^S), \theta)$ and $\kappa^*(Q(p^S), \theta)$, so the regulator can achieve second-best efficiency by choosing the lowest price p^S such that total revenue covers total cost or $p^S = P(q^*)$. If second-best efficiency is not achieved, it thus must be due to incomplete information, limited observability, or restricted authority.

The Averch–Johnson model thus may be given two interpretations. One interpretation is that the regulator and the firm have symmetric information about demand and cost, and the regulator acts naively by regulating profit by controlling the rate of return. Since this interpretation provides no explanation for why the regulator does not regulate in a sophisticated manner, it is not very compelling. The second interpretation is that information is asymmetric and/or that the regulator has only a limited ability to observe the actions of the firm. For example, if the regulator does not know the parameter θ of the production function and is only able to observe the capital input and profit, the Averch–Johnson model represents one form that regulation could take. A more satisfactory approach, however, is to ask if the representation of regulation in the Averch–Johnson model would arise endogenously as the optimal form of regulation when information is either incomplete or observability is limited.[11] The approach taken in the following sections is thus not to focus on the properties of

[11] Besanko (1984) adopts this approach, and his model is considered in Subsection 4.7.

exogenously-specified mechanisms but to derive endogenously the regulatory mechanisms as a function of the information, observable variables, and authority present in the regulatory setting.

3. Asymmetric information and regulatory mechanisms

3.1. Introduction

The consideration of endogenous regulatory mechanisms will begin with the case in which the firm has private information about its costs. Suppose that the cost function $C(q, \theta)$ of the firm is a function of output q and a parameter $\theta \in \Theta \subset \mathfrak{R}^1$, which represents private information about its costs. The parameter θ will at times be referred to as the "type" of the firm. The parameter θ might, for example, represent as in the previous section a characteristic of the production function, or factor prices that are observable only to the firm because they involve opportunity costs, or managerial ability. The cost function will be assumed to be an increasing function of θ for all $q > 0$, so higher values of θ correspond to a less efficient firm. In addition, marginal cost C_q will be assumed to be increasing in θ. Higher θ thus correspond to higher average and marginal costs. The firm is assumed to know θ, but the regulator has only imperfect information about θ as represented by a density function $f(\theta)$ defined on the domain Θ of possible types. All other information is assumed to be common knowledge.

The regulator is assumed to have the authority to control certain aspects of the firm's operations, and in the case of public utilities, the most widespread authority is over prices. The authority to regulate prices is generally accompanied by the requirement that the firm satisfy all demand at the designated price.[12] The price is important for the efficiency of the regulatory mechanism, since if the price structure involves only a unit price so that revenue equals $pQ(p)$, the resulting mechanisms may be quite inefficient if, for example, production is characterized by increasing returns to scale.[13] Efficiency can be improved if a nonlinear price structure can be used. To simplify the analysis, the nonlinear price structure will be assumed to be two-part, composed of a unit price p and a fixed payment. The fixed payment could be a direct transfer from the state paid from taxes, or a fixed charge in a two-part pricing policy in which consumers pay a unit price p plus an amount independent of the quantity purchased. The two-part pricing policy interpretation will be used here. To simplify the analysis,

[12] The regulator need not monitor or police all the activities of the firm directly. For example, the regulator may post the price for the firm's output and let customers detect any deviations. McCubbins and Schwartz (1984) refer to this as fire alarm monitoring, since consumers can be relied upon to alert the regulator to any deviation from the established price or for failure to satisfy demand at that price.

[13] Baron (1985a) analyzes this case in the context of a simple model.

the demand of consumers will be assumed to depend only on the price p.[14] The analysis thus can be conducted in terms of the aggregate fixed charges T paid to the firm by consumers. The regulatory instruments thus are the price p (or equivalently the quantity q) and the aggregate fixed charges T transferred between consumers and the firm, where $T > (<) 0$ represents a transfer from (to) consumers to (from) the firm.

To represent the institutional structure of regulation in which the regulator has authority over aspects of the firm's operations, the regulator is assumed to move first by making a take-it-or-leave-it offer of a mechanism. The regulator, however, does not know θ, so it is unable to specify directly the first-best pricing policy. Instead, the regulator will prefer to offer a mechanism, a menu of price policies (p, T), to the firm and to let the firm select from the menu the policy that it prefers given its type. The task of the regulator is to design the mechanism in such a manner that the policy chosen by the firm is efficient given the incomplete information available to the regulator.[15]

The regulatory relationship may be modeled as a Bayesian game as defined by Harsanyi (1967–68). Formally, the players, the regulator and the firm, are assumed to have common knowledge about the distribution $f(\theta)$ of possible types, and Nature moves first by drawing a type θ for the firm. The regulator moves next by choosing a mechanism which is a set of pricing policies (p, T). The firm moves last, and its strategy is the selection of one of the policies. The regulatory policy to be studied is then the equilibrium of this game.

This regulatory game can be viewed in terms either of delegation or of revelation. In the delegation formulation, the regulator is viewed as delegating the price decision to the firm by specifying a mechanism $\{t(p),\ p \in [0, \infty)\}$, where $t(p)$ is the fixed charges expressed as a function of the price p the firm chooses. By making $t(p)$ a decreasing function of the price, the firm can be induced to choose a price below the monopoly price. In this formulation, a strategy of the firm is thus a mapping $p(\cdot)$: $\Theta \to [0, \infty)$. In the revelation approach, the price $p(\hat{\theta})$ and the fixed charges $T(\hat{\theta})$ can be viewed as functions of $\hat{\theta} \in \Theta$, where $\hat{\theta}$ denotes the choice made by the firm. That choice may be modeled as the firm choosing a report $\hat{\theta}$ to make to the regulator and the regulator then using the report to set the prices $(p(\hat{\theta}), T(\hat{\theta}))$. Thus, regulation involves a report about, or a revelation of, the firm's true type θ. A strategy of the firm thus is a response function $\hat{\theta}(\cdot)$: $\Theta \to \Theta$. The delegation and the revelation formulations are based on the principle of self-selection in which the regulator chooses a mechanism or menu of policies and the firm chooses a policy from that menu. Actual regulatory

[14] The total fixed charge may thus be thought of as apportioned among consumers in such a manner that no consumer is excluded from purchasing the good.

[15] This structure is closely related to that in the optimal taxation literature as initiated in the seminal work of Mirrlees (1971).

procedures may be thought of as having this feature, since pricing rules are generally responsive to the information about costs reported by the firm.

With either formulation of the regulatory game, the natural incentive of the firm is to choose too high a price, or equivalently, to overstate ($\hat{\theta} = \hat{\theta}(\theta) > \theta$) its cost, in order to obtain a higher price and thereby a higher profit. To illustrate this incentive, consider the case of constant marginal cost with the cost function specified as

$$C(q, \theta) = \theta q + K,$$

where θ is marginal cost and K is the fixed cost. Suppose that the regulator attempted to implement the first-best policy $p(\hat{\theta}) = \hat{\theta}$ and $T(\hat{\theta}) = K$. Given this policy, the profit $\pi(\hat{\theta}; \theta)$ of the firm when it reports $\hat{\theta}$ and its true marginal cost is θ, is

$$\pi(\hat{\theta}; \theta) = p(\hat{\theta})Q\big(p(\hat{\theta})\big) - \theta Q\big(p(\hat{\theta})\big) - K = (\hat{\theta} - \theta)Q\big(p(\hat{\theta})\big) - K.$$

The firm will choose its report $\hat{\theta}(\theta)$ to satisfy the first-order condition:

$$Q\big(\hat{\theta}(\theta)\big) + \big(\hat{\theta}(\theta) - \theta\big)Q'\big(\hat{\theta}(\theta)\big) = 0,$$

which implies that $\hat{\theta}(\theta) > \theta$. The firm thus has a natural incentive to overstate its cost to obtain a higher price and a higher profit. This is not to be thought of as something approaching fraud but instead might correspond to the selective presentation of data and choice of methodologies intended to achieve a more profitable policy.[16] To mitigate this incentive, the regulator can choose both a price function that differs from marginal cost and a fixed charges function that dampens the incentive to overstate costs. In the equilibrium to be characterized in Section 4, the regulator finds it optimal to choose a mechanism from the class of mechanisms which induce the firm to choose a truthful report $\hat{\theta}(\theta) = \theta$.

The next two subsections present the delegation and revelation approaches in more detail.

[16] Ruff (1981) describes a federal expenditure program that illustrates the information problem faced by the designers of institutions and procedures. The Federal Water Pollution Control Act of 1972 established a program under which federal funds would be allocated to build municipal sewage treatment facilities. In 1971 prior to enactment, the EPA had assessed the funds requirements of municipalities to be \$18 billion, but by 1974 the needs estimate had increased to \$342.3 billion. In part this was due to additional pollution control requirements included in the Act, but it also undoubtedly reflected "that municipalities are competing for federal funds by overstating their 'needs,'..." [Ruff (1981, p. 256)]. Although this expenditure program may be as much pork barrel as pollution control, the informational asymmetry between the municipalities and the program administrators undoubtedly limits the efficiency of the program.

3.2. The delegation approach

Consider the case in which the regulatory objective is the maximization of total surplus TS where

$$TS = CS + \Pi,$$

and

$$CS \equiv \int_p^{\infty} Q(p^0)\,\mathrm{d}p^0 - t(p) \tag{3.1}$$

is consumer surplus, and

$$\Pi = pQ(p) + t(p) - \theta Q(p) - K$$

is profit.[17] The optimal regulatory policy in this case has been given by Loeb and Magat (1979) who observed that if the transfer $t(p)$ equals consumer surplus plus the fixed cost K, the profit of the firm will equal total surplus plus K. The firm then will choose to price at marginal cost.[18]

To demonstrate this, suppose that the regulator delegates the price (or equivalently, the output) decision to the firm and specifies the transfer $t(p)$ as

$$t(p) = \int_p^{\infty} Q(p^0)\,\mathrm{d}p^0 + K. \tag{3.2}$$

The profit $\Pi(\theta)$ of the firm with parameter θ then is

$$\Pi(\theta) = pQ(p) + \int_p^{\infty} Q(p^0)\,\mathrm{d}p^0 - \theta Q(p). \tag{3.3}$$

This equals total surplus plus K, so by acting as a profit-maximizer the firm will find it in its interest to set $p(\theta)$ equal to marginal cost θ. To verify this, the first-order condition for the maximum of profit in (3.3) is

$$\frac{\mathrm{d}\Pi(\theta)}{\mathrm{d}p} = [p(\theta) - \theta]Q'(p(\theta)) = 0. \tag{3.4}$$

Whatever its type, the firm thus finds it in its interests to choose the welfare maximizing price.

[17]More general welfare functions could be used in the analysis, but the use of consumer surplus is convenient for relating regulatory policy to pricing.

[18]This result was also noted by Weitzman (1978, p. 685).

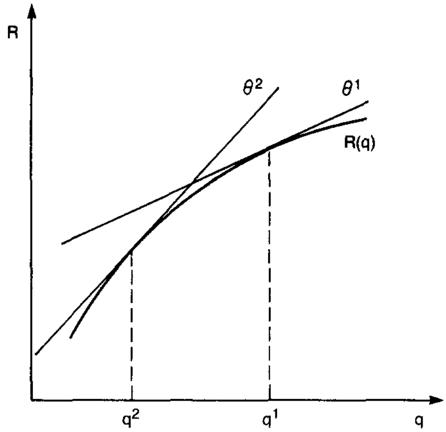

Figure 24.1. Self-selection.

This delegation approach relies on self-selection where a type θ is given the incentive to choose a price $p(\theta)$ that equals marginal cost thus yielding first-best efficiency. The self-selection nature of this mechanism may be illustrated graphically in quantity–revenue space. The quantity $q = Q(p)$ the firm chooses to produce under the regulatory policy corresponds to a revenue $R(q) \equiv P(q)q + t(P(q))$, so profit is $\Pi = R(q) - \theta q - K$. An indifference curve of the firm in R–q space thus has slope

$$\frac{\mathrm{d}R}{\mathrm{d}q} = \theta.$$

The revenue function $R(q)$, or offer curve, specified by the regulator has slope

$$R'(q) = P(q),$$

which is decreasing in q, as indicated in Figure 24.1. The optimality condition in (3.4) is equivalent to a firm of type θ choosing a quantity that equates the slope of its indifference curve to the slope of the regulator's offer curve. A firm with a low marginal cost θ^1 has a flatter indifference curve than a firm with a high marginal cost θ^2 ($\theta^2 > \theta^1$), so as indicated in Figure 24.1, a firm with type θ^1 will select a greater quantity q^1 than a firm with higher marginal cost θ^2 will select.[19] The regulatory mechanism thus induces the firm to choose the quantity appropriate for its type.

An important feature of this mechanism is that it has minimal information requirements, since the regulator only needs to know the demand function and

[19] This is the familiar "single-crossing" property employed in signalling models.

requires no information about the cost function. The regulator thus can use the same mechanism whatever is its prior information about θ. Furthermore, if the costs of the firm are random and realized after the firm has produced, first-best efficiency is still attained. The regulator thus has no need to monitor the activities of the firm and hence has no demand for observable measures of performance.

The firm will choose to participate in the regulatory relationship only if its profit is non-negative, and the profit $\Pi(\theta)$ is

$$\begin{aligned}\Pi(\theta) &= p(\theta)Q(p(\theta)) + \int_{p(\theta)}^{\infty} Q(p^0)\,\mathrm{d}p^0 + K - \theta Q(p(\theta)) - K,\\ &= \int_{p(\theta)}^{\infty} Q(p^0)\,\mathrm{d}p^0 \geq 0. \end{aligned} \tag{3.5}$$

Profit is a strictly decreasing function of θ, since $p(\theta)$ is an increasing function of θ. A low-cost firm thus earns greater profit than does a high-cost firm.

Consumer surplus under the equilibrium mechanism is determined by substituting (3.2) into (3.1), which indicates that consumer surplus equals $-K$. In contrast, the profit of the firm equals total surplus plus K. This regulatory mechanism thus achieves first-best efficiency but leaves a distributional problem, since the firm captures all the surplus leaving none for consumers.[20] One response to this distributive problem is to auction the right to be the franchise monopolist and to distribute the proceeds to consumers in the form of lump-sum payments. This issue will be considered in more detail in Section 7.

3.3. The revelation approach

In the revelation approach, a regulatory policy is represented by a pair of functions $(p(\hat{\theta}), T(\hat{\theta}))$ that give the price and fixed charges as a function of the report $\hat{\theta}$ made by the firm. The resulting profit $\pi(\hat{\theta}; \theta)$ is

$$\pi(\hat{\theta}; \theta) = p(\hat{\theta})Q(p(\hat{\theta})) + T(\hat{\theta}) - \theta Q(p(\hat{\theta})) - K. \tag{3.6}$$

The transfer corresponding to $t(p)$ in (3.2) is

$$T(\hat{\theta}) = \int_{p(\hat{\theta})}^{\infty} Q(p^0)\,\mathrm{d}p^0 + K. \tag{3.7}$$

Assuming that $p(\hat{\theta})$ is differentiable, substitution of $T(\hat{\theta})$ into (3.6) and differ-

[20] Consumers, of course, receive profits in proportion to their ownership share.

entiation with respect to $\hat{\theta}$ yields the necessary optimality condition:

$$\frac{\partial \pi(\hat{\theta}; \theta)}{\partial \hat{\theta}} = \big(p(\hat{\theta}) - \theta\big)Q'\big(p(\hat{\theta})\big)p'(\hat{\theta}) = 0. \tag{3.8}$$

If the price function is specified as $p(\hat{\theta}) = \hat{\theta}$, the firm will thus report truthfully, i.e. $\hat{\theta} = \theta$, and price then equals marginal cost. The first-best allocation is thus attained.

As with the delegation approach, this mechanism can be interpreted as a self-selection mechanism. In the revenue–quantity space in Figure 24.1, a firm reports a type which determines the quantity to be supplied and the revenue to be received. The mechanism induces a firm with a lower marginal cost θ^1 to choose a point on the offer curve corresponding to a greater output than that chosen by a firm with a higher marginal cost θ^2. The offer curve chosen by the regulator in equilibrium induces the firm to choose the pricing policy corresponding to its true marginal cost.

3.4. A generalized welfare measure

The mechanism characterized in the previous two subsections results in first-best efficiency because the objective of the regulator is the maximization of total surplus. Although this welfare function is consistent with normative principles, it does not appear to be descriptive of the actual objectives of regulators nor does it reflect the costs associated with implementing regulatory policies. Consequently, from a positive perspective the equilibrium may not be a good predictor of the efficiency consequences of implementing a regulatory mechanism when information is asymmetric. Laffont and Tirole (1986, 1988), for example, argue that transfers between a firm and either consumers or the state may involve administrative costs, tax distortions, or inefficiencies that must be taken into account in the design of the regulatory mechanism. Baron and Myerson (1982) consider a regulatory objective that is a weighted function of consumer and producer surplus. A rationale for this specification is that regulators are interested in serving the interests of the citizens in their jurisdiction, and since all the consumers reside in the regulatory's jurisdiction but not all of the owners of the firm do, state regulatory commissions adopt a perspective that favors consumer interests over producer interests. Both Bower (1981) and Bailey (1976), who have served on regulatory commissions, argue that this is descriptive of the approach of regulatory commissions.

A complete regulatory theory would explain how regulatory objectives arise in addition to characterizing the regulatory policy following from those objectives.

Baron (1988) presents a positive model of the choice of a regulatory objective based on the control of a regulatory commission by a legislature. Suppose, for example, that the institutional arrangement is hierarchical with a legislature choosing the regulatory objective and the regulatory commission choosing the mechanism optimal for that objective. If each legislator has (induced) preferences over the well-being of consumers and of the owners of the firm who reside in his or her jurisdiction, the preferences of the legislators will not be identical because of differences in constituencies and differences in the distributive consequences of policies. To simplify the analysis, suppose that the legislature is to choose the weight $\alpha, \alpha \in [0,1]$, in the "welfare" function W^* or regulatory mandate given by

$$W^* = CS + \alpha\pi. \tag{3.9}$$

If the legislature is to choose α by majority rule and if induced preferences are single-peaked in α, the equilibrium α will be the ideal point of the median legislator.[21] This ideal point would be expected to be an $\alpha < 1$ if a majority of legislators favor consumer, and hence voter, interests over the interests of the owners of the firm.

With this specification, a transfer of a dollar from consumers to the firm would result in a "loss" of $(1 - \alpha)$ dollars. The Loeb and Magat mechanism is thus costly to implement, since it results in a loss equal to a $(1 - \alpha)$ proportion of the fixed charges in (3.7) transferred between consumers and the firm. In the remainder of this chapter the more general and descriptive specification of the regulatory objective in (3.9) will be employed. This specification, of course, includes when $\alpha = 1$ – the special case of total surplus.

An implication of the use of a total surplus specification of the regulatory objective is that the equilibrium mechanism is independent of the prior information $f(\theta)$ the regulator has about marginal cost θ. Consequently, if the regulator knows θ or if it has very imprecise information, the same mechanism would be employed. This is a result of the assumption that transfers between the firm and consumers are costless. For $\alpha < 1$ in (3.9), the equilibrium mechanism will depend on the information the regulator has about θ.

4. Asymmetric information: A general revelation approach

4.1. Feasible mechanisms

To characterize the equilibrium in this regulatory game, the approach of Baron and Myerson (1982) and Guesnerie and Laffont (1984) will be adopted. They

[21]See Black (1958) for the demonstration of this result.

view mechanism design as involving two stages. In the first, the class of implementable or feasible mechanisms is characterized, and in the second stage, the optimal or equilibrium mechanism is selected from that class. More formally, in the revelation approach the regulatory relationship is represented as a Bayesian game in which the regulator chooses a mechanism that is optimal given the optimal response of the firm, and given that mechanism the firm chooses an optimal strategy conditional on its private information. The game will be modeled as a direct revelation game in which a strategy of the firm is a mapping $\hat{\theta}(\theta)$ from the set Θ of possible types into itself or $\hat{\theta}(\cdot)$: $\Theta \to \Theta$. A strategy for the regulator is a collection of policies $(p(\hat{\theta}), T(\hat{\theta}))$ for each type $\hat{\theta}$ that the firm may report. Such a strategy is referred to as a mechanism and is denoted by $M = \{(p(\hat{\theta}), T(\hat{\theta})), \hat{\theta} \in \Theta\}$.[22] When the strategy set is the set of types, the game form is referred to as direct, and M is said to be a direct revelation mechanism.

In the Bayeisan approach, the regulator is assumed to have prior information about the parameter θ represented by a density function $f(\theta)$, which, to avoid technical problems, will be assumed to be positive on its support which will be specified as $\Theta = [\theta^-, \theta^+]$. A Bayesian Nash equilibrium of this game is (1) a mechanism $M^* = \{(p^*(\hat{\theta}), T^*(\hat{\theta})), \hat{\theta} \in \Theta\}$ that maximizes the regulator's objective given the strategy $\hat{\theta}^*(\cdot)$ of the firm, and (2) a strategy $\{\hat{\theta}^*(\theta), \theta \in \Theta\}$ that maximizes the firm's profit for each possible type given the mechanism M^*.

To determine an equilibrium of this game, it is useful to apply the *revelation principle* which states that, given any mechanism $M^+ = \{(p^+(\hat{\theta}), T^+(\hat{\theta})), \hat{\theta} \in \Theta\}$ such that the optimal response of the firm is $\hat{\theta}^+(\theta)$, there exists another mechanism $M = \{(p(\theta), T(\theta)), \theta \in \Theta\}$ that induces a response $\hat{\theta}(\theta) = \theta$, $\forall \theta \in \Theta$, and is at least as good in terms of the regulator's objective as is the mechanism M^+.[23] The revelation principle thus states that the regulator can restrict its attention to the class of mechanisms in response to which the firm reports its type truthfully. To demonstrate this, define the policies by

$$p(\cdot) \equiv p^+(\hat{\theta}^+(\cdot)) \quad \text{and} \quad T(\cdot) \equiv T^+(\hat{\theta}^+(\cdot)).$$

Given the mechanism $M = \{(p(\theta), T(\theta)), \theta \in \Theta\}$, the firm finds it optimal to report θ truthfully, since doing so yields the same outcome attained with the

[22] The firm can choose to participate in the game and will do so only if its profit is non-negative, but that decision will be suppressed to simplify the notation. Similarly, the regulator's strategy can be defined to include the decision of whether to allow the firm to produce as a function of $\hat{\theta}$. To simplify the notation, consumer surplus is assumed to be sufficiently great that the regulator prefers to have all types produce.

[23] The revelation principle is established in Myerson (1979), Dasgupta, Hammond and Maskin (1979), and Harris and Townsend (1981).

original, and optimal, response $\hat{\theta}^+(\theta)$ to the mechanism M^+. The revelation principle thus implies that the regulator can restrict its attention to the class of mechanisms such that the firm has no incentive to misrepresent its type. Such mechanisms are said to be incentive compatible.[24]

The advantage of the revelation approach is that it provides a means of characterizing the class of feasible mechanisms and allows the equilibrium to be computed from a programming problem. The first step in the characterization of the regulatory equilibrium is thus to determine the class of implementable incentive compatible mechanisms. A mechanism is implementable, or feasible, if it is incentive compatible and induces the firm to participate in the regulatory relationship.

The firm will choose a response function $\hat{\theta}(\theta) = \theta$ if its profit $\pi(\theta; \theta)$ is at least as great as the profit $\pi(\hat{\theta}; \theta)$ it could obtain for any report $\hat{\theta}$. Thus, the class of incentive compatible mechanisms is the set of mechanisms that satisfy the constraints:

$$\pi(\theta) \equiv \pi(\theta; \theta) \geq \pi(\hat{\theta}; \theta), \quad \forall \hat{\theta} \in [\theta^-, \theta^+], \quad \forall \theta \in [\theta^-, \theta^+]. \tag{4.1}$$

These constraints are *global* in the sense that for each θ, they must be satisfied for all reports $\hat{\theta} \in [\theta^-, \theta^+]$.

The firm is assumed to have the right not to participate in the regulatory relationship and will participate only if its profit $\pi(\theta)$ is at least as great as its reservation profit, which will be assumed to be zero. A mechanism thus must satisfy:[25]

$$\pi(\theta) \geq 0, \quad \forall \theta \in [\theta^-, \theta^+]. \tag{4.2}$$

These constraints are referred to as individual rationality or participation constraints.

A mechanism $M = \{(p(\theta), T(\theta)),\ \theta \in [\theta^-, \theta^+]\}$ will be said to be implementable or *feasible* if it satisfies (4.1) and (4.2). The firm will respond to any feasible mechanism with a strategy $\hat{\theta}(\theta) = \theta$ for all $\theta \in [\theta^-, \theta^+]$. Characteriza-

[24] For the class of incentive compatible mechanisms, the firm has a dominant strategy of responding truthfully.

[25] To deal with the case in which the firm's cost is sufficiently high that the regulator's objective function is negative, the regulator can be viewed as denying the firm the franchise. In the formulation here, this can be modeled as the regulator specifying as a component of the mechanism a probability $r(\hat{\theta})$ that the firm will be granted a franchise when it reports $\hat{\theta}$. The equilibrium in this model specifies a $\theta^* \in [\theta^-, \theta^+]$ such that the probability equals zero for $\theta > \theta^*$ and equals one for $\theta \leq \theta^*$ as Baron and Myerson show. This specification is used in Subsection 4.3 for the case of asymmetric information about fixed costs.

tion of the class of feasible mechanisms will proceed in four steps based on the approach in Baron and Myerson. The first step is to determine a property of the profit function implied by the constraints in (4.1). The second step is to use that property to replace the set of individual rationality constraints in (4.2) by a single constraint. The third step is to specify the form of the fixed charges function $T(\theta)$ that implements "locally" any price function $p(\theta)$. The fourth step is to develop a necessary and sufficient condition on $p(\theta)$ for $\hat{\theta}(\theta) = \theta$ to be a globally optimal or equilibrium response of the firm to the mechanism $M = \{(p(\theta), T(\theta)),\ \theta \in [\theta^-, \theta^+]\}$. Once the class of feasible mechanisms has been characterized, the regulator can solve a programming program to determine the optimal, and thus equilibrium, mechanism.

For the first step, note that the profit $\pi(\hat{\theta};\theta)$ of the firm of type θ that reports its type as $\hat{\theta}$ can be rewritten as

$$\pi(\hat{\theta};\theta) = \pi(\hat{\theta}) + C\big(Q(p(\hat{\theta})),\hat{\theta}\big) - C\big(Q(p(\hat{\theta})),\theta\big). \tag{4.3}$$

For an incentive compatible mechanism the constraints in (4.1) imply, using (4.3):

$$\begin{aligned}\pi(\theta) &\geq \pi(\hat{\theta};\theta)\\ &= \pi(\hat{\theta}) + C\big(Q(p(\hat{\theta})),\hat{\theta}\big) - C\big(Q(p(\hat{\theta})),\theta\big),\end{aligned} \tag{4.1a}$$

which implies that

$$\pi(\theta) - \pi(\hat{\theta}) \geq C\big(Q(p(\hat{\theta})),\hat{\theta}\big) - C\big(Q(p(\hat{\theta})),\theta\big). \tag{4.4}$$

Reversing the roles of θ and $\hat{\theta}$ in (4.3) and (4.1a) implies that

$$\pi(\theta) - \pi(\hat{\theta}) \leq C\big(Q(p(\theta)),\hat{\theta}\big) - C\big(Q(p(\theta)),\theta\big). \tag{4.5}$$

Combining (4.4) and (4.5) yields for all $\hat{\theta}$ and θ:

$$\begin{aligned}C\big(Q(p(\theta)),\hat{\theta}\big) - C\big(Q(p(\theta)),\theta\big) \geq \pi(\theta) - \pi(\hat{\theta}) \geq C\big(Q(p(\hat{\theta})),\hat{\theta}\big)&\\ - C\big(Q(p(\hat{\theta})),\theta\big).&\end{aligned} \tag{4.6}$$

Dividing the inequalities in (4.6) by $\hat{\theta} - \theta$ for $\hat{\theta} > \theta$, and taking the limit as

$\hat{\theta} \to \theta$ yields:[26]

$$\frac{\mathrm{d}\pi(\theta)}{\mathrm{d}\theta} = -C_\theta(Q(p(\theta)),\theta), \tag{4.7}$$

almost everywhere. Viewing the profit function $\pi(\theta)$ as a state variable, its derivative is thus equal to the negative of the derivative of the cost function with respect to the type θ. Since a derivative is a local property of a function, (4.7) is a local condition that indicates that for any incentive compatible mechanism the profit of the firm viewed across the possible types is a decreasing function of θ since $C_\theta > 0$. The profit of a high-cost firm (high θ) is thus less than the profit of a low-cost firm (low θ) for any incentive compatible mechanism. The condition in (4.7) may be integrated to obtain an equivalent local condition on the profit function:[27]

$$\pi(\theta) = \int_\theta^{\theta^+} C_\theta\big(Q(p(\theta^0)),\theta^0\big)\,\mathrm{d}\theta^0 + \pi(\theta^+), \tag{4.8}$$

where $\pi(\theta^+)$ is the profit of a firm with the highest possible marginal cost. This condition completes the first step of the characterization. Note from (4.8) that profit is a decreasing function of θ.

Since the profit function $\pi(\theta)$ is a decreasing function of the parameter θ for any incentive compatible policy, the individual rationality constraints in (4.2) will be satisfied if the profit of the highest cost type θ^+ is non-negative. The continuum of constraints in (4.2) can thus be replaced by the single constraint:

$$\pi(\theta^+) \geq 0. \tag{4.9}$$

[26]Given differentiable policies $p(\theta)$ and $T(\theta)$, this condition can also be derived by differentiating the profit $\pi(\theta)$ which yields:

$$\begin{aligned}\frac{\mathrm{d}\pi(\theta)}{\mathrm{d}\theta} &= \left.\frac{\mathrm{d}\pi(\hat{\theta}(\theta);\theta)}{\mathrm{d}\theta}\right|_{\hat{\theta}=\theta}\\ &= \left.\frac{\partial\pi(\hat{\theta}(\theta);\theta)}{\partial\hat{\theta}}\frac{\mathrm{d}\hat{\theta}(\theta)}{\mathrm{d}\theta}\right|_{\hat{\theta}=\theta} + \left.\frac{\partial\pi(\hat{\theta}(\theta);\theta)}{\partial\theta}\right|_{\hat{\theta}=\theta}\\ &= \left.\frac{\partial\pi(\hat{\theta}(\theta);\theta)}{\partial\theta}\right|_{\hat{\theta}=\theta}\\ &= -C_\theta(Q(p(\theta)),\theta).\end{aligned}$$

The third equality follows from the first-order condition for the firm's optimal choice of its response function $\hat{\theta}(\theta)$.

[27]This is the same condition developed in (3.5).

The second step in the characterization has thus been completed.

The third step involves demonstrating that a price function $p(\theta)$ can be implemented locally by choosing the fixed charges $T(\theta)$ to induce the firm to choose the strategy $\hat{\theta}(\theta) = \theta$. To determine $T(\theta)$, equate the representation of the profit function in (4.8) with the definition of $\pi(\theta)$, which is

$$\pi(\theta) = p(\theta)Q(p(\theta)) + T(\theta) - C(Q(p(\theta)), \theta). \tag{4.10}$$

Solving for $T(\theta)$ yields:

$$T(\theta) = \int_{\theta}^{\theta^+} C_\theta\big(Q(p(\theta^0)), \theta^0\big)\,\mathrm{d}\theta^0 - p(\theta)Q(p(\theta)) + C(Q(p(\theta)), \theta) + \pi(\theta^+). \tag{4.11}$$

Substituting $T(\hat{\theta})$ into $\pi(\hat{\theta}; \theta)$ in (4.3), and differentiating with respect to $\hat{\theta}$ indicates that $\hat{\theta}(\theta) = \theta$ satisfies the first-order condition for all θ. Consequently, $T(\theta)$ given in (4.11) induces the firm to prefer locally to report truthfully.[28]

For the fourth step, a necessary and sufficient condition on the price function $p(\theta)$ for the firm to report $\hat{\theta}(\theta) = \theta$ for all $\theta \in [\theta^-, \theta^+]$ will be presented. To develop this condition, note that from (4.6) incentive compatibility requires that the price function $p(\cdot)$ satisfy

$$C(Q(p(\theta)), \hat{\theta}) - C(Q(p(\theta)), \theta) \geq C\big(Q(p(\hat{\theta})), \hat{\theta}\big) - C\big(Q(p(\hat{\theta})), \theta\big), \quad \forall \hat{\theta}, \theta \in [\theta^-, \theta^+]. \tag{4.12}$$

The necessary and sufficient condition will be developed for the case in which the marginal cost is constant and equal to θ or

$$C(q, \theta) = \theta q + K. \tag{4.13}$$

The condition in (4.12) then is

$$(\hat{\theta} - \theta)Q(p(\theta)) \geq (\hat{\theta} - \theta)Q(p(\hat{\theta})), \quad \forall \hat{\theta}, \theta \in [\theta^-, \theta^+]. \tag{4.14}$$

If $\hat{\theta} > \theta$, then (4.14) requires that $Q(p(\theta)) \geq Q(p(\hat{\theta}))$. Consequently, for this specification of the cost function a necessary condition for the price function $p(\theta)$ to be implementable, or to be globally incentive compatible, is that it be a nondecreasing function of θ. This corresponds to the intuitive notion that the price should be (weakly) higher the higher is the marginal cost of the firm.

[28] A sufficient condition is developed in (4.15) below.

For the specification in (4.13), the necessary condition that the price function $p(\theta)$ is a nondecreasing function can be shown also to be sufficient for the policy to be incentive compatible. Substituting $\pi(\hat{\theta})$ from (4.8) for $\hat{\theta}=\theta$ into (4.3) yields:

$$\pi(\hat{\theta};\theta)=\pi(\theta^{+})+\int_{\hat{\theta}}^{\theta^{+}}Q(p(\theta^{0}))\,\mathrm{d}\theta^{0}+(\hat{\theta}-\theta)Q(p(\hat{\theta})).$$

Substituting $\pi(\theta^{+})$ from (4.8) yields:

$$\pi(\hat{\theta};\theta)=\pi(\theta)-\int_{\theta}^{\hat{\theta}}Q(p(\theta^{0}))\,\mathrm{d}\theta^{0}+(\hat{\theta}-\theta)Q(p(\hat{\theta})).$$

Combining terms yields:

$$\pi(\hat{\theta};\theta)=\pi(\theta)-\int_{\theta}^{\hat{\theta}}\left[Q(p(\theta^{0}))-Q(p(\hat{\theta}))\right]\mathrm{d}\theta^{0}. \tag{4.15}$$

Consequently, global incentive compatibility, i.e. $\pi(\theta)\geq\pi(\hat{\theta};\theta)$ for all $\hat{\theta}$ and all θ, is satisfied if the integral in (4.15) is non-negative. That integral is non-negative if the price function $p(\theta)$ is nondecreasing. To see this, note that if $\hat{\theta}>\theta$, the integrand is non-negative, and if $\hat{\theta}<\theta$, the integrand is nonpositive but the direction of the integral is reversed, so the integral is non-negative. Consequently, if the price function $p(\theta)$ is nondecreasing, the regulatory policy that induces a response function $\hat{\theta}(\theta)=\theta$ is incentive compatible.[29] The class of feasible, i.e. incentive compatible mechanisms that satisfy the individual rationality constraints in (4.2) and can be implemented by the regulator, is thus composed of those policies in which the price function is nondecreasing in θ and the corresponding fixed charges $T(\theta)$ satisfy (4.11). This completes the characterization of the class of mechanisms from which the regulator will choose.

4.2. *The equilibrium*

The characterization of the class of feasible mechanisms provides the basis for a method to determine the regulatory equilibrium. Any mechanism with a nondecreasing price function is feasible and thus can be implemented, so the firm's strategic behavior can be captured by the regulator taking the report $\hat{\theta}$ to be the

[29] Note that this necessary and sufficient condition is independent of the demand function. This is due to the assumption of constant marginal cost. If the cost function is not linear in θ, the necessary condition for $p(\theta)$ to be implementable is that $C(Q(p(\theta)),\theta)$ be a nondecreasing function of θ. The sufficient condition is that the integral in (4.15) be non-negative. The condition required on $p(\theta)$ then depends on the properties of the demand function.

firm's true type θ. This allows the game to be converted to a programming problem incorporating the constraints in (4.1) and (4.2) and the constraint that $p(\theta)$ be nondecreasing. As indicated above, the regulator can replace the individual rationality constraints by the single constraint in (4.9). Similarly, the constraints in (4.1) are satisfied by choosing $T(\theta)$ to satisfy (4.11) when $p(\theta)$ is nondecreasing, and then the condition in (4.8) can be used to replace (4.1). The constraint that $p(\theta)$ is nondecreasing is difficult to incorporate into a mathematical program without assuming that $p(\theta)$ is differentiable. The approach taken here is to ignore this constraint and then to check if the solution obtained has the required property. If it does not, then the regulator's program has to be "convexified" as in Maskin and Riley (1984), Baron and Myerson, and Guesnerie and Laffont. The technical details of this convexification will not be addressed here.

The objective or welfare function W of the regulator is the maximization of the ex ante, or expected, weighted sum W^* of consumer and producer surplus in (3.9) using the prior information $f(\theta)$ of the regulator regarding θ or

$$W = \int_{\theta^-}^{\theta^+} \left\{ \int_{p(\theta)}^{\infty} Q(p^0)\,\mathrm{d}p^0 - T(\theta) + \alpha\pi(\theta) \right\} f(\theta)\,\mathrm{d}\theta. \tag{4.16}$$

Appendix A presents a control theoretic solution of the regulator's program of maximizing this objective function subject to the constraints in (4.2), (4.7), and (4.10). The approach taken here is to derive a less constrained formulation of the program that can be solved with simpler methods. To develop this approach, first note that the welfare measure in (4.16) can be rewritten by substituting $T(\theta)$ from (4.10) into (4.16) to yield:

$$W = \int_{\theta^-}^{\theta^+} \left\{ \int_{p(\theta)}^{\infty} Q(p^0)\,\mathrm{d}p^0 + p(\theta)Q(p(\theta)) - \theta Q(p(\theta)) \right.$$

$$\left. - K - (1-\alpha)\pi(\theta) \right\} f(\theta)\,\mathrm{d}\theta. \tag{4.17}$$

This representation of the regulator's objective is the expectation of the social surplus from the firm's output less the "loss" $(1-\alpha)\pi(\theta)$ from the portion of the firm's profits that is not counted in the regulatory objective.

The profit $\pi(\theta)$ of the firm is a state variable in (4.17), which for an incentive compatible policy has the form given in (4.8). The state variable can replace its representation in (4.8), which incorporates the local representation of the incentive compatibility constraints. This eliminates the local constraint in (4.7). This also expresses welfare solely in terms of the control $p(\theta)$. Since the expression for W in (4.17) involves the expectation of $\pi(\theta)$, so the expectation of (4.8) will be substituted into (4.17). Taking the expectation of $\pi(\theta)$ and integrating by parts yields:

$$\int_{\theta^-}^{\theta^+} \pi(\theta) f(\theta)\, \mathrm{d}\theta = \int_{\theta^-}^{\theta^+} Q(p(\theta)) F(\theta)\, \mathrm{d}\theta + \pi(\theta^+),$$

where $F(\theta)$ is the distribution function corresponding to $f(\theta)$. Substituting this into (4.17) and collecting terms yields:

$$\begin{aligned} W = \int_{\theta^-}^{\theta^+} \Bigg\{ & \int_{p(\theta)}^{\infty} Q(p^0)\, \mathrm{d}p^0 + p(\theta) Q(p(\theta)) \\ & - \left(\theta + (1-\alpha)\frac{F(\theta)}{f(\theta)}\right) Q(p(\theta)) - K \Bigg\} f(\theta)\, \mathrm{d}\theta \\ & - (1-\alpha)\pi(\theta^+). \end{aligned} \tag{4.18}$$

The regulator's "relaxed" or "unconstrained" programming program is thus to maximize W in (4.18) with respect to $p(\theta)$ and $\pi(\theta^+)$ subject to the single constraint in (4.9). Since W is decreasing in $\pi(\theta^+)$, it is immediate that $\pi(\theta^+) = 0$ is optimal. Consequently, the firm with the highest cost has zero profit under an optimal mechanism.

The necessary condition for the optimal price function $p(\theta)$ is obtained by pointwise differentiation of W which yields:

$$\frac{\partial W}{\partial p(\theta)} = \left[p(\theta) - \left(\theta + (1-\alpha)\frac{F(\theta)}{f(\theta)}\right)\right] Q'(p(\theta)) f(\theta) = 0,$$

so the optimal price is

$$p(\theta) = y_\alpha(\theta) \equiv \theta + (1-\alpha)\frac{F(\theta)}{f(\theta)}. \tag{4.19}$$

Because marginal cost is constant, the optimal price is independent of the demand function and depends only on the marginal cost, the prior information of the regulator, and α.

The price function satisfying (4.19) maximizes the regulator's welfare function when the constraint that $p(\theta)$ is nondecreasing is ignored. To determine if that constraint is binding, note from (4.19) that the price function will be nondecreasing in θ if and only if $y_\alpha(\theta)$ is nondecreasing. A sufficient condition is $F(\theta)/f(\theta)$ nondecreasing, and since $F(\theta)$ is an increasing function, this condition will be satisfied if the density function does not increase too rapidly. The term $F(\theta)/f(\theta)$ is nondecreasing for the uniform, normal, exponential, and other frequently used distributions, so throughout the remainder of this chapter, the assumption that $y_\alpha(\theta)$ is nondecreasing in θ will be maintained. If this condition is not satisfied, the regulator's program must be convexified.

The equilibrium mechanism is thus composed of the price function given in (4.19) and a fixed charges function given in (4.11). To interpret the equilibrium, first note that price exceeds marginal cost θ when $\alpha < 1$ for all θ other than θ^-. The type with the lowest marginal cost receives a price equal to its marginal cost, and all higher cost types receive a price that is greater than their marginal cost. The price is a decreasing function of α, so the more weight the regulator gives to the profit of the firm the lower is the price. To see why the price is set above marginal cost, the profit of the firm must be interpreted.

The profit of the firm is due solely to the private information of the firm, since if information were symmetric the regulator would set price equal to marginal cost and the fixed payments would equal the fixed cost. The profit is thus a rent to the private information of the firm. That rent is given in (4.8), which for a constant marginal cost is

$$\pi(\theta) = \int_\theta^{\theta^+} Q(p(\theta^0))\,\mathrm{d}\theta^0. \tag{4.8a}$$

The rent is greater the lower is the firm's marginal cost and the greater is the quantity resulting from the price function $p(\theta)$. Since the price function is a decreasing function of α, the more weight given to profit in the regulator's objective, and hence the smaller the loss $(1 - \alpha)\pi(\theta)$, the lower is the price and the greater the rent.

The information rents result because, as indicated in Section 3.1, a firm with marginal cost θ has a natural incentive to report its costs as $\theta + \Delta\theta$, $\Delta\theta > 0$ in order to obtain higher profits. The gain from such a report is approximately $\Delta\theta Q(p(\theta + \Delta\theta))$, and thus the rents are the sum of these increments as indicated in (4.8a). To eliminate this incentive, the regulator must offer the firm with marginal cost θ rents sufficient to negate that incentive. This is accomplished by structuring the fixed charges function appropriately as is evident by comparing (4.8a) and (4.11) for the specification in (4.13). As is evident from the welfare measure in (4.17), the information rents represent a reduction in welfare when $\alpha < 1$, so the regulator prefers that those rents be as small as possible. The regulator cannot eliminate the rents, however, because they arise from the need to induce the firm with marginal cost θ to choose the pricing policy designed for it.

Since the information rents in (4.8a) depend on the quantity produced, and hence the price $p(\theta)$, the regulator can reduce those rents by increasing the price. The gains from reducing the information rents by raising the price, of course, come at the expense of a reduction in consumer surplus. The optimal tradeoff between these two involves a reduction in consumer surplus equal to $Q'(p(\theta))p(\theta)$ and a reduction in ex ante or expected rents given by $(\theta + (1-\alpha)[F(\theta)/f(\theta)])Q'(p(\theta))$. The optimal tradeoff is reflected in the distortion indicated in (4.19) of price from marginal costs. The term $((1-\alpha)[F(\theta)/f(\theta)])$ represents the marginal information rents, and thus the equilibrium mechanism establishes a price equal to the sum of the marginal cost θ and the marginal information rents. The regulator thus finds it optimal to distort price from marginal cost for all but the most efficient type of firm when $\alpha < 1$. For higher α price is distorted less from marginal cost because the rents represent a smaller loss in the regulator's welfare function. For $\alpha = 1$ the price equals marginal cost, and the resulting regulatory policy is the same as that obtained by Loeb and Magat.

As an example, if $f(\theta)$ is uniform on $[0, \theta^+]$, the price is

$$p(\theta) = (2-\alpha)\theta,$$

since the marginal information rent is $(1-\alpha)\theta$. The corresponding fixed charges function $T(\theta)$ is then

$$\begin{aligned} T(\theta) &= -(p(\theta)-\theta)Q(p(\theta)) + K + \int_{\theta}^{\theta^+} Q(p(\theta^0))\,\mathrm{d}\theta^0 \\ &= -(1-\alpha)\theta Q((2-\alpha)\theta) + K + \int_{\theta}^{\theta^+} Q((2-\alpha)\theta^0)\,\mathrm{d}\theta^0. \end{aligned}$$

The mechanism derived here is ex ante optimal for the regulator in the sense that it maximizes expected welfare given the prior information of the regulator. The mechanism, however, is not ex post efficient, or perfect, because price is distorted from marginal cost. Consequently, once the firm has made its report, both the regulator and the firm have an incentive to revise the regulatory policy and to share the efficiency gains. If the firm knew that this would occur, however, it would have an ex ante incentive to report a different $\hat{\theta}$. The regulator then would have to take this strategy into account and thus would be faced with a game similar to that addressed above. The equilibrium when this renegotiation cannot be precluded is a price function $p(\theta) = \theta$ and fixed charges given in (3.7). Because of the loss $(1-\alpha)\pi(\theta)$, the welfare function W is lower than when price is distorted from marginal cost as in (4.19). The regulator thus prefers to sacrifice ex post efficiency for ex ante efficiency whenever it has an objective other than the maximization of total surplus. The equilibrium mechanism characterized here thus requires that the regulator be able to commit credibly not to renegotiate the policy once the firm has reported its marginal cost.

The model presented in this section has been interpreted as pertaining to the case in which the firm takes no actions and the regulator has no opportunity to observe the actual cost of the firm. The model, however, can be given other interpretations. For example, the model is analogous to a model in which the firm has private information about its marginal costs, costs can be observed ex post by the regulator, and the firm takes an unobservable effort decision. To demonstrate this, suppose that the cost function of the firm is $c(q;\theta,a)=(\theta-a)q$, where a denotes the effort expended by the manager of the firm. Effort is assumed to have a disutility given by $\psi(a)$, which is strictly increasing and strictly convex. A policy specifies a price $p(\hat{\theta})$, a cost target $C(\hat{\theta})$, and fixed charges $T(\hat{\theta})$. Since the actual cost realized equals $(\theta-a)Q(p(\hat{\theta}))$, the fixed charges can be chosen so that the firm is severely penalized if its actual cost differs from the cost target. Consequently, the firm must choose its effort $a(\hat{\theta};\theta)$ to satisfy the restriction:

$$(\theta-a(\hat{\theta};\theta))Q(p(\hat{\theta}))+K=C(\hat{\theta})=(\hat{\theta}-a(\hat{\theta};\hat{\theta}))Q(p(\hat{\theta}))+K.$$

This condition can be solved for $a(\hat{\theta};\theta)$ which expresses the effort in terms of the true θ and the report $\hat{\theta}$. The profit of the firm is then $\pi^*(\hat{\theta},a(\hat{\theta};\theta);\theta)$, which can be written as

$$\begin{aligned}\pi^*(\hat{\theta},a(\hat{\theta};\theta);\theta)&=p(\hat{\theta})Q(p(\hat{\theta}))+T(\hat{\theta})-\psi(\hat{\theta}-\theta+a(\hat{\theta};\hat{\theta}))\\&\quad-(\hat{\theta}-a(\hat{\theta};\hat{\theta}))Q(p(\hat{\theta}))-K.\end{aligned}$$

This formulation is analogous to that considered above with $\pi(\hat{\theta};\theta)\equiv\pi^*(\hat{\theta},a(\hat{\theta};\theta);\theta)$. The formulation considered in this subsection thus also pertains to the case of the regulator observing the actual cost of the firm when the firm has private information and takes an unobservable effort decision. This formulation will be considered in more detail in Section 5.

4.3. *Private information about fixed costs*

The model in the previous subsection can be directly applied to the case in which the private information θ affects fixed rather than marginal costs. To illustrate the features of the equilibrium mechanism, consider the case in which marginal cost c is common knowledge and the fixed cost θ is known only to the firm. In this case the mechanism problem must deal with the possibility that the fixed cost may be sufficiently high that the regulator prefers that certain types not produce.

Using the same approach presented above, the welfare function analogous to (4.18) is

$$W = \int_{\theta^-}^{\theta^+} \left[\int_{p(\theta)}^{\infty} Q(p^0)\,\mathrm{d}p^0 + p(\theta)Q(p(\theta)) - cQ(p(\theta)) - \theta - (1-\alpha)\frac{F(\theta)}{f(\theta)} \right] f(\theta)\,\mathrm{d}\theta. \tag{4.20}$$

Since the regulator knows the marginal cost c, the optimal price is

$$p(\theta) = c, \quad \forall \theta \in [\theta^-, \theta^+].$$

The welfare $W(\theta)$ conditional on θ is the integrand in (4.20) and is equal to

$$W(\theta) = \int_c^{\infty} Q(p^0)\,\mathrm{d}p^0 - y_\alpha(\theta). \tag{4.21}$$

Letting $r(\theta) = 1$ indicate that the firm is allowed to produce and $r(\theta) = 0$ indicate that the firm is not allowed to produce, the optimal policy is to allow the firm to produce if and only if consumer surplus is at least as great as $y_\alpha(\theta)$ or

$$r(\theta) = \begin{cases} 1, & \text{if } \int_c^{\infty} Q(p^0)\,\mathrm{d}p^0 \geq y_\alpha(\theta), \\ 0, & \text{if } \int_c^{\infty} Q(p^0)\,\mathrm{d}p^0 < y_\alpha(\theta). \end{cases}$$

Since $y_\alpha(\theta)$ is a strictly increasing function of θ, the policy may be restated as

$$r(\theta) = \begin{cases} 1, & \text{if } \theta \leq \theta_c, \\ 0, & \text{if } \theta > \theta_c, \end{cases} \tag{4.22}$$

where θ_c is defined by $y_\alpha(\theta_c) \equiv \int_c^{\infty} Q(p^0)\,\mathrm{d}p^0$. If $\theta_c \geq \theta^+$, all types of the firm produce, but if $\theta_c \in [\theta^-, \theta^+)$, the optimal regulatory mechanism will result in some types not producing even though it is ex post efficient for them to produce. This ex post inefficiency is desirable because it reduces the rents of the firm.[30] The rent under the optimal mechanism is given by

$$\pi(\theta) = \begin{cases} \theta_c - \theta, & \text{if } \theta \le \theta_c, \\ 0, & \text{if } \theta > \theta_c. \end{cases}$$

This optimal regulatory mechanism can be implemented by the regulator announcing that it will pay θ_c to the firm if it will produce the quantity $Q(c)$ and sell it at the price c. If the firm has a fixed cost less than or equal to θ_c, it will accept the offer, and if it has a higher fixed cost, it will decline the offer.

4.4. *Multiple information parameters*

An important limitation of the theory presented above is that it is based on the assumption that the private information of the firm has only one dimension. That is, the private information pertains only to marginal cost or to fixed cost or to both in a perfectly correlated manner. If, for example, the marginal cost and the fixed cost are private information and are not perfectly correlated, the mechanism design is considerably complicated.[31] Rochet (1984) has characterized the optimal mechanism for the case in which the marginal cost θ and the fixed cost ϕ are not perfectly correlated. He shows that the optimal mechanism may involve randomization between allowing the firm to produce and not.[32] He also shows that the optimal price function may depend on the properties of the demand function even though marginal cost is constant.

Rochet provides an explicit solution for the case in which θ and ϕ are independent and uniformly distributed and the demand function is linear. He demonstrates that on the subset of the support of (θ, ϕ) for which the firm is allowed to produce with probability one, the price is independent of the demand function and equals $y_\alpha(\theta)$. On the subset on which the regulator randomizes between production and no production, the price depends on both marginal and fixed costs. On the other subsets the firm is either not allowed to produce, produces a quantity of zero, or earns no profit.

The difficulty in extending the theory developed in the previous subsections to multiple information parameters constitutes a significant limitation to the application of the theory of mechanism design with asymmetric information.

[30] Since $y_\alpha(\theta)$ is decreasing in α, the higher is α, the more likely it is that the firm will produce when it is ex post efficient for it to produce.

[31] The principal technical difficulty is that the conditions analogous to (4.7) represent partial differential equations the solution to which is difficult to characterize.

[32] Baron and Myerson (1982) provide a discrete example with this property.

4.5. Multiple outputs

The model analyzed in this section has only one output, but the extension to multiple outputs is straightforward as long as there is only one information parameter. Sappington (1983a) considers the case of a firm with multiple products produced with a technology conditioned on a parameter θ known to the firm but not known to the regulator. The regulator can choose a two-part pricing system with a unit price for each output and fixed charges paid by consumers to the firm. Although it is feasible for the regulator to induce the firm to choose an efficient technology for all θ, Sappington shows that the regulator adopts a pricing policy that induces the firm to choose an inefficient technology at least for some θ. As in the single-output case, the regulator chooses to distort the price from marginal cost in order to reduce the information rents and to distort the technology as well to control more efficiently the rents.

4.6. Unobservable actions

In the above models the only action of the firm is to select a regulatory policy from the menu of policies offered. The firm, however, may have actions that can be taken that affect the cost it will incur in satisfying demand at the price specified in the regulatory policy. These decisions can be considered in the context of either a value maximization or a managerial model. In a value maximization model, the firm is typically represented as having a choice among technologies or factor inputs. In a managerial model, the manager of the firm is typically represented as making an unobservable effort decision. Managerial models are based on the separation of ownership and control and represent the manager as pursuing his own interests rather than those of the owners. When the actions of the manager are only imperfectly observable to the owners, the manager has an opportunity to serve his own interests rather than those of the owners. The owners then will structure the incentives of the manager so that they are more closely aligned with the interests of the owners. A simple version of such a managerial model is considered in the following subsection and more complex models are considered in Subsections 5.3 and 5.4.

Consistent with the models considered above in this section, these cases will be considered under the assumption that the regulator observes no ex post measure of performance.[33] The price and the payment specified in the regulatory policy can thus depend only on the report of the firm. The case of observable performance is considered in Section 5.

[33] If the actions of managers were perfectly observable, the manager can be forced to serve the interest of owners, since otherwise he can be replaced with a manager who will do so. In that case, the manager will maximize the profit of the firm as in the models considered above.

4.6.1. *Effort in a managerial model*

In the managerial model the firm is assumed to be operated by a risk neutral manager, who contributes effort a to reduce cost and in doing so incurs a disutility $\psi(a)$ of effort which the regulator does not take into account in its welfare function. The disutility is assumed to be strictly increasing and strictly convex with $\psi(0) = 0$. In the context of the model considered in the previous subsections, suppose that the marginal cost is $c(\theta, a)$, where $c_a < 0$ and $c_\theta > 0$. Assuming that the manager is risk neutral, his utility $V(\hat{\theta}, a; \theta)$ is[34]

$$V(\hat{\theta}, a; \theta) \equiv \pi(\hat{\theta}, a; \theta) - \psi(a) \equiv p(\hat{\theta})Q(p(\hat{\theta})) + T(\hat{\theta})$$
$$-c(\theta, a)Q(p(\hat{\theta})) - K - \psi(a), \tag{4.23}$$

so given a regulatory policy $(p(\theta), T(\theta))$, the manager will choose his effort response function $a(\hat{\theta}; \theta)$ to satisfy the first-order condition:

$$-c_a(\theta, a(\hat{\theta}; \theta))Q(p(\hat{\theta})) - \psi'(a(\hat{\theta}; \theta)) = 0. \tag{4.24}$$

Letting $a(\theta) \equiv a(\theta; \theta)$, the fixed charges function $T(\theta)$ that locally implements a price function $p(\theta)$ is

$$T(\theta) = -p(\theta)Q(p(\theta)) + c(\theta, a(\theta))Q(p(\theta)) + K$$
$$+\int_{\theta}^{\theta^+} c_\theta(\theta^0, a(\theta^0))Q(p(\theta^0))\,\mathrm{d}\theta^0 + \psi(a(\theta)). \tag{4.25}$$

Substituting $T(\hat{\theta})$ from (4.25) into (4.23) and maximizing $V(\hat{\theta}, a; \theta)$ with respect to $\hat{\theta}$ and a, assuming that $a(\theta)$ and $p(\theta)$ are differentiable, indicates that the maximum is attained (locally) at $\hat{\theta} = \theta$ and $a(\hat{\theta}, \theta) = a(\theta)$.[35] Then, (4.24) implies that the effort $a(\theta)$ is efficient given the quantity $Q(p(\theta))$. Using the methodology developed in the previous section, the optimal price is

$$p(\theta) = c(\theta, a(\theta)) + (1 - \alpha)\frac{F(\theta)}{f(\theta)}c_\theta(\theta, a(\theta)),$$

[34] To simplify the notation, the compensation of the manager is assumed to equal the profit of the firm. The manager thus may be viewed as an entrepreneur.

[35] If $p(\theta)$ is nondecreasing in θ, the local second-order condition for the report $\hat{\theta}$ is satisfied.

For example, if $c(\theta, a) = \theta\bar{c}(a)$, the price is

$$p(\theta) = \left(\theta + (1-\alpha)\frac{F(\theta)}{f(\theta)}\right)\bar{c}(a(\theta)) = y_\alpha(\theta)\bar{c}(a(\theta)).$$

The choice of effort in a managerial model in which there is no ex post observable is thus efficient given the quantity produced, and the price is distorted from marginal cost only as a result of the marginal information rents associated with the private information of the firm. That is, there is no moral hazard problem when there is no ex post observable and the manager is risk neutral.

4.6.2. The choice of technology and factor inputs for a value-maximizing firm

Consider the choice of factor inputs given a production function $G(\kappa, L, \theta)$, where κ and L are capital and labor inputs, respectively. A value-maximizing firm will choose inputs to maximize its profits, and since the firm must satisfy all demand at the price $p(\hat{\theta})$, those inputs will be a function of θ and $\hat{\theta}$ and satisfy:

$$Q(p(\hat{\theta})) = G(\kappa, L, \theta).$$

Letting $L(q, \kappa, \theta)$ denote the labor requirements function, profit is

$$\pi(\hat{\theta}, \kappa; \theta) = p(\hat{\theta})Q(p(\hat{\theta})) + T(\hat{\theta}) - r\kappa - wL(Q(p(\hat{\theta}), \kappa, \theta).$$

The firm will choose its capital input $\kappa(\hat{\theta}; \theta)$ to satisfy:

$$L_\kappa(Q(p(\hat{\theta})), \kappa(\hat{\theta}; \theta), \theta) = -\frac{r}{w},$$

which is the efficient input given the quantity produced. Proceeding as above, the optimal price satisfies:

$$p(\theta) = wL_Q + w(1-\alpha)L_{Q\theta}\frac{F(\theta)}{f(\theta)},$$

and the fixed charges function $T(\theta)$ satisfies (4.11). If θ represents an inefficiency parameter such that the labor requirements function is

$$L = \theta\bar{L}(q, \kappa), \tag{4.26}$$

then the price is

$$p(\theta) = w\left[\theta + (1-\alpha)\frac{F(\theta)}{f(\theta)}\right]\bar{L}_Q(Q(p(\theta)), \kappa(\theta))$$

$$= wy_\alpha(\theta)\bar{L}_Q(Q(p(\theta)), \kappa(\theta)),$$

where $\kappa(\theta) \equiv \kappa(\theta; \theta)$. The price is thus based on the efficient input choices. That is, if the regulator could choose the capital and labor inputs as a function of θ, its choices would be the same as those chosen by the firm. The choice of technology or factor inputs thus does not bias the pricing rule or the efficiency of the regulatory mechanism when there is no ex post observable.

4.7. *A regulated factor input and the Averch–Johnson model*

If the regulator were able to observe a factor input, it could not only base the pricing policy on the report of the firm but it could also specify the input as a function of the report. Besanko (1984) notes that regulators of public utilities have the authority to approve major capital investments of the firms they regulate. He thus considers the case in which the regulator can regulate the price and the observable capital stock of the firm and demonstrates that the resulting regulatory policy has a form analogous to the exogenously-specified regulatory policy in the Averch–Johnson model. In his formulation the regulator is not restricted to choose a policy from the class of rate-of-return policies but instead may choose any relationship between price, and hence profit, and the capital stock of the firm.[36] Since the capital stock chosen by the firm is a function of θ, the regulatory policy can be determined using the method of Subsection 4.2 by choosing functions $p(\theta)$ and $\kappa(\theta)$, and then expressing p as a function of κ. His model specifies a technology of the form in (4.26) and specifies the regulator's objective as the maximization of expected consumer surplus. Besanko demonstrates that for the quantity produced the optimal regulatory policy induces the firm to overcapitalize relative to the efficient capital–labor ratio.[37] The regulator chooses to induce the firm to produce inefficiently in this manner in order to reduce the information rents of the firm.

[36] In Besanko's model, the regulator is assumed to use only a unit price rather than a two-part pricing policy.
[37] As demonstrated in Subsection 4.6.2, the regulator can induce an efficient choice of technology by regulating only the price, but the sacrifice in technical efficiency is warranted by the resulting reduction in information rents.

The optimal regulatory policy may be interpreted in terms of rate-of-return regulation by forming the ratio of profit $\pi(\theta)$ to the capital $\kappa(\theta)$.[38] The resulting rate of return is a decreasing function of the capital employed, which is a property proposed by Klevorick (1966) who labeled it a "graduated allowed rate-of-return" policy. Although the mechanism characterized by Besanko has the features of rate-of-return regulation, it is an endogenous response by the regulator to the private information of the firm when the regulator has the authority to regulate the capital stock. This then provides a prediction of the form of the Averch–Johnson model, but in this case the regulatory mechanism is derived endogenously rather than assumed as a description of practice.

5. Observable performance

The above models involve adverse selection resulting from an asymmetry of information between the regulator and the firm. A feature of these models is that the regulatory mechanism is based only on a report by the firm or equivalently on the quantity that the firm selects to produce given the mechanism offered by the regulator. More realistically, the regulator may be able to observe the actual performance of the firm, or some ex post monitor of performance, and use that information to improve the efficiency of the regulatory mechanism. If there is an observable and verifiable ex post monitor of performance, the mechanism can be based both on an ex ante report and on the ex post monitor. This section extends the above mechanisms to incorporate monitors of performance to improve the efficiency of the self-selection. Basing the regulatory policy on an ex post monitor induces a moral hazard problem if the firm takes an action unobservable by the regulator. As indicated in Subsection 4.6, the regulator can avoid the moral hazard problem by ignoring the observable and basing the regulatory policy only on the report of the firm. The regulator may prefer to induce a moral hazard problem, however, if the efficiency of the mechanism is improved by reducing information rents.

5.1. The ex post observation of private information

As a first step in the development of mechanisms based on observable performance, consider the special case in which the regulator can perfectly observe at the end of the period the actual marginal cost the firm incurs. Since the price must be set before the cost is incurred, the price can only be a function of the

[38]The profit is a decreasing function of θ, but the capital stock may not be monotone in θ.

report, but the regulator can base the fixed charges T on both the report and the actual marginal cost. When cost involves no randomness, any report $\hat{\theta}$ above the marginal cost θ will be detected by the regulator unless the firm creates waste or goldplating ω to "verify" its report. If the regulator is able to observe the sum $\theta + \omega$ and can impose a penalty if $(\theta + \omega) \neq \hat{\theta}$, a sufficiently large penalty would prevent the firm from choosing a report $\hat{\theta}$ that differs from the actual marginal cost $(\theta + \omega)$ it will incur.[39] Thus, the price $p(\hat{\theta})$ is a function only of $\hat{\theta}$, and the fixed charges are a function $T(\hat{\theta}, \theta_\omega)$ of both $\hat{\theta}$ and the observable $\theta_\omega = \theta + \omega$. The profit $\pi(\hat{\theta}, \omega; \theta)$ is thus

$$\pi(\hat{\theta}, \omega; \theta) = p(\hat{\theta})Q(p(\hat{\theta})) - (\theta + \omega)Q(p(\hat{\theta})) - K + T(\hat{\theta}, \theta_\omega). \tag{5.1}$$

An optimal mechanism in this case is $p(\hat{\theta}) = \hat{\theta}$ and

$$\begin{aligned} T(\hat{\theta}, \theta_\omega) = {} & \int_{\hat{\theta}}^{\theta^+} Q(p(\theta^0))\,\mathrm{d}\theta^0 - \int_{\theta_\omega}^{\theta^+} Q(p(\theta^0))\,\mathrm{d}\theta^0 \\ & - p(\hat{\theta})Q(p(\hat{\theta})) + \hat{\theta}Q(p(\hat{\theta})) + K. \end{aligned} \tag{5.2}$$

Given this mechanism, $\omega = 0$ is optimal, and

$$\pi(\hat{\theta}, \omega; \theta) = 0, \quad \forall \theta \in [\theta^-, \theta^+].$$

The mechanism is incentive compatible, so the firm has no incentive to misreport its marginal cost or to waste. Consequently, if the regulator can perfectly observe the expenditures of the firm, first-best efficiency is attainable.

This result is not robust, however. For example, suppose that the actual marginal cost depends on a random variable. In this case the above mechanism cannot be implemented, since the firm cannot guarantee that its actual cost equals its report. In addition to uncertainty affecting costs, the regulator may only be able to observe a noisy monitor of costs, which will also preclude implementing the first-best policy. The following subsections address the mechanism design problem when these limitations are present. The first case considered in Subsection 5.2 is Baron and Besanko's (1984a) extension of the Baron and Myerson mechanism to the case in which the regulator can conduct a costly audit of the actual cost of the firm. The second case considered in Subsection 5.3 is due to Laffont and Tirole (1986) and involves a costless monitor and both an adverse selection problem and a moral hazard problem. The third case considered in Subsection 5.4 is an extension of the Laffont and Tirole mechanism to the case of a managerial model with risk aversion.

[39] The penalty will not be formally incorporated into the model but is assumed to be sufficiently high that it forces the firm to choose ω such that $\theta + \omega$ equals $\hat{\theta}$.

5.2. Auditing of performance

Regulators of public utilities generally have the authority to audit the costs incurred by the firm and may have the authority to impose penalties if the realized costs differ from anticipated costs. Auditing is costly, however, since it involves investigation of costs in a manner sufficiently detailed that they would be verifiable to an independent party such as a court. Baron and Besanko (1984a) extend the adverse selection model of Section 4 to the case in which the regulator has the authority to audit and to impose a penalty $N(\hat{\theta}, C)$ based both on the information $\hat{\theta}$ the firm originally reported to the regulator and on the total cost C incurred by the firm once production has been completed. The price must be set prior to the commencement of production, so price can only be a function of $\hat{\theta}$. The observation of C, however, is useful to the regulator because it permits an inference about the true parameter θ, and that inference can be used to reduce the information rents of the firm. The optimal regulatory mechanism can be determined in a manner analogous to that used in Section 4 with the complication that the imposition of the penalty may cause the individual rationality constraint to be binding for some $\theta < \theta^+$.

The observable cost C incurred by the firm is assumed to be the realization of a random variable $\tilde{C}$ given by

$$\tilde{C} = \tilde{c}q + K,$$

where $\tilde{c}$ is a random marginal cost that depends on the private information θ of the firm. The random variable $\tilde{c}$ induces a density function $h(C|\theta)$ on total cost. The observation of total cost C is thus only imperfectly informative about θ. The penalty $N(\hat{\theta}, C)$ is assumed to be non-negative and bounded above by a constant $\bar{N}$. The bound $\bar{N}$ is to be interpreted as a statutory limitation on the authority of the regulator to impose a sanction. In the context of public utility regulation, a penalty could correspond to the regulator disallowing a cost from inclusion in the revenue requirement.

Auditing is assumed to be costly with the cost A borne by the regulator. Because of this cost, the regulator may prefer not to audit all possible types of the firm and thus will choose whether to audit based on the information the firm reports at the time the price is set. The regulator is thus modeled as choosing the probability $\rho(\hat{\theta})$ that it will audit when the firm reports $\hat{\theta}$. The regulatory mechanism M^A is thus[40]

$$M^A = \{(p(\theta), T(\theta), \rho(\theta), N(\theta, C)), \theta \in [\theta^-, \theta^+]\}.$$

[40] Baron (1985c) applies this approach to the regulation of pollution emitted by a firm that has private information about its abatement costs.

The expected penalty $\bar{N}(\hat{\theta}, \theta)$ faced by the firm when it reports $\hat{\theta}$ is then

$$\bar{N}(\hat{\theta}, \theta) = \rho(\hat{\theta}) \int_{\Gamma} N(\hat{\theta}, C) h(C|\theta) \, \mathrm{d}C,$$

where Γ is the support of C which is assumed to be independent of θ. The expected penalty $\bar{N}(\hat{\theta}, \theta)$ thus depends on both the report and the true parameter θ, so the information rents of the firm are affected by the auditing policy $\rho(\theta)$ and the penalty $N(\theta, C)$.

The optimal auditing strategy involves auditing if the firm reports a sufficiently high $\hat{\theta}$ and imposing the maximum allowable penalty $\bar{N}$ if the realized cost is lower than anticipated. More formally, if the density function $h(C|\theta)$ is continuously differentiable and satisfies the monotone–likelihood ratio property,[41] the optimal penalty function is

$$N(\hat{\theta}, C) = \begin{cases} \bar{N}, & \text{if } C < Z(\hat{\theta}), \\ 0, & \text{if } C \geq Z(\hat{\theta}), \end{cases} \tag{5.3}$$

where $Z(\cdot)$ is the inverse of the maximum likelihood estimator $\theta^*(C)$ of θ. For example, if $h(C|\theta)$ is normal and θ is the mean of the random marginal cost $\tilde{c}$, then the penalty is imposed if the observed cost is less than $Z(\hat{\theta}) = \hat{\theta}Q(p(\hat{\theta})) + K$. The maximum penalty is imposed because the regulator's objective function is linear in $N(\hat{\theta}, C)$. Although the firm bears the expected penalty, the regulator must increase $T(\theta)$ to cover the expected penalty, since the firm will participate only if its expected or ex ante profit is nonnegative.

An important feature of this policy is that the penalty in (5.3) is imposed for low, rather than high, realized costs. To understand the rationale for this, recall that the firm has a natural incentive to overstate its cost parameter θ. A low realized cost is evidence that the firm may have overstated its parameter, so the regulator imposes a penalty in that event. Thus, by overstating its parameter, the firm increases the probability that the realized cost will be below the cost $(\hat{\theta}Q(p(\hat{\theta})) + K)$ anticipated for the report it makes. The regulator thus can discourage the firm from overstating its cost parameter by announcing that a penalty will be imposed if the realized cost is lower than expected. Of course, the regulatory policy is incentive compatible, so the firm will actually report truthfully, and the regulator knows this. Once the firm has reported $\hat{\theta}$, the regulator thus prefers to rescind its decision to audit to avoid the auditing cost. The regulator, however, must credibly commit to audit and to impose the penalty if

[41]The density $h(C|\theta)$ satisfies the monotone-likelihood-ratio property if for $\theta^1 > \theta^2$, the ratio $h(C|\theta^1)/h(C|\theta^2)$ is monotone increasing in C. This property is satisfied for a number of commonly-used distributions including the normal.

realized cost is below $Z(\hat{\theta})$ even though it knows that the firm will report truthfully, since if the firm recognized that the regulator might not audit, it would lose its deterrence value. Consequently, this model requires that the regulator be able to commit credibly to the auditing policy.

Baron and Besanko further characterize the optimal auditing and pricing policy for the case in which $\tilde{c}$ is normally distributed with variance σ^2 and mean $\bar{c}(\theta)$. The mean is assumed to be a differentiable, nondecreasing, convex function of θ. The optimal auditing strategy is then to audit if $\hat{\theta}$ is at least as great as θ_A defined by

$$(1-\alpha)\frac{F(\theta_A)}{f(\theta_A)}\frac{\bar{N}}{\sqrt{2\pi}\,\sigma}\bar{c}'(\theta_A) \equiv A. \tag{5.4}$$

The optimal auditing policy is thus a three-stage process. First, the regulator authorizes an audit if the reported $\hat{\theta}$ is greater than θ_A. Second, if an audit is authorized, the realized cost C is compared to the critical point $Z(\hat{\theta})$. Third, if the realized cost is less than the critical point, the maximum penalty is imposed. Otherwise no penalty is imposed.

To interpret the set of reports $\hat{\theta}$ on which the regulator will audit, consider the case in which the individual rationality constraint is binding only at $\theta = \theta^+$. In that case, θ_A has the following properties:

(1) $\partial\theta_A/\partial A > 0$,
(2) $\partial\theta_A/\partial\sigma > 0$,
(3) $\partial\theta_A/\partial\bar{N} < 0$,
(4) $\partial\theta_A/\partial\alpha > 0$.

(1) The greater is the cost of auditing, the smaller is the set on which the regulator will audit, as would be expected.

(2) That set is also decreasing in the standard deviation σ of cost, since the noisier is the cost signal the less valuable is the observation for the inference about θ.

(3) The greater is the maximum penalty $\bar{N}$ that can be imposed, the more effective is the deterrent, so auditing becomes more desirable and the regulator audits over a larger set. In the limit, the first-best outcome can be approximated arbitrarily closely as $\bar{N}$ increases.

(4) The greater is the weight α on the firm's profit in the regulator's welfare function, the smaller is the set over which the regulator will audit. This results because the welfare loss associated with the firm's information rents is reduced as α increases.

An important property of the pricing policy when the regulator can audit is that the price function is independent of the auditing policy if the individual rationality constraints in (4.2) are binding only at the upper bound $\theta = \theta^+$. In this case, the price is $p(\theta) = y_\alpha(\theta)$ as in the model in which there is no auditing. If the expected penalty causes the individual rationality constraint to be binding for some θ less than θ^+, the regulator does not have to distort price from marginal production cost as much as called for by (4.19), because the individual rationality constraint works to reduce the marginal information rents. The price is then equal to $y_\alpha(\theta)$ less an amount equal to the sum of the multipliers on the individual rationality constraints in (4.2) for lower θ. The resulting price can even be below the marginal production cost. Because auditing reduces the information rents, the profit $\pi(\theta)$ of the firm is lower when the regulator can audit than when it does not have that authority.

5.3. Costlessly observable ex post cost and moral hazard

Laffont and Tirole (1986) consider a managerial model in which ex post the regulator is able to observe the cost of a firm that has private information θ and takes an unobservable effort decision a. In their model, the cost C incurred by the firm is observable and is specified as

$$C = (\theta - a)q + K + \sqrt{\nu}\,\varepsilon, \tag{5.5}$$

where ε is the realization of a random variable $\tilde{\varepsilon}$ and ν is a parameter that scales the randomness of cost. The manager incurs a disutility $\psi(a)$ of effort, where $\psi(a)$ is a strictly increasing, convex function with $\psi(0) = 0$. Since the regulator does not know θ and is unable to observe effort, even perfect observation of cost does not eliminate the moral hazard problem. The regulator thus faces both adverse selection and moral hazard problems. An important feature of the specification of the cost function in (5.5) is that the marginal rate of substitution of effort for type is independent of the quantity.[42]

Since C is observable, the fixed charges can be based on both $\hat{\theta}$ and C. The price, however, must be set, and the quantity must be produced, before the cost C can be observed, so price can only be a function of the report $\hat{\theta}$.[43] Laffont and Tirole specify their mechanism in terms of the quantity q the firm chooses to produce, given a fixed-charge schedule $T^*(q, c)$ offered by the regulator. They show that if the manager of the firm is risk neutral and $F(\theta)/f(\theta)$ is nondecreasing, the optimal regulatory policy can be implemented using a mechanism composed of a fixed charge schedule that is linear in the observed cost and

[42] This feature allows Laffont and Tirole to establish global incentive compatibility for their mechanism.

[43] A derivation of the Laffont and Tirole mechanism is presented in Appendix B.

nonlinear in the quantity. The fixed charges function $T^*(q, C)$ has the form:

$$T^*(q, C) = b(q) + C + m(q)(\bar{C}(q) - C), \tag{5.6}$$

where $m(q) > 0$ and $\bar{C}(q)$ is a cost target for a firm that produces a quantity q. The firm thus receives the sum of a fixed payment $b(q)$, reimbursement of its cost C, and a bonus for any cost "underrun" ($C < \bar{C}(q)$) or a penalty for any cost "overrun" ($C > \bar{C}(q)$). Since the firm is risk neutral, the moral hazard problem could be eliminated by a fixed-price contract ($m(q) = 1$) in which the firm is paid a lump sum for the quantity delivered; that is, with fixed charges independent of the monitored cost. With a fixed-price contract, however, the regulator bears information costs given in (4.8).[44] Those costs can be reduced by basing the fixed charges on observed costs, and the regulator does so by reimbursing the firm for some but not all of its cost in (5.6).

Laffont and Tirole show that the fraction $(1 - m(q))$ of the cost reimbursed is less than one, so the manager has an incentive to reduce costs by increasing his effort. The fraction of cost reimbursed decreases with output, because with higher output the marginal product of effort increases allowing the function $m(q)$ to be scaled down. That is, for lower θ the greater output naturally mitigates the moral hazard problem by inducing greater effort, so the regulator can use the incentive features of $T(q, C)$ to reduce the information rents. The regulator does so by reimbursing more of the cost. Laffont and Tirole show that, as the regulator's information about θ becomes more precise, the contract in (5.6) approaches a fixed-price contract; that is, the fraction $m(q)$ approaches one. This is the standard result in moral hazard models that with risk-neutral principal the optimal contract involves a lump-sum payment $b(q)$ which induces the agent to expend the first-best level of effort.

In the Baron–Myerson model, the regulator distorts price above marginal cost to reduce the information rents the firm earns. In the Laffont and Tirole model in which cost is observable, the regulator has the same incentive, but the regulator also faces a moral hazard problem. The asymmetric information problem provides an incentive for the regulator to distort price above marginal cost to reduce the information costs. The incentive to exert effort, however, is greater the greater is the quantity the firm produces, since from (5.5) the marginal product of effort is an increasing function of the quantity. The regulator thus has an incentive to respond to the moral hazard problem by distorting price below marginal cost to increase the marginal product. Because the marginal rate of substitution of effort for type is constant, the regulator's incentive to respond to the moral hazard problem is exactly offset by the incentive to respond to the asymmetric informa-

[44] The contract in the Baron–Myerson model is a fixed-price contract.

tion problem.[45] That is, for the case in which the firm is risk neutral, the optimal price satisfies:

$$p(\theta) = \theta - a(\theta), \tag{5.7}$$

where $a(\theta)$ is the firm's effort response function. The marginal information costs to the regulator are thus exactly offset by the marginal gain from inducing more effort, so price is set equal to marginal cost.

Although the mechanism specifies a price equal to marginal cost, the marginal cost is not first-best because the effort $a(\theta)$ of the firm is less than the first-best effort. The effort is also less than the effort that the regulator prefers given the informational asymmetry and the unobservability of effort. That is, if it were possible for a third party to subsidize the effort of the firm, the regulator's welfare function W would be increased. Since effort is too low, the marginal cost is greater than the first-best marginal cost and greater than the marginal cost the regulator prefers given the asymmetric information and moral hazard problems. The higher marginal cost implies that the quantity produced is below the first-best quantity.

Picard (1987) extends the Laffont–Tirole model, specialized for the case of an indivisible project ($q = 1$), by weakening the requirement that the ratio $F(\theta)/f(\theta)$ be nondecreasing.[46] Laffont and Tirole demonstrate that if $F(\theta)/f(\theta)$ is nondecreasing, a linear function $T^*(q, C)$ is optimal,[47] and Picard shows that if $\theta + F(\theta)/f(\theta)$ is increasing, a quadratic payment function can be used to implement the optimal regulatory policy. Even with no assumption on $F(\theta)/f(\theta)$, an efficient mechanism exists if $a(\theta) - \theta$ is nonincreasing, since a quadratic payment function can be used to approximate arbitrarily closely any efficient mechanism. The welfare in these cases is the same independent of the distribution of θ.

5.4. Cost observability and monitoring for a risk-averse firm

Baron and Besanko (1987b) consider a managerial model similar to that of Laffont and Tirole but focus on the case in which the firm is risk averse and the cost of the firm is only imperfectly observable because of noise in the monitor of cost.

[45]That is, the multiplier on the moral hazard constraint equals the negative of the multiplier on the derivative of the state variable $\pi(\theta)$. This is demonstrated in Appendix B.

[46]Surplus is taken to be $a - \theta$.

[47]If the regulator has a quantity decision, Laffont and Tirole's assumption that $F(\theta)/f(\theta)$ is nondecreasing appears to be necessary for a mechanism to be implementable with a linear payment function.

The preferences of the manager are expressed as

$$U(\pi) - \psi(a), \tag{5.8}$$

where U is a strictly increasing, concave utility function. In addition to the consideration in the Laffont and Tirole model, risk aversion creates an incentive for risk-sharing to reduce the risk premium the firm requires to participate in the regulatory relationship. The regulatory policy thus involves tradeoffs among responses to risk-sharing, asymmetric information, and moral hazard problems.

Baron and Besanko distinguish between randomness in the costs of the firm and noisiness of the monitor of costs. The random variable $\tilde{\varepsilon}$ in (5.5) is interpreted as randomness of costs due to uncertain factor prices, technology shocks, etc. In addition, even though the true cost C is observed by the firm, the regulator may only be able to observe the realization z of a monitor $\tilde{z}$ of cost. The realization z is assumed to be verifiable, so the regulatory policy can be based on the monitor. As in the model in the previous two subsections, the price can only be a function of the report $\hat{\theta}$, but the fixed charges $T(\hat{\theta}, z)$ can also be based on the monitor.

The monitor $\tilde{z}$ may be a noisy signal of cost due to imperfections in accounting systems or in measurement, so $\tilde{z}$ is modeled as

$$\tilde{z} = \tilde{C} + \sqrt{\xi}\,\tilde{\eta},$$

where $\tilde{\eta}$ denotes the noise in the monitor and ξ is a parameter that scales the noisiness. It is convenient to work with the conditional distribution of C and the unconditional distribution of z, which, for $\tilde{\varepsilon}$ and $\tilde{\eta}$ independent normal random variables with means of zero and variances of one, are given by

$$g(C|z) = N\left((c(\theta, a)q + K)\frac{\xi}{\xi + \nu} + z\frac{\nu}{\xi + \nu}, \frac{\xi\nu}{\xi + \nu}\right)$$

and

$$h(z) = N(c(\theta, a)q + K, \xi + \nu).$$

Here, $N(\mu, \sigma^2)$ denotes the normal density function with mean μ and variance σ^2, and $c(\theta, a)$ denotes the mean of marginal cost, which in the Laffont and Tirole model is specified as $c(\theta, a) = \theta - a$.[48] If $\nu = 0$, the cost of the firm is

[48] The equilibrium in this model can be determined using an extension of the analysis presented in Appendix B.

deterministic, but the noise in the monitor impairs the inference the regulator can draw about the private information θ and the effort a of the manager. If $\xi = 0$, the regulator observes cost perfectly, but it is the randomness of cost that impairs the inference about θ and a.

To indicate the distinction between the randomness of cost and the noisiness of the monitor, consider the two extreme cases: (1) a deterministic cost and a noisy monitor ($\xi > 0$, $\nu = 0$), and (2) a random cost and perfect monitor ($\xi = 0$, $\nu > 0$). In the first case, the firm bears no risk directly, but since the monitor is noisy, the regulator will impose risk on the firm if it bases the fixed charges on the monitor. In the second case, the firm bears risk directly, and the regulator can use the fixed charges to relieve the firm of a portion of that risk. In both cases, the fixed charges will be used to affect the allocation of risk, to provide incentives for the manager to exert effort, and to reduce the information rents that the manager earns.

At one extreme, in the case of a deterministic cost and a noisy monitor, the regulator could make the fixed charges independent of the monitor of cost (a fixed-price contract), which would provide the most efficient risk bearing and the strongest incentive to exert effort. As in the Baron and Besanko (1984a) model of auditing considered in Subsection 5.2, however, the regulator has an incentive to base the fixed charges on the monitor as a means of reducing the rents the firm earns on its private information.[49] The regulator thus may prefer to worsen risk-sharing and moral hazard if the marginal costs of those problems are less than the welfare consequences of the marginal reduction in the information rents.[50] At the other extreme, if the cost of the firm is random and the monitor is deterministic, basing the fixed charges on the monitor can relieve the firm of risk, but improved risk-sharing is achieved only at the expense of diminished incentives for effort. The optimal regulatory policy in both cases involves basing the fixed charges on the monitor, so there are tradeoffs among the three problems that affect the form of $T(\hat{\theta}, z)$. In all cases, however, the equilibrium provides the same incentives from the manager's perspective. For example, the incentive for effort always depends on the share of the actual or monitored cost borne by the firm.

The extent to which the fixed charges vary with the monitor depends on the relative costs of responding to the moral hazard and adverse selection problems. Those marginal costs are measured by the multipliers on the moral hazard

[49] The gain from reducing the information rents is both from the "welfare loss" $(1 - \alpha)$ on any transfer between the firm and consumers and from the reduction in the marginal information costs which allows a lower price and a greater quantity to be produced.

[50] If effort and type are complements, an increase in effort increases the rate at which the marginal cost increases in θ, and this increases the information rents. In this case, the regulator may prefer that the effort of the firm be taxed rather than subsidized.

constraint analogous to (B.4) and on the incentive compatibility constraints analogous to (B.3) as developed in Appendix B. As indicated in the context of the Laffont and Tirole model, if the firm is risk neutral the multipliers have offsetting values. If the firm is risk averse, however, the mulipliers are not equal in general.

To illustrate the effect of risk aversion, consider the case in which the utility function $U(\pi)$ in (5.8) exhibits constant absolute risk aversion. In this case, the first-best regulatory policy, that which the regulator would implement if it knew θ and could observe a, specifies a fixed charges function that reimburses the firm for a proportion $\nu/(\nu + \xi)$ of the monitored cost. Intuitively, when θ is private information and a is not observable, reimbursing a higher proportion of the monitored cost reduces the cost of the adverse selection problem and increases the cost of the moral hazard problem. If, when evaluated at the first-best reimbursement proportion, the marginal cost of responding to the adverse selection problem exceeds the marginal cost of responding to the moral hazard problem, a higher proportion of monitored costs is reimbursed in the equilibrium regulatory mechanism. The price $p(\theta)$ is then greater than the marginal production cost $c(\theta, a(\theta))$ as in the adverse selection model of Section 4.[51] If the marginal benefit from responding to the adverse selection problem is less than the marginal cost of the moral hazard problem, the equilibrium regulatory policy reimburses a smaller proportion of the monitored cost in order to induce more effort. The price in this case is set below the marginal production cost in order to stimulate effort, since the marginal product of effort is proportional to the quantity produced.

6. Dynamic models

6.1. Introduction

The above mechanisms are static in the sense that they involve only one production opportunity. When there is a sequence of production decisions, information may become available over time as uncertainty is resolved and technology and demand evolve. The regulator then may wish to design the mechanism to be responsive to the evolution of information and performance. Responsiveness, however, allows opportunistic behavior by the regulator and the firm, and as Williamson (1975, 1983) has argued, opportunism can result in

[51] If the equilibrium quantity is less than the first-best quantity, the equilibrium effort is less than the first-best effort. In the special case in which the preferences of the firm have a mean–variance representation, the quantity produced and the effort are unambiguously less than the first-best quantity and effort, respectively. See Baron and Besanko (1988).

ex ante inefficiences. For example, if the choice of a pricing policy from the mechanism offered by the regulator in the first period reveals information about the firm's type, the regulator will have an ex post incentive to act opportunistically by fully exploiting that information in future periods. The firm will anticipate this opportunistic behavior and thus will revise its strategy for the first period. As will be demonstrated below in Subsections 6.3 and 6.4, the resulting equilibrium will be ex ante inefficient. Efficiency can be improved only by developing means to limit the opportunism. This requires some means of committing not to act opportunistically when doing so would result in ex ante inefficiency.

The efficiency of the mechanisms used to deal with the dynamics of regulatory relationships thus depends importantly on the ability of the parties to commit to strategies. The significance of commitment has been demonstrated in a number of works,[52] and this section deals with three principal cases. In the first case considered in Subsection 6.2, the regulator is assumed to have the ability to commit credibly to a multiperiod mechanism that will govern the regulatory relationship for the duration of the (finite) horizon. In particular, the regulator can commit to use in any way it chooses the information that will be generated in the implementation of the mechanism. For example, at one extreme it can commit not to use the information it observes, and at the other extreme it can commit to a policy that is fully responsive to that information. In the second case considered in Subsection 6.3, the regulator cannot commit to future policies, so the only recourse of the regulator is to choose a mechanism at the beginning of each period. The third case considered in Subsection 6.4 is intermediate and allows the regulator and the firm to agree to an institutional arrangement in which the regulator, although unable to commit credibly to a multiperiod mechanism, is required to treat the firm "fairly". In exchange, the firm agrees not to quit the regulatory relationship as long as it is treated fairly. That is, in the first two cases, the firm is allowed to decide in each period whether it wishes to participate in the regulatory relationship, whereas in the third case the firm relinquishes its right to quit the relationship in exchange for assurance that it will be treated fairly.

6.2. Commitment to a multiperiod mechanism

6.2.1. Extension of the basic model

The model considered in this subsection is an extension, developed in Baron and Besanko (1984b), of the model in Section 4 in which the firm has private

[52] In the macroeconomics literature, the issue of the optimality of policies in the absence of commitment is referred to as "dynamic consistency" in the terminology introduced by Kydland and Prescott (1977). Roberts (1982, 1984) and Crawford (1988) have also examined the differences between long-term contracts in cases in which commitment is and is not possible.

information about its marginal cost and the regulatory mechanism is a set of pricing policies. The regulator is assumed to have the ability to commit to a mechanism for the duration of the regulatory relationship, so it can specify how the price in each period responds to information that becomes available during execution of the selected regulatory policy. In addition, commitment on the part of the regulator means that it can commit to preclude the firm from operating in future periods if the firm chooses not to participate in a previous period.

The complication in a dynamic model is that the private information of the firm may evolve over time in a manner that is observable only to the firm. Suppose that prior to the choice of the regulatory mechanism the firm knows the marginal cost θ_1 it will have in period 1, and the regulator's prior information is represented by a density function $f_1(\theta_1)$. At the beginning of each subsequent period i, the firm privately observes its marginal cost θ_i, which is given by a function $\theta_i = \theta_i(\theta_{i-1}, \varepsilon) \in [\theta_i^-, \theta_i^+]$, where ε is the realization of a random variable $\tilde{\varepsilon}$.[53,54] The function $\theta_i(\theta_{i-1}, \varepsilon)$ is common knowledge, but only the firm observes the realized θ_i. The distribution function of θ_i will be denoted by $F_i(\theta_i|\theta_{i-1})$ and the density function by $f_i(\theta_i|\theta_{i-1})$. The marginal cost θ_i is assumed to be a nondecreasing function of θ_{i-1}, so an increase in θ_{i-1} shifts the distribution function $F_i(\theta_i|\theta_{i-1})$ downward or $\partial F_i(\theta_i|\theta_{i-1})/\partial\theta_{i-1} \leq 0$ for all θ_i for all θ_{i-1}.

Since the firm has private information at the beginning of each period, the regulator faces an adverse selection problem in each period with the complication that the report made in one period provides information about the marginal cost in the next period. The self-selection mechanism designed for each period thus must take into account how the revelation of information in that period influences the rents that the firm earns on the information it will privately observe in the future. This then affects the strategy the firm will employ in selecting a policy from the mechanism offered by the regulator.

A mechanism with commitment specifies at the beginning of the regulatory relationship the price $p_i(\theta_1, \ldots, \theta_i)$ and the fixed charges $T_i(\theta_1, \ldots, \theta_i)$ in each period i.[55] A mechanism M for a horizon of I periods is thus

$$M = \{(p_i(\theta_1, \ldots, \theta_i), T_i(\theta_1, \ldots, \theta_i)), i = 1, \ldots, I,$$

$$\forall \theta_i \in [\theta^-, \theta^+], i = 1, \ldots, I\}.$$

The strategy of the firm in each period is to report a type $\hat{\theta}_i$ and either to participate or to quit the regulatory relationship. The latter decision can be

[53] To avoid complicating the notation, the support $[\theta_i^-, \theta_i^+]$ is assumed not to depend on θ_{i-1}.

[54] The process that generates the marginal costs is thus Markovian.

[55] When it can do so credibly, the regulator always prefers to commit to a mechanism that will govern performance over the entire horizon of the regulatory relationship.

denoted by ϕ_i with $\phi_i = 0$ indicating that the firm quits and $\phi_i = 1$ indicating that the firm accepts the policy and produces in period i. In the model with commitment developed in this subsection, the regulator prefers to offer policies that the firm will accept, so $\phi_i = 1$, $i = 1, \ldots, I$.[56] The participation decision will thus be suppressed in the subsequent analysis.

Characterization of an equilibrium mechanism is facilitated by the revelation principle which in this case applies in a nested manner as developed in Baron and Besanko (1984b). The method of analysis and the properties of the mechanism can be fully indicated in the context of a two-period model. In the second period the regulator has observed the report $\hat{\theta}_1$, and the firm will report $\hat{\theta}_2$, so the pricing policy is a function of $(\hat{\theta}_1, \hat{\theta}_2)$. The second-period profit $\pi_2(\hat{\theta}_1, \hat{\theta}_2; \theta_2)$ is given by[57]

$$\pi_2(\hat{\theta}_1, \hat{\theta}_2; \theta_2) = \left(p_2(\hat{\theta}_1, \hat{\theta}_2) - \theta_2\right)Q\left(p_2(\hat{\theta}_1, \hat{\theta}_2)\right) + T_2(\hat{\theta}_1, \hat{\theta}_2) - K_2. \tag{6.1}$$

Incentive compatibility in period two requires that

$$\pi_2(\hat{\theta}_1; \theta_2) \equiv \pi_2(\hat{\theta}_1, \theta_2; \theta_2) \geq \pi_2(\hat{\theta}_1, \hat{\theta}_2; \theta_2),$$
$$\forall \hat{\theta}_2, \forall \theta_2 \in [\theta_2^-, \theta_2^+], \quad \forall \hat{\theta}_1 \in [\theta_1^-, \theta_1^+]. \tag{6.2}$$

Proceeding as in Section 4, a regulatory policy $(p_2(\hat{\theta}_1, \theta_2), T_2(\hat{\theta}_1, \theta_2), \theta_2 \in [\theta_2^-, \theta_2^+])$ for period two is implementable if $p_2(\hat{\theta}_1, \theta_2)$ is a nondecreasing function of θ_2 for all $\hat{\theta}_1$. The profit can then be expressed as

$$\pi_2(\hat{\theta}_1; \theta_2) = \int_{\theta_2}^{\theta_2^+} Q\left(p_2(\hat{\theta}_1, \theta_2^0)\right) \mathrm{d}\theta_2^0 + \pi_2(\hat{\theta}_1; \theta_2^+). \tag{6.3}$$

A policy that satisfies this condition will (locally) induce the firm to report its second-period marginal cost truthfully whatever is the report $\hat{\theta}_1$. The firm will participate in period two if $\pi_2(\hat{\theta}_1; \theta_2) \geq 0$, and since $\pi_2(\hat{\theta}_1; \theta_2)$ is decreasing in θ_2, this can be satisfied by setting $\pi_2(\hat{\theta}_1; \theta_2^+) = 0$.

The mechanism must also specify a period-one policy that takes into account the firm's incentive to misreport its first-period marginal cost not only to obtain a higher first-period profit but also to obtain a higher second-period profit. The

[56] This decision becomes important in Subsection 6.3 when the regulator cannot credibly commit to a mechanism to govern the duration of the regulatory relationship.

[57] A fixed cost K_i is assumed to be incurred in each period.

two-period profit $\Pi(\hat{\theta}_1; \theta_1)$ is defined by

$$\begin{aligned}\Pi(\hat{\theta}_1; \theta_1) &\equiv \pi_1(\hat{\theta}_1; \theta_1) + \beta \int_{\theta_2^-}^{\theta_2^+} \pi_2(\hat{\theta}_1; \theta_2) f_2(\theta_2 | \theta_1)\, \mathrm{d}\theta_2 \\ &= \left(p_1(\hat{\theta}_1) - \theta_1\right) Q\left(p_1(\hat{\theta}_1)\right) - K_1 \\ &\quad + T_1(\hat{\theta}_1) + \beta \int_{\theta_2^-}^{\theta_2^+} Q\left(p_2(\hat{\theta}_1, \theta_2)\right) F_2(\theta_2 | \theta_1)\, \mathrm{d}\theta_2, \end{aligned} \tag{6.4}$$

where $\beta \in [0,1]$ is the discount factor.[58] Incentive compatibility requires that

$$\Pi(\theta_1) \equiv \Pi(\theta_1; \theta_1) \geq \Pi(\hat{\theta}_1; \theta_1), \quad \forall \hat{\theta}_1, \forall \theta_1 \in [\theta_1^-, \theta_1^+]. \tag{6.5}$$

An incentive compatible period-one policy, given that the second-period policy is incentive compatible, must satisfy a local condition on profit $\Pi(\theta_1)$ analogous to (4.7) or

$$\frac{\mathrm{d}\Pi(\theta_1)}{\mathrm{d}\theta_1} = -Q(p_1(\theta_1)) + \beta \int_{\theta_2^-}^{\theta_2^+} Q(p_2(\theta_1, \theta_2)) \frac{\partial F_2(\theta_2 | \theta_1)}{\partial \theta_1} \mathrm{d}\theta_2. \tag{6.6}$$

Since $\partial F_2(\theta_2 | \theta_1)/\partial \theta_1 \leq 0$, the second term on the right-hand side of (6.6) is nonpositive. The derivative in (6.6) takes into account the effect of a variation in θ_1 both on the first-period information rents and on the second-period information rents given that second-period incentive compatibility is satisfied. The necessary condition for an incentive compatible policy in (6.6) can be integrated to obtain a condition analogous to (4.8):

$$\begin{aligned}\Pi(\theta_1) &= \Pi(\theta_1^+) + \int_{\theta_1}^{\theta_1^+} Q\left(p_1(\theta_1^0)\right) \mathrm{d}\theta_1^0 \\ &\quad - \beta \int_{\theta_1}^{\theta_1^+} \int_{\theta_2^-}^{\theta_2^+} Q\left(p_2(\theta_1^0; \theta_2)\right) \frac{\partial F_2(\theta_2 | \theta_1^0)}{\partial \theta_1} \mathrm{d}\theta_2\, \mathrm{d}\theta_1^0. \end{aligned} \tag{6.7}$$

A fixed charges function $T_1(\theta)$ specified below in (6.20) locally implements any price function $p_1(\theta)$ in the sense that the firm is made worse off by any local variation in its report from its true type. This, however, does not establish global incentive compatibility as addressed in the development of (4.15). A

[58] The beliefs of the regulator are specified as $f_2(\theta_2 | \hat{\theta}_1)$, and in equilibrium $\hat{\theta}_1 = \theta_1$, so the beliefs are correct.

sufficient condition for the policy to be globally incentive compatible is difficult to develop.

The regulator's objective function analogous to (4.18) can be derived as in Section 4 and is

$$W = \int_{\theta_1^-}^{\theta_1^+} \Bigg\{ \Bigg[\int_{p_1(\theta_1)}^{\infty} Q(p_1^0)\,\mathrm{d}p_1^0 + p_1(\theta_1)Q(p_1(\theta_1)) - y_\alpha(\theta_1)Q(p_1(\theta_1)) - K_1 \Bigg]$$
$$+ \beta \int_{\theta_2^-}^{\theta_2^+} \Bigg[\int_{p_2(\theta_1,\theta_2)}^{\infty} Q(p_2^0)\,\mathrm{d}p_2^0 + p_2(\theta_1,\theta_2)Q(p_2(\theta_1,\theta_2))$$
$$- z_\alpha(\theta_1,\theta_2)Q(p_2(\theta_1,\theta_2)) - K_2 \Bigg]$$
$$\times f_2(\theta_2|\theta_1)\,\mathrm{d}\theta_2 \Bigg\} f_1(\theta_1)\,\mathrm{d}\theta_1 - (1-\alpha)\Pi(\theta_1^+), \tag{6.8}$$

where

$$y_\alpha(\theta_1) = \theta_1 + (1-\alpha)\frac{F_1(\theta_1)}{f_1(\theta_1)} \tag{6.9}$$

and

$$z_\alpha(\theta_1,\theta_2) \equiv \theta_2 - (1-\alpha)\frac{F_1(\theta_1)}{f_1(\theta_1)}\,\frac{\partial F_2(\theta_2|\theta_1)/\partial\theta_1}{f_2(\theta_2|\theta_1)}. \tag{6.10}$$

Proceeding as in Section 4, the optimal prices satisfy:

$$p_1(\theta_1) = y_\alpha(\theta_1) \tag{6.11}$$

and

$$p_2(\theta_1,\theta_2) = z_\alpha(\theta_1,\theta_2). \tag{6.12}$$

As in the single-period model, the price in each period is set equal to the sum of the marginal production and information costs in that period. In the first period, the price is the same as in a static model because the firm has the same information advantage relative to the first period as in a static model. The regulator thus prefers to distort the price above marginal cost θ in the same manner to deal with the information advantage of the firm. The presence of future periods thus has no effect on the price in the first period.

The regulatory policy in the second period also sets the price equal to the marginal production and information costs, but in this case the marginal information cost depends on what the firm knows ex ante at the beginning of period one about its costs in the second period. For example, if the marginal cost in period two were independent of the marginal cost in period one, the firm's knowledge of θ_1 at the beginning of period one would provide no information about marginal cost in period two. The firm then can extract no information rents for period two, and hence the regulator bears no marginal information cost for period two. More formally, independence of the marginal costs implies that

$$\frac{\partial F_2(\theta_2|\theta_1)}{\partial \theta_1} = 0, \quad \forall \theta_2, \forall \theta_1,$$

so $z_\alpha(\theta_1, \theta_2) = \theta_2$, and the price in period two equals marginal production cost. Efficiency thus results in every period after the first when the θ_i are independent.

If θ_1 is informative about θ_2, then $\partial F_2(\theta_2|\theta_1)/\partial\theta_1$ is not equal to zero for all θ_2. The marginal information cost is then nonzero, and the price is distorted away from marginal production cost. If, for example, θ_1 is "fully informative" about θ_2, i.e. $\theta_2 = \theta_1$ so the marginal costs are perfectly correlated, then it can be shown that[59]

$$z_\alpha(\theta_1, \theta_2 = \theta_1) = \theta_1 + (1 - \alpha)\frac{F_1(\theta_1)}{f_1(\theta_1)} = y_\alpha(\theta_1). \tag{6.10a}$$

Consequently, when the marginal cost in the first period is fully informative about the marginal cost in the second period, the optimal regulatory mechanism involves repeating the static policy in each period. The regulator thus does not exploit in period two the information it receives in period one. It is the ability of the regulator to commit to repeat the same policy in each period that is necessary for the regulator to be able to ignore the information revealed in the first period. As will be indicated in Subsection 6.3, if the regulator is unable to commit not to exploit this information, it will act opportunistically and ex ante inefficiency will result.

If knowledge of the marginal cost in the first period is only partially informative about the second-period marginal cost, the distortion of price from marginal cost θ_2 is "between" that of the independent and the perfect correlation cases.

[59]An analogous result obtains if θ_2 is a deterministic function $\theta_2(\theta_1)$ of θ_1.

The pricing policy thus has memory. To illustrate the "informativeness" of θ_1 about θ_2, consider the following specification of second-period marginal cost:

$$\tilde{\theta}_2 = \gamma\tilde{\theta}_1 + (1-\gamma)\tilde{\varepsilon}, \quad \gamma \in [0,1], \tag{6.13}$$

where $\tilde{\theta}_1$, $\tilde{\theta}_2$, and $\tilde{\varepsilon}$ have the same support.[60] For θ_2 such that $F_2(\theta_2|\theta_1) \in (0,1)$, the "informativeness" measure is

$$\frac{\partial F_2(\theta_2|\theta_1)/\partial\theta_1}{f_2(\theta_2|\theta_1)} = -\gamma.$$

The price in the second period is then

$$p_2(\theta_1,\theta_2) = z_\alpha(\theta_1,\theta_2) = \theta_2 + (1-\alpha)\gamma\frac{F_1(\theta_1)}{f_1(\theta_1)}, \tag{6.12a}$$

which is increasing in both θ_2 and γ. The price is thus lower the less informative (lower γ) is first-period marginal cost about second-period marginal cost; that is, the less accurate is the firm's private ex ante information about second-period marginal cost. If $\gamma = 0$, the marginal cost in the second period is independent of the marginal cost in the first period, so the firm has no information advantage relative to the regulator, and the information rents for the second period are identically zero. The regulator thus does not need to distort the price in period two. If $\gamma = 1$, the second-period marginal cost equals the first-period marginal cost, so the firm has the same information advantage regarding marginal cost in both periods, and the best the regulator can do is to employ the static policy in each period.

The case of perfect correlation of the marginal costs indicates the power of commitment. When the static policy is used in each period, the regulator learns the marginal cost in the first period when the firm selects the regulatory policy corresponding to its marginal cost. The regulator prefers not to utilize that information in subsequent periods, however, because responding to it would increase the information rents by more than the gain in consumer surplus. It is the power to commit not to exploit that information that allows the regulator to repeat the static contract. In Subsection 6.3, the commitment assumption will be relaxed, and the equilibrium contract will be shown to be radically different.

To examine why the regulator prefers to commit to ignore the information revealed in the first period when the marginal costs are perfectly correlated, consider the regulatory policy in which the static policy is employed in the first

[60] For example, the random variables may all be normally distributed. The assumption of normality requires bounding the marginal costs at zero and may require an upper bound on the cost at which the regulator no longer prefers to purchase from the firm. The normality assumption is useful for illustration because the support of θ_2 is independent of θ_1.

period and the regulator fully exploits the information revealed in the first period by setting the second-period price equal to marginal cost. The second-period regulatory policy is thus, writing $\theta_2 = \theta_1$:

$$p_2(\theta_1, \theta_1) = \theta_1 \quad \text{and} \quad T(\theta_1, \theta_1) = K_2. \tag{6.14}$$

The period-two profit of the firm thus equals zero, and the firm will take this into account in making its first-period report $\hat{\theta}_1$. For example, if the firm with marginal cost θ_1 reported in period one that its marginal cost was $\theta_1 + \Delta\theta_1$, where $\Delta\theta_1 > 0$, it would earn profits $\Delta\theta_1 Q(p_2(\theta_1 + \Delta\theta_1, \theta_1 + \Delta\theta_1))$ in the second period. The regulator must respond to this incentive, so the variation in the two-period profit in (6.6) is

$$\frac{\mathrm{d}\Pi(\theta_1)}{\mathrm{d}\theta_1} = -Q(y_\alpha(\theta_1)) - \beta Q(\theta_1). \tag{6.15}$$

The firm thus takes into account the effect of its first-period report on both its first-period and second-period profit. The two-period profit of the firm is then

$$\Pi(\theta_1) = \int_{\theta_1}^{\theta_1^+} \left[Q\big(y_\alpha(\theta_1^0)\big) + \beta Q\big(\theta_1^0\big)\right] \mathrm{d}\theta_1^0. \tag{6.16}$$

The difference $\Delta\Pi(\theta_1)$ in the information rents between this mechanism in which the information revealed in the first period is fully exploited in the second period and the mechanism in which the static policy is repeated in each period is

$$\Delta\Pi(\theta_1) = \int_{\theta_1}^{\theta_1^+} \beta\left[Q(\theta_1) - Q(y_\alpha(\theta_1))\right] \mathrm{d}\theta_1, \tag{6.17}$$

which is positive when $\alpha < 1$ for all $\theta_1 > \theta_1^-$, since $y_\alpha(\theta_1) > \theta_2$. The greater rents then reduce ex ante welfare. The corresponding difference $\Delta W(\theta_1)$ in welfare conditional on θ_1 is

$$\Delta W(\theta_1) = \beta\left[\int_{\theta_1}^{y_\alpha(\theta_1)} \big(Q(\theta_1^0) - Q\big(y_\alpha(\theta_1^0)\big)\big)\,\mathrm{d}\theta_1^0 - (\theta_1 - y_\alpha(\theta_1))Q(\theta_1)\right]. \tag{6.18}$$

The difference in welfare in (6.18) is negative for all $\alpha < 1$ and for all $\theta_1 > \theta_1^-$ as is illustrated in Figure 24.2 where $D(\theta_1)$ denotes the integrand in (6.18). The additional rents in (6.17) that the firm earns thus exceed the gain in consumer surplus resulting from the lower price in period two. The regulator thus prefers to implement the static policy in each period.

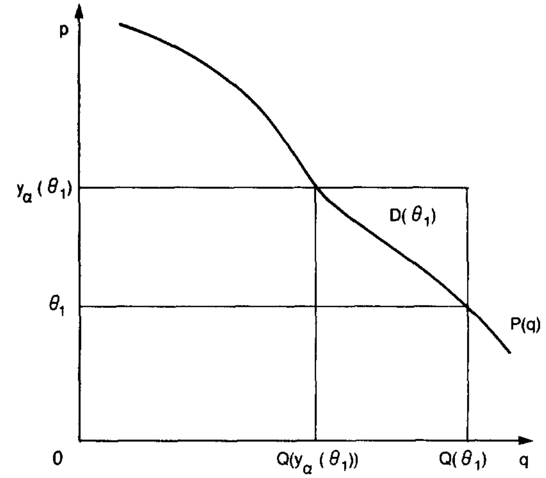

Figure 24.2. Welfare loss with no commitment.

The case in which marginal costs are perfectly correlated across periods stands in opposition to the case in which marginal costs are independent across periods. In the former, the regulator prefers to repeat the static mechanism in each period as a means of reducing the information rents. In the latter, the regulator is able to use marginal cost pricing in each period after the first. Intuitively, the regulator employs marginal cost pricing in the second period because at the beginning of the first period, when the firm chooses a pricing policy from the mechanism offered, the firm has no information advantage relative to the regulator regarding θ_2. The firm thus can earn no rents from the second period, so the regulator need not distort the second-period price from the marginal cost θ_2.

The mechanism, however, must induce the firm to report θ_2 at the beginning of the second period, and to do so, the fixed charges must be specified as

$$T_2(\theta_1, \theta_2) = \int_{\theta_2}^{\theta_2^+} Q\big(p_2(\theta_1, \theta_2^0)\big)\,\mathrm{d}\theta_2^0 + \theta_2 Q\big(p_2(\theta_1, \theta_2)\big) + K_2 - p_2(\theta_1, \theta_2) Q\big(p_2(\theta_1, \theta_2)\big). \tag{6.19}$$

For the case of independent marginal costs, this is

$$T_2(\theta_1, \theta_2) = \int_{\theta_2}^{\theta_2^+} Q\big(\theta_2^0\big)\,\mathrm{d}\theta_2^0 + K_2, \tag{6.19a}$$

and the second-period profit $\pi_2(\theta_1; \theta_2)$ in (6.3) equals $T_2(\theta_1, \theta_2) - K_2$. The fixed charges $T_1(\theta_1)$, however, take away the conditional (on θ_1) expectation $E[\pi_2(\theta_1;\theta_2)]$ of the second-period profit. The general expression for $T_1(\theta_1)$ is

$$T_1(\theta_1) = \int_{\theta_1}^{\theta_1^+}\left[Q(p_1(\theta_1^0)) - \beta\int_{\theta_2^-}^{\theta_2^+} Q(p_2(\theta_1^0,\theta_2))\frac{\partial F_2(\theta_2|\theta_1^0)}{\partial\theta_1}\mathrm{d}\theta_2\right]\mathrm{d}\theta_1^0$$
$$+\theta_1 Q(p_1(\theta_1)) + K_1 - p_1(\theta_1)Q(p_1(\theta_1)) - \beta E[\pi_2(\theta_1;\theta_2)], \tag{6.20}$$

and when θ_1 and θ_2 are independent, this is

$$T_1(\theta_1) = \int_{\theta_1}^{\theta_1^+} Q(p_1(\theta_1^0))\,\mathrm{d}\theta_1^0 + \theta_1 Q(p_1(\theta_1))$$
$$+K_1 - p_1(\theta_1)Q(p_1(\theta_1)) - \beta E[\pi_2(\theta_1,\theta_2)].$$

In the first period, the expectation of the second-period profit is thus deducted from the fixed charges.[61] The profit in the first-period, however, equals the first term in (6.20), so it reflects the rents that the firm earns as a result of its private information about θ_1. In general that information pertains not only to first-period marginal cost but also, through the informativeness of first-period marginal cost, to the second-period marginal cost. When the marginal costs are independent, however, the latter is zero, so

$$\Pi(\theta_1) = \int_{\theta_1}^{\theta_1^+} Q(p_1(\theta_1^0))\,\mathrm{d}\theta_1^0.$$

Since the two-period profit $\Pi(\theta_1)$ of the firm is equal to the first term in (6.20), it is evident that the firm has higher profit the lower is the second-period price $p_2(\theta_1,\theta_2) = z_\alpha(\theta_1,\theta_2)$. Thus, (roughly) the more informative the first-period marginal cost is about the second-period marginal cost, the greater is the profit $\Pi(\theta_1)$.

This analysis can be extended to models in which the regulator has the ability to commit to future regulatory policies and the firm has private information at the time of contracting that is informative about what future marginal cost will be. For example, in Section 9 a model of the selection of a franchise monopolist will be considered in which at the time the regulatory mechanism is chosen the firm has imperfect information about what its marginal costs will be, but the actual marginal cost will not be observed until fixed costs have been sunk. The optimal regulatory mechanism for the selected franchise monopolist is a special case of the mechanism presented in this subsection.

[61] In the regulatory relationship characterized by commitment, transfers are possible across periods.

6.2.2. *Application: Private information after contracting*

The theory of mechanism design in multiperiod models with commitment can be used to determine the optimal regulatory mechanism for a number of important special cases. For example, consider a single-period setting in which the regulator and the firm have symmetric information at the time at which the regulatory mechanism is chosen but in which the firm will observe its marginal cost before production begins. The price can thus be based on a report of marginal cost after the regulatory mechanism has been agreed to but before production commences.[62]

This case may be thought of as involving two periods, the first of which involves no production, and all production takes place in the second period. At the beginning of the first period at the time the regulatory policy is determined, the firm has uninformative private information about what its marginal costs θ_2 will be in the second period. The informativeness measure in (6.10) is thus equal to zero, so the regulatory contract specifies a period-two price $p_2(\hat{\theta}_2)$ equal to the reported marginal cost $\hat{\theta}_2$ and fixed charges given in (6.19) that implement that pricing policy.

Since the firm has no private information at the time it must decide whether to participate, it will participate if its expected profit is nonnegative. The individual rationality constraint thus holds as an expectation rather than conditionally on each possible value of an information parameter.[63] That is,

$$T_1 + \int_{\theta_2^-}^{\theta_2^+} \pi_2(\theta_2) f_2(\theta_2)\, \mathrm{d}\theta_2 \geq 0, \tag{6.21}$$

where the distribution of θ_2 is unconditional and the θ_1 notation is suppressed. The fixed charges T_1 in (6.20) are thus

$$T_1 = -\int_{\theta_2^-}^{\theta_2^+} \pi_2(\theta_2) f_2(\theta_2)\, \mathrm{d}\theta_2. \tag{6.20a}$$

This may be interpreted as a franchise fee paid by the firm to consumers at the time at which the firm agrees to participate in the regulatory relationship. In (6.21) the expected profit net of the franchise fee is thus zero, so the firm is

[62] Baron and DeBondt (1981) consider a related case of the design of a fuel-adjustment mechanism when the regulator and the firm are symmetrically informed at the time the regulatory policy is agreed to but a factor price will subsequently be realized. The regulator is unable to observe the factor price but can observe the unit cost which depends on factor inputs that are unobservable to the regulator. The optimal regulatory policy involves a price adjustment mechanism in response to the observed unit cost.

[63] The firm is not assumed to face any bankruptcy or limited liability constraints. Such constraints are considered in the following subsection.

willing to participate. This mechanism is optimal for all α, so the first-best outcome is attained for any regulatory welfare function.[64,65] That is, the private information that the firm will observe in the future causes no inefficiency.

The firm earns no rents on its information because at the time the mechanism is agreed to the firm and the regulator are symmetrically informed. The mechanism induces the firm to report its true marginal cost once it is observed, and it earns non-negative profit $\pi_2(\theta_2)$ after the franchise fee has been sunk, so it is willing to supply the specified quantity once it observes θ_2. The firm thus has no incentive to quit the regulatory relationship. Although the firm earns rents on its information in the second period, the regulator extracts the expected rent as a franchise fee at the time the mechanism is agreed to, so ex ante profit is zero.

This model can be directly extended to the case in which the manager of the firm takes an unobservable action as in Subsection 4.6.1. Suppose that marginal cost $c(\theta_2, a)$ is a function of θ_2 and effort a, which is unobservable to the regulator. The first-best mechanism above will clearly induce the manager to take the first-best effort level $a^*(\theta_2)$, which satisfies:[66]

$$-c_a(\theta_2, a^*(\theta_2))Q(\theta_2) - \psi'(a^*(\theta_2)) = 0.$$

Consequently, when the regulator and the firm have symmetric information at the time the mechanism is proposed and agreed to, the first-best allocation can be achieved for any regulatory objective even though the firm will subsequently have private information and take an unobservable action.

6.2.3. *Limited liability*

In models in which the regulator and the firm are symmetrically informed at the time the mechanism is agreed to but in which the firm will obtain information prior to taking an action, the first-best allocation can be implemented using the fixed charges functions given in (6.19) and (6.20a). Once the franchise fee has been sunk, the profits $\pi_2(\theta_2)$ are non-negative, so the firm always has an incentive to produce the specified quantity. A complication may arise, however, if either the firm has an incentive to quit the regulatory arrangement once it observes θ_2 or the firm is unable to fulfill the terms of the policy.

[64] Weitzman (1978) obtained the same result with multiple firms for the case of $\alpha = 1$ and a linear marginal benefits function.

[65] Riordan (1984) obtains a similar result for the case in which the regulator and the firm are symmetrically informed at the time the mechanism is agreed to, but subsequent to the agreement the firm privately observes the realization θ of a random variable $\tilde{\theta}$ that affects demand. He demonstrates that a mechanism exists that results in both the ex ante efficient capacity and the ex post efficient price. This is attainable because information is symmetric at the time at which the agreement is made.

[66] Note that the equilibrium level of effort in (4.24) is second best because the price is distorted above marginal cost.

Sappington (1983b) considers the case in which the firm will be unable to fulfill the terms of the regulatory policy if profit net of the franchise fee falls below a limit L, where L is nonpositive. That is, the firm is able to fulfill the policy only if the realized θ_2 is such that[67]

$$-T_1 + \pi_2(\theta_2) \geq L, \quad L \leq 0. \tag{6.22}$$

He refers to this condition as limited liability.[68,69]

The nature of the optimal mechanism in this case can be determined by noting that the constraint in (6.22) is of the same form as the participation constraint in (4.2) for the case in which the firm has private information prior to contracting. The regulator thus will choose a mechanism that distorts output from the first-best level. The equilibrium mechanism specifies efficient production only for the most efficient type θ^-, and for all other types that produce, output is below the first-best level. These properties of the optimal mechanism are analogous to those of the mechanisms employed in the case in which the firm has private information at the time the regulatory mechanism is chosen. Even though the firm here has no private information at the time the mechanism is agreed to, the first-best allocation cannot be attained because the limited liability constraints force a distortion of price from marginal cost.

Since limited liability as represented in (6.22) can affect the regulatory mechanism, the relevant issue is when such a condition might be present. If the firm could commit to abide by the prearranged terms of the agreement not to quit the relationship, then the constraint would not be present. Similarly, if the firm could pay T_1 ex ante at the time at which the regulatory policy was chosen so that it was sunk by the time θ_2 was observed, the constraint would not be present as indicated in the previous subsection. If the firm did not have the equity to pay T_1 ex ante, it could borrow T_1 in a capital market and repay it with interest, provided that if there were default on the loan payment the lender could take over the firm, observe θ_2, and make the effort a.[70] The explanation for the limited liability condition thus is either an imperfection in the capital markets or an inability of an outsider to observe θ_2 or to make the effort a. That is, either the information or the effort must be specific to the present ownership of the

[67]This constraint can be incorporated directly into the control theoretic formulation in Appendix A.

[68]Similar constraints arise in the study of the breach of contracts. See, for example, Melumad (1988).

[69]In the mechanism characterized in the previous section, the limit L was $L \leq -T_1$, so the firm produces for whatever θ_2 is realized.

[70]The equilibrium loan contract carries an interest rate such that the firm will default with probability one. That is, the firm is sold to a party that can pay the franchise fee ex ante.

firm. This may be characteristic of a managerial model in which the manager has specific ability or observability powers independent of the position occupied.[71]

6.2.4. Observable costs

Sappington and Sibley (1986) consider a dynamic model in which the regulator can at the end of each period perfectly observe the costs incurred by the firm. As in the model in Subsection 5.1, the firm can increase its costs by choosing additional expenditures ω to confirm its reported marginal cost. The regulator is assumed to be able to commit to a mechanism, and the firm is unable to quit the regulatory relationship. The mechanism begins with an exogenous price in the first period. The actual costs in each period are perfectly observable by the regulator, which may impose an infinite penalty on the firm if actual costs differ from its reported cost. The actual costs observed in one period are used as a basis for pricing in the next period, but the observed cost in the final period cannot be so used.

Sappington and Sibley show that the optimal regulatory mechanism for the case in which the marginal cost is the same in each period involves a price equal to reported marginal cost in every period after the initial period with the exception of the final period.[72] In the final period the regulatory policy is the optimal static policy characterized in Subsection 4.2. The fixed charge for the multiperiod mechanism in this case is the fixed charge for the single-period mechanism. This mechanism results in considerable efficiency gains relative to the case in which the regulator cannot observe any aspect of performance. The efficiency gains result both because marginal cost pricing can be achieved in all periods other than the first and the last and because the transfer includes an information rent that is paid in the last period and thus has a present value that is diminished by discounting.

6.3. Multiperiod mechanisms with no commitment

6.3.1. Introduction

The mechanisms in the previous subsection are based on the assumption that the regulator is able to commit to a policy for the duration of the regulatory relationship. The inability of one government to bind a future government to a

[71] In the context of a managerial model, limited liability may also be interpreted as infinite risk aversion for losses below L, and risk neutrality for gains.

[72] Cost must be deterministic and observable without error for this mechanism to be implementable.

particular policy, however, makes commitment to public policies difficult to assure. Any party to a multiperiod relationship has an incentive to act opportunistically, but as Baron and Besanko (1987a) state:

> opportunism may be more characteristic of the policies of public agencies than of private parties because although courts will prohibit inefficient breach by private parties they generally will not proscribe revisions of policies by regulatory or administrative agencies. Instead courts tend to restrict their review to procedure, process, and consistency. Perhaps the greatest impediment to establishing commitment in governmental and regulatory settings arises from electoral competition. Presidential candidates and parties can pledge to preserve or to rescind laws or to force regulatory agencies to alter policies either through the appointment process, executive orders, or the authorization and appropriations process. Similarly, Congress can alter policies as well as initiate new ones. The political incentive to respond to an *ex post* opportunity, even though that opportunity results from an event anticipated under an *ex ante* efficient policy, seems unavoidable in many settings.

If the regulator is unable to commit to a mulitperiod policy, the firm must form expectations about which policies will be adopted in the future. In the context of the self-selection model considered in Section 6, the firm must anticipate the policy the regulator will adopt given what it learns about the firm during previous periods. For example, if the marginal cost of the firm were known to be the same in every period and if the regulatory policy implemented in the first period were fully separating, the regulator would know the marginal cost in every subsequent period. The regulator then has an incentive to exploit fully that information by adopting the policy that is optimal given that information. The firm, of course, recognizes this incentive, and in making its first-period decision it will take into account the policy the regulator will adopt in future periods as a consequence of the information its first-period choice reveals about its marginal costs. The equilibrium concept appropriate for this case in which the regulator cannot credibly commit is a perfect Bayesian equilibrium or sequential equilibrium in which actions must be optimal for the regulator conditional on the information it has at the beginning of each period.[73,74]

[73]The perfectness property was introduced by Selten (1975) and is addressed in Chapter 5 of this Handbook.

[74]Sappington (1986) considers a model in which the regulator wants to motivate the firm to seek information about cost-reducing investment opportunities but is unable to commit to how it will use information it obtains through monitoring the firm's performance. Through monitoring, the regulator can observe the marginal cost the firm will have after it makes its investment, and if the regulator is unable to commit, it will set prices so that the profit of the firm is zero. Recognizing this, the firm has no incentive to seek information about the investment opportunities. If commitment were possible, the regulator could assure the firm that it could earn positive profits if it took the appropriate

If the regulatory policy were separating in the first period, the information of the regulator at the beginning of the second period would be represented by the conditional distribution function $F_2(\theta_2|\theta_1)$. The regulator would then have an incentive to fully exploit that information by choosing the regulatory mechanism that is optimal given that information. That optimal mechanism satisfies the perfectness condition and is simply the single-period mechanism that would be established given that information. The price in the second period is thus of the form of (4.19) with $F_2(\theta_2|\theta_1)/f_2(\theta_2|\theta_1)$ replacing $F(\theta)/f(\theta)$. The firm would recognize that this price would be established in the second period if it were to report its marginal cost truthfully in the first period, and thus it takes into account the period-two consequences of the information it reveals in the first period. The opportunism of the regulator and the response by the firm result in ex ante inefficiency.

This subsection is concerned with the nature of the equilibria when the regulator cannot commit to multiperiod policies and hence is unable to commit not to act in an opportunistic manner.[75] The inability to commit to multiperiod policies can result in equilibria quite different from those with commitment. The objective of this section is to develop the intuition underlying this difference and to indicate the nature of the equilibrium mechanisms. The first case considered is that studied by Laffont and Tirole (1988) in which the marginal cost of the firm is the same in each period. In Subsection 6.3.3 an institutional arrangement is proposed that limits the opportunism and results in improvements in ex ante welfare. The case in which the marginal cost may change over time in an imperfectly predictable manner is then considered in the subsequent subsection.

6.3.2. *Perfectly correlated marginal costs $\theta_1 = \theta_2$*

With perfectly correlated marginal costs and commitment in a multiperiod model, the firm as in a static model has an incentive to overstate its costs in an attempt to obtain a more profitable regulatory contract. The incentive compati-

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information acquistion and investment actions. Sappington assumes that although the regulator cannot commit to how information would be used in pricing, it can commit to how costly the monitoring will be. By choosing a costly monitoring technology, the regulator assures the firm that it will not monitor the firm as accurately ex post as it would if that cost were lower. This provides an opportunity for the firm to realize profits, and thus the firm has some incentive to acquire information and to invest efficiently given that information. Employing a costly monitoring technology thus provides some degree of commitment.

[75] Baron and Besanko (1987a) and Roberts (1982) also analyze the case in which the regulator is unable to commit to a multiperiod policy. Using a repeated game approach, Lewis (1986) considers a model of project execution in which neither party can commit to a policy. Tirole (1986a) and Grout (1984) also consider models without commitment in which the second-period outcome is determined by bargaining.

bility constraints in (6.5) thus are binding "upwards", and the fixed charges must be structured to offset the incentive the firm with marginal cost θ_1 has to report its costs as $\theta_1 + \Delta\theta_1$, where $\Delta\theta_1 > 0$. Also, with commitment the regulatory mechanism is always such that the firm's profits were non-negative for all θ_1, so it has an incentive to participate. The participation decision becomes important in the absence of commitment because as indicated next the firm has an incentive to understate its cost in the first period and to quit in the second period. This implies that the incentive compatibility constraints are binding "downwards" as well as upwards.

To illustrate this, suppose that the regulator were to attempt to implement a separating mechanism in the first period. The firm recognizes that if it were to report its true marginal cost in the first period, the regulator would know its marginal cost for all subsequent periods. Then in the second period the regulator could only be expected to implement a policy of marginal cost pricing with the fixed charges equal to the fixed cost, which would yield zero profit for the firm in period two. The two-period profit $\Pi(\hat{\theta}_1; \theta_1)$ under this policy, writing the second-period quantity as a function only of $\hat{\theta}_1$, is

$$\begin{aligned}\Pi(\hat{\theta}_1; \theta_1) = {} & \left(p_1(\hat{\theta}_1) - \theta_1\right)Q\left(p_1(\hat{\theta}_1)\right) - K_1 \\ & + T_1(\hat{\theta}_1) + \beta(\hat{\theta}_1 - \theta_1)Q(\hat{\theta}_1),\end{aligned} \tag{6.23}$$

where $p_2(\hat{\theta}_1) = \hat{\theta}_1$, $T_2(\hat{\theta}_1) = K_2$, $p_1(\hat{\theta}_1) = y_\alpha(\hat{\theta}_1)$, and $T_1(\hat{\theta}_1)$ is

$$\begin{aligned}T_1(\hat{\theta}_1) = {} & \int_{\hat{\theta}_1}^{\theta_1^+} \left[Q\left(p_1(\theta_1^0)\right) + \beta Q(\theta_1^0)\right] \mathrm{d}\theta_1^0 \\ & - \left(p_1(\hat{\theta}_1) - \hat{\theta}_1\right)Q\left(p_1(\hat{\theta}_1)\right) + K_1.\end{aligned} \tag{6.24}$$

The firm has no incentive to overstate its cost, since the payment,

$$\beta \int_{\hat{\theta}_1}^{\theta_1^+} Q(\theta_1^0)\, \mathrm{d}\theta_1^0, \tag{6.25}$$

negates the incentive, created by the exploitation of the information revealed in period one, to overstate marginal cost. It is important to note that when the regulator is unable to commit to a regulatory policy, the period-one fixed charges $T_1(\theta_1)$ must include the incentive payment in (6.25), since the regulator is unable to commit to pay it in period two. That is, the only credible beliefs in period two are that the fixed payments would only cover the fixed cost K_2 in that period.

Although the fixed charges in (6.24) induce the firm not to overstate costs, the firm may have an incentive to understate its costs in the first period and quit in the second period if producing in that period would yield negative profits. To see this, note that the profit function of the firm with the fixed charges given in (6.24) is actually

$$\Pi(\hat{\theta}_1;\theta_1) = (\hat{\theta}_1 - \theta_1)Q(p_1(\hat{\theta}_1)) + \int_{\hat{\theta}_1}^{\theta_1^+} [Q(p_1(\theta_1^0)) + \beta Q(\theta_1^0)]\,\mathrm{d}\theta_1^0$$

$$+\beta \max\{0, (\hat{\theta}_1 - \theta_1)Q(\hat{\theta}_1)\}, \tag{6.26}$$

where, in the last term, the zero results from the possibility of quitting in period two rather than producing $Q(\hat{\theta}_1)$. The right-hand derivative of (6.26) with respect to $\hat{\theta}_1$ equals zero at $\hat{\theta}_1 = \theta_1$, so the firm has no incentive to overstate its costs. The left-hand derivative of (6.26) evaluated at $\hat{\theta}_1 = \theta_1$ is, however,

$$\left.\frac{\partial \Pi(\hat{\theta}_1;\theta_1)}{\partial \hat{\theta}_1}\right|_{\hat{\theta}_1=\theta_1} = -\beta Q(\theta_1), \tag{6.27}$$

since for $\hat{\theta}_1 < \theta_1$, the last term in (6.26) is zero. The profit function in (6.26) is thus not differentiable, and as (6.27) indicates, the firm has an incentive to understate its costs. This incentive is present because the firm has the incentive to obtain a larger transfer in the first period by reporting $\hat{\theta}_1 < \theta_1$ and then to quit in the second period rather than produce at a price $p_2(\hat{\theta}_1) = \hat{\theta}_1$ that is below its true marginal cost θ_1.[76]

If the regulator were able to commit to a multiperiod policy, it would commit to second-period fixed charges that include the term in (6.25). That would induce the firm to produce in the second period eliminating the incentive to understate costs in the first period. When the regulator is unable to make credible commitments, however, the only credible belief about what the regulator will do in the second period is that it will offer fixed charges that cover only the fixed cost and will set price equal to marginal cost. The regulator in this case still must induce the firm not to overstate its cost, so the first-period transfer in (6.24) must include the second-period incentive terms in (6.25). But as indicated in (6.27), this induces the firm to understate its marginal costs. Consequently, a mechanism that employs a separating mechanism in the first period and a mechanism satisfying the perfectness condition in the second period is not feasible because the incentive compatibility constraints cannot be satisfied. This conclusion holds in general for any mechanism that in period one would separate types over any closed interval. The demonstration of this important result is due to Laffont and Tirole (1988) who show that there exists no mechanism that separates the types

[76] Production in the second period would yield a negative profit $(\hat{\theta}_1 - \theta_1)Q(\hat{\theta}_1)$.

on any interval with positive measure.[77] They provide conditions for the existence of an equilibrium and some characterization of the types of equilibria that may exist.

If the regulator is unable to commit to multiperiod policies, it is natural to inquire if the regulator could take actions that would endogenously generate the commitment that would allow it to implement the multiperiod contract optimal with commitment. To do so, the regulator must assure the firm that at the end of the first period it will not revise its policy and revert to marginal cost pricing once it has learned the marginal cost of the firm. The regulator might, for example, post a bond claimable by the firm in the event that the regulator deviated from the multiperiod policy announced at the beginning of the relationship. A bond sufficient to ensure that the regulator would not shirk on this commitment would have to be greater than the difference in second-period welfare under the (perfect) marginal cost pricing policy and the second-period welfare under the equilibrium policy with commitment. With such a bond the regulator would have no incentive to shirk and hence the bond need never be paid. The regulator thus is willing to post it thus guaranteeing its commitment. Such a bond would be sufficient to generate commitment, but any posted bond would be subject to the same political forces addressed above that make commitment difficult to assure. Means of endogenously generating commitment thus seem to be subject to the same type of limitations.[78]

6.3.3. *Perfectly correlated marginal costs and fair regulatory mechanisms*

The inefficiency that results from the opportunism identified above would be expected to generate incentives for the establishment of institutional arrangements that would limit that opportunism and improve efficiency. The characteristics of the resulting institution would be expected to deal with the two causes of the inefficiency: (1) the regulator is unable to give assurance to the firm about how it will be treated under future policies, and (2) the firm can choose whether to participate in each period.

Even though a person cannot commit not to breach a labor contract because the courts will not enforce contracts that are difficult to distinguish from involuntary servitude, a contract between two private parties may be enforceable, particularly if the parties have made reliance expenditures as a consequence of the contract. Similarly, a regulatory authority may have some ability to commit to a pricing policy to the extent that procedural requirements and legal prece-

[77] Note that this result is stronger than the result that the equilibrium mechanism is not separating. It indicates that no separating mechanism is feasible.

[78] Williamson (1983) provides an insightful analysis of endogenous means of generating commitment in private contracting.

dents restrict its ability to alter its policies ex post. For example, Supreme Court decisions such as *Smyth v. Ames 169 U.S.* 466 (1898) and *Federal Power Commission et al. v. Hope Natural Gas Co.* 320 U.S. 591 (1944) provide a lower bound on the earnings of public utilities on used and useful assets employed in a regulated activity. In addition, the procedural requirements of administrative law protect a firm from arbitrary and capricious actions by the regulator. With respect to the firm's ability to withdraw from a regulatory relationship, state statutes generally prohibit a regulated utility from withdrawing assets from regulated services without regulatory approval.[79] As with private contracts, the restrictions placed on regulators by the courts may be intended to yield efficiency gains to a continuing regulatory relationship by limiting opportunism and thereby improving reliance.

Such restrictions could be imposed by legislation, but it is also possible that the regulator and the firm would have incentives to reach a voluntary arrangement in which the firm is offered some protection from the actions of the regulator and, in exchange, limits its ability to withdraw from the arrangement. One such arrangement would involve the firm exchanging its right to withdraw from the regulatory relationship for restrictions on the opportunism of the regulator. A regulatory relationship with this property will be said to be *fair*.[80] Under such an arrangement, however, the regulator still is allowed to choose a policy that is optimal given the information it has as the beginning of each period. Opportunism is restricted by requiring the regulator to choose policies that are compensatory given the information revealed by the firm in earlier periods. Such an arrangement may correspond to the state statutes and Supreme Court decisions referred to above.

In regulatory contexts with informational asymmetries, the adequacy of the profit of a firm must be relative to information that both is observable by all parties and is verifiable by a third party with enforcement powers. The only such information in this context is the report of the firm or equivalently the information revealed by the firm in its selection of a policy from the mechanism offered by the regulator. Thus, the natural fairness condition is that the firm be guaranteed a non-negative profit in each period conditional on the information it reports or reveals in earlier periods. The case considered here is that in which it is common knowledge that marginal cost is the same in each period ($\theta_1 = \theta_2 = \theta$), so if in period one the firm reported $\hat{\theta}_1$, then the period-two profit $\pi_2(\hat{\theta}_1; \hat{\theta}_1)$ for that type is required to be non-negative. In exchange, the firm is not allowed to quit the relationship. That is, if the firm reported that its period-one marginal

[79]See Drobak (1986) for an analysis of the right to withdraw assets.

[80]Greenwald (1984) considers a different fairness arrangement based on the relationship between the market value of the firm and the cost of its assets.

cost is $\hat{\theta}_1$ even though its marginal cost is θ, the firm is required to produce in the second period as long as the second-period regulatory policy would provide a non-negative profit to a firm with marginal cost $\hat{\theta}_1$.

The remaining issue is why a firm would agree to surrender its right to quit a regulatory relationship in exchange for protection against the opportunism of the regulator. At an informal level the firm might so agree because the alternative is unclear. As Laffont and Tirole have shown, an equilibrium in the absence of commitment may have quite complex properties.[81] A firm may well prefer the assurance of a fairness arrangement to an unpredictable outcome. Baron and Besanko (1987a) provide an example in which both the regulator and the firm prefer the fairness arrangement to a policy feasible with no commitment in which all types of the firm are pooled together in the first period.[82] While this is not a general result, both parties may well prefer a regulatory relationship characterized by fairness to one characterized by no commitment.

If the regulator and the firm prefer an arrangement characterized by fairness to one in which there is no commitment, it is natural to ask if they both prefer an arrangement characterized by commitment to one characterized by fairness. As will be indicated below, not only do they have opposing preferences regarding commitment but there exists no transfer between the regulator and the firm that would cause both to agree to implement the commitment policy. Consequently, if fairness arises endogenously in a regulatory relationship in which otherwise no commitment is possible, it would be expected to persist.

The fairness condition prohibits the regulator from offering a policy in the second period that would yield a negative profit to a firm with the type revealed in the first period. A formal statement of the fairness requirement distinguishes between first-period mechanisms that are separating and those that induce pooling over sets $\Theta^i \subseteq [\theta^-, \theta^+]$. If a first-period mechanism $M_1 = \{(p_1(\hat{\theta}_1), T_1(\hat{\theta}_1)), \hat{\theta}_1 \in [\theta^-, \theta^+]\}$ is separating so that the firm's response function $\hat{\theta}_1(\theta)$ is invertible, the fairness requirement is that

$$\pi_2(\hat{\theta}_1) \equiv \pi_2(\hat{\theta}_1; \hat{\theta}_1) = p_2(\hat{\theta}_1) Q(p_2(\hat{\theta}_1))$$

$$+ T_1(\hat{\theta}_1) - \hat{\theta}_1 Q(p_2(\hat{\theta}_1)) - K_2 \geq 0. \tag{6.28}$$

If the first-period mechanism is pooling on a set Θ^i so that $p_1(\hat{\theta}_1) = p^i$ and

[81] For example, they show that an equilibrium may involve "infinite reswitching" in which a sequence of types that are arbitrarily close together will alternate between two reports $\hat{\theta}^a$ and $\hat{\theta}^b$.

[82] Since no information is revealed in the first period under such a policy, in period two the optimal single-period policy is implemented.

$T_1(\hat{\theta}_1) = T_1^i$ for all $\hat{\theta}_i \in \Theta^i$, then the fairness requirement is

$$\pi_2(\hat{\theta}_2) = p_2(\hat{\theta}_2)Q(p_2(\hat{\theta}_2)) + T_2(\hat{\theta}_2) - \hat{\theta}_2 Q(p_2(\hat{\theta}_2)) - K_2 \geq 0, \quad \forall \hat{\theta}_2 \in \Theta^i. \tag{6.29}$$

Note that fairness allows the regulator to exploit any information revealed in the first period. That is, if the mechanism is fully separating in the first period so that $\hat{\theta}_1 = \theta$, the regulator can offer in period two the single policy $p_2(\hat{\theta}_2) = \theta$ and $T_2(\hat{\theta}_2) = K_2$, which yields the firm zero profit.

One implication of the fairness condition is that it renders feasible the separating policies that cannot be implemented when no commitment is possible. That is, fully-separating policies are feasible with fairness. This does not imply, however, that a fully-separating policy is optimal. The regulator faces a tradeoff between the benefits that accrue from flexible pricing in the first period and the benefits that can be achieved by pooling in the first period as a means of limiting opportunism in the second period. Pooling limits opportunism because the regulator learns only that $\theta \in \Theta^i$ and thus cannot fully exploit the firm in the second period.

The cost associated with pooling in the first period is the reduction in consumer surplus that results because price is not responsive to the marginal cost of the firm. The benefit from pooling is a reduction in the rents earned by the firm by allowing lower quantities to be produced in the second period. That is, with a fully-separating mechanism the regulator would fully exploit the information revealed in the first period by implementing marginal cost pricing in the second period. The fixed charges required to induce the firm to select the policy intended for it is given in (6.24) which results in two-period rents given by

$$\Pi(\theta) = \int_{\theta}^{\theta^+} \left(Q(p_1(\theta^0)) + \beta Q(\theta^0)\right) d\theta^0. \tag{6.30}$$

If the regulator were to pool in the first period on a set $\Theta = [\theta_a, \theta_b]$, the price $p_2(\hat{\theta}_2)$ in period two would be given by

$$p_2(\hat{\theta}_2) = z(\hat{\theta}_2) \equiv \hat{\theta}_2 + (1-\alpha)\frac{F(\hat{\theta}_2 | \hat{\theta}_2 \in \Theta^i)}{f(\hat{\theta}_2 | \hat{\theta}_2 \in \Theta^i)} = y_\alpha(\hat{\theta}_2) - (1-\alpha)\frac{F(\theta_a)}{f(\hat{\theta}_2)}.$$

Since this price is above marginal cost except at θ_a, the rents in the second period are reduced by pooling in the first period.

To indicate the tradeoff between the benefit and cost of pooling, note that the optimal separating mechanism for the first period is $p_1(\theta) = y_\alpha(\theta)$ with $T_1(\theta)$

given in (6.24). With pooling at a price $\bar{p}$ on an interval $[\theta_a, \theta_b]$, the welfare W^f of the regulator can be written as

$$W^f = \int_{\theta^-}^{\theta^+} \Bigg\{ \int_{p_1(\theta)}^{\infty} Q(p^0)\,\mathrm{d}p^0 + (p_1(\theta) - y_\alpha(\theta))Q(p(\theta)) - K_1$$

$$+\beta\left[\int_{\theta}^{\infty} Q(\theta^0)\,\mathrm{d}\theta^0 + (\theta - y_\alpha(\theta))Q(\theta) - K_2\right]\Bigg\} f(\theta)\,\mathrm{d}\theta$$

$$+\int_{\theta_a}^{\theta_b}\Bigg\{\left[\int_{\bar{p}}^{p_1(\theta)} Q(p^0)\,\mathrm{d}p^0 - (\bar{p} - y_\alpha(\theta))Q(\bar{p})\right]$$

$$+\beta\left[-\int_{\theta}^{z(\theta)} Q(p^0)\,\mathrm{d}p^0 - (z(\theta) - y_\alpha(\theta))Q(z(\theta))\right.$$

$$\left. + (\theta - y_\alpha(\theta))Q(\theta)\right]\Bigg\} f(\theta)\,\mathrm{d}\theta - (1-\alpha)\Pi(\theta^+), \tag{6.31}$$

where the optimal separating mechanism in the first period is the static mechanism characterized in Section 4. The tradeoff between pooling and separation can be seen in the second integral in (6.31). The term $[\int_{\bar{p}}^{p_1(\theta)} Q(p^0)\,\mathrm{d}p^0 - (\bar{p} - y_\alpha(\theta))Q(\bar{p})]$ in the integrand represents the welfare loss from pooling in the first period that results because price is not responsive to marginal cost.[83] Pooling, however, results in a welfare gain in the second period because pooling allows the price $z(\theta)$ to be implemented in period two rather than the price equal to θ. As demonstrated above, a price equal to marginal cost results in greater information rents (when $\alpha < 1$). The gain from pooling is represented by the second term in the integrand of the second integral in (6.31) and results because the regulator implements the price $z(\hat{\theta}_2)$ rather than θ in the second period. The following analysis provides a characterization of the types of equilibria that can occur when the benefits and costs associated with pooling are considered.

Within the class of fully-separating mechanisms Baron and Besanko (1987a) demonstrate that the optimal mechanism is to implement the price $p_1(\theta) = y_\alpha(\theta)$ in the first period, using the fixed charges in (6.24), and the first-best policy in the

[83] This term is negative, since $p_1(\theta) = y_\alpha(\theta)$ maximizes first-period welfare.

second period.[84] They show that the optimal fully-separating mechanism is an equilibrium under fairness if $\alpha = 1$ in which case the mechanism implements the first-best outcome in each period. The first-best policy is an equilibrium in this case because the rents of the firm do not represent a welfare loss. Fairness thus allows the first-best mechanism to be implemented, whereas with no commitment the first-best policy is infeasible.

Baron and Besanko show that when $\alpha < 1$ the regulator may prefer to pool in period one. They provide an example in which multiple pooling intervals are optimal.[85] Such pooling is more likely to be optimal the lower is α, since then the reduction in rents of the firm resulting with pooling is counted more in the welfare function used by the regulator. Pooling is also more likely to be optimal when the discount factor β is higher, since then the gains from restricting opportunism are greater. Baron and Besanko also show in the context of the example that the pooling intervals are shorter the lower are the costs. This results because the gain in consumer surplus from prices that are responsive to costs is greater for low marginal costs than for high marginal costs. Thus, the gains from pooling are greater at higher marginal costs than at lower marginal costs.

This issue of whether a fairness arrangement would arise endogenously can be analyzed both from an ex ante and an ex post perspective. As indicated above, the comparison will be between the equilibrium mechanism with fairness, as characterized by Baron and Besanko, and with no commitment a first-period mechanism that completely pools the types ($\Theta = [\theta^-, \theta^+]$) in the first-period and then employs the optimal static mechanism in the second period. Since the regulator does not know the marginal cost of the firm, its preferences are determined by the ex ante welfare W. The mechanism with full pooling in the first period and the static mechanism in the second period is a feasible mechanism under fairness, so the regulator prefers fairness to no commitment.

The firm's preferences can be analyzed both from an ex ante and ex post perspective. From an ex post perspective once the firm knows its marginal cost, the firm would voluntarily agree to a fairness arrangement if its profit $\Pi(\theta)$ with fairness is greater than its profit with no commitment. Baron and Besanko demonstrate that compared to this mechanism feasible with no commitment all types of the firm prefer fairness when the profits of the firm are not counted ($\alpha = 0$) in the welfare employed by the regulator. For higher α the types of the firm with high costs prefer no commitment to fairness.

[84] The fairness condition in (6.28) can thus also be thought of as a condition sufficient to make separation feasible when commitment is not possible.

[85] The equilibrium in the fairness case must be supported by off-the-equilibrium path beliefs. The equilibrium in this example is sensitive to the specification of those beliefs. The assumption employed by Baron and Besanko is that each of the types in a pooling interval randomizes its report among the types in that interval.

The decision to enter into a fairness arrangement, however, may be made prior to the firm learning its marginal cost. In that case the firm would compare its ex ante or expected profits under a fairness arrangement to the ex ante profits with no commitment and complete pooling in the first period.[86] Baron and Besanko show in the context of their example that fairness is more likely to be preferred the lower is α and the higher is the discount factor β.

If from an ex ante perspective the firm and the regulator prefer fairness to no commitment, would they both also prefer commitment to fairness if commitment could somehow be assured? The regulator clearly prefers commitment because any mechanism feasible with fairness is also feasible with commitment. Since the equilibrium mechanism with commitment is to repeat the static mechanism in each period, fairness with the optimal separating mechanism results in higher profit in (6.30) because the quantity under fairness is greater in the second period than with commitment. Furthermore, there is no transfer that consumers would be willing to make and the firm would be willing to accept in exchange for agreeing to participate in a relationship characterized by commitment. The ex ante profit is greater with the optimal fully-separating mechanism, but with pooling the comparison is ambiguous. In the example presented by Baron and Besanko the expected profit with pooling is greater than with commitment. In these cases, fairness would be sustainable.

6.3.4. Imperfectly correlated marginal costs

To identify the source of Laffont and Tirole's result that there is no feasible mechanism that is separating for the case in which marginal costs are perfectly correlated, consider the case in which it is common knowledge that marginal costs are independent across periods. Knowledge of the marginal cost in one period thus provides no information about the marginal cost in any other period. Recall that in this case the optimal mechanism when the regulator can commit to a multiperiod policy is to employ the single-period price in the first period and the first-best policy thereafter as indicated in (6.11) and (6.12). When the regulator cannot commit to a multiperiod mechanism, the optimal regulatory mechanism for the independent cost case is to repeat in each period the single-period mechanism characterized in (4.19) and (4.11). At the beginning of each period the firm observes its marginal cost, and given the single-period mechanism, the firm selects the regulatory policy appropriate for its costs. The regulator can do no better than this because it cannot commit to transfers across

[86] The mechanism is still chosen by the regulator after the firm has learned its marginal cost.

periods nor can it commit to offer a particular second-period policy to the firm if it will accept the first-period policy.[87]

The case in which marginal costs are independent indicates that the nonseparation result obtained by Laffont and Tirole is not pervasive. To investigate the robustness of their result, consider the case in which marginal cost θ_2 in the second period is a function of the marginal cost θ_1 in the first period and a random variable $\tilde{\varepsilon}$ or $\theta_2 = \theta_2(\theta_1, \varepsilon)$, where ε is a realization of $\tilde{\varepsilon}$. The induced distribution $F_2(\theta_2|\theta_1)$ of θ_2 conditional on θ_1 is assumed to be common knowledge and to have a support $[\theta_2^-, \theta_2^+]$ that is invariant to θ_1. When this distribution is not degenerate, it is possible that the firm has no incentive to quit the regulatory relationship even when commitment is not possible and the period-one mechanism is separating.

To show this, note that perfectness requires that the price in the second period have the same form as the price in (4.19) for a single-period model with the conditional distribution $F_2(\theta_2|\theta_1)$ replacing the unconditional distribution. Consider the mechanism in which the second-period price is[88]

$$p_2(\theta_1, \theta_2) = \theta_2 + (1-\alpha)\frac{F_2(\theta_2|\theta_1)}{f_2(\theta_2|\theta_1)} \tag{6.32}$$

and the fixed charges are

$$\begin{aligned} T_2(\theta_1, \theta_2) = {} & \theta_2 Q(p_2(\theta_1, \theta_2)) + K_2 - p_2(\theta_1, \theta_2) Q(p_2(\theta_1, \theta_2)) \\ & + \int_{\theta_2}^{\theta_2^+} Q_2(p(\theta_1, \theta_2^0))\, \mathrm{d}\theta_2^0. \end{aligned} \tag{6.33}$$

Once the firm observes its second-period marginal cost θ_2, it can earn a profit $\pi_2(\hat{\theta}_1; \theta_2)$, given by

$$\pi_2(\hat{\theta}_1; \theta_2) = \int_{\theta_2}^{\theta_2^+} Q(p_2(\hat{\theta}_1, \theta_2^0))\, \mathrm{d}\theta_2^0, \tag{6.34}$$

by producing in the second period and reporting truthfully. For any period-one report $\hat{\theta}_1$, this period-two profit is strictly positive for any $\theta_2 < \theta_2^+$. Thus, for any report $\hat{\theta}_1$ in period one, the period-two profit in (6.34) provides an incentive to continue rather than quit. Intuitively, if the incentive to continue is stronger than

[87]Ex ante welfare is the same as in the case in which the regulator is able to commit and the firm is known to have the same marginal cost in each period. The ex ante profit of the firm viewed from prior to the point at which the firm learns its marginal cost is also the same.

[88]The ratio $F_2(\theta_2|\theta_1)/f_2(\theta_2|\theta_1)$ is assumed to be nondecreasing in θ_2 for all θ_1.

the incentive to quit as identified in Subsection 6.3.2, a separating mechanism may be feasible even with an inability to make credible commitments. More formally, a separating mechanism can be implemented if the condition in (4.15) for global incentive compatibility is satisfied. That condition is never satisfied if marginal costs are perfectly correlated, is always satisfied if the marginal costs are independent, and may or may not be satisfied with imperfect correlation. Laffont and Tirole (1986a) demonstrate that for small uncertainty about θ_2, that is, near perfect correlation, the regulator never prefers to separate over any closed interval. In that case, separation is too costly. In other cases, a separating mechanism may be both feasible and optimal.

Among the class of separating mechanisms, the optimal mechanism is given by (6.32) and (6.33) and the first-period policies:

$$p_1(\theta_1) = y_\alpha(\theta_1), \tag{6.35}$$

$$\begin{aligned} T_1(\theta_1) = {} & \int_{\theta_1}^{\theta_1^+}\left[Q(p_1(\theta_1^0)) - \beta\int_{\theta_2^-}^{\theta_2^+} Q(p_2(\theta_1^0,\theta_2))\frac{\partial F_2(\theta_2|\theta_1^0)}{\partial\theta_1}\mathrm{d}\theta_2\right]\mathrm{d}\theta_1^0 \\ & + \theta_1 Q(p_1(\theta_1)) + K_1 - p_1(\theta_1)Q(p_1(\theta_1)) - \beta E[\pi_2(\theta_1;\theta_2)], \end{aligned} \tag{6.36}$$

where the expected period-two profit is

$$\begin{aligned} E[\pi_2(\theta_1;\theta_2)] &= \int_{\theta_2^-}^{\theta_2^+}\int_{\theta_2}^{\theta_2^+} Q(p_2(\theta_1,\theta_2^0))\,\mathrm{d}\theta_2^0 f(\theta_2|\theta_1)\,\mathrm{d}\theta_2 \\ &= \int_{\theta_2^-}^{\theta_2^+} Q_2(p(\theta_1,\theta_2))F(\theta_2|\theta_1)\,\mathrm{d}\theta_2. \end{aligned}$$

This is the optimal separating mechanism under the fairness condition. As in the fairness case, however, it may be possible to improve on this mechanism by pooling in the first period as a means of limiting opportunism.

7. Ex ante competition: The selection of the monopolist

The mechanisms developed above establish regulatory policies for a firm that has already been selected to be the franchise monopolist. More generally, however, the regulator may be viewed as selecting a franchise monopolist from among a set of possible suppliers and then implementing a regulatory policy that responds to information that may be obtained once performance has commenced. The context in which the selection and regulation policies will be considered here involves a first period in which the selection is made and a second period in which production takes place. Although the selection and regulation problems must be dealt with simultaneously, a separation exists between the selection and the regulation phases of the regulatory relationship as will be indicated below. Furthermore, the optimal regulatory or pricing policy is that characterized in the previous section.

For the case in which $\alpha = 1$, Loeb and Magat (1979) propose to resolve the selection problem through an auction in which potential suppliers bid a lump-sum for the right to the monopoly franchise. The franchise carries with it the fixed charges in (3.1) and the obligation to satisfy all demand at the price, equal to marginal cost, the firm chooses.[89] The auction may be progressive where lump-sum bids are made sequentially and in public until no more bids are forthcoming or may be a sealed-bid, Vickery (second-price) auction in which the highest bidder is awarded the franchise but pays an amount equal to the second highest bid.[90] In a symmetric model in which the marginal cost of each potential supplier is drawn from the same distribution, the bid function (a mapping from marginal cost to the bid) of each firm will be the same and will be a strictly decreasing function of marginal cost. The highest bid will thus be made by the firm that has the lowest marginal cost, and that firm will pay an amount equal to the profit that the bidder with the second lowest marginal cost would earn if it were selected. The winning bidder thus earns a rent determined by the difference between its marginal cost and the second lowest marginal cost. For the case in which the regulatory objective is the maximization of total surplus ($\alpha = 1$), this mechanism is efficient and deals effectively with the distributive problem, since the franchise payment can be used to offset a portion of the fixed charges in (3.1) paid under the regulatory policy to the selected firm.[91]

If, however, the regulatory objective is to maximize a weighted function of consumer and producer surplus with $\alpha < 1$, the regulator prefers to distort price from marginal cost in order to improve the distribution of surplus. The optimal mechanism in this case still involves the straightforward combination of an auction with the optimal regulatory policy characterized in the previous sections. To demonstrate this in a more general setting, the model developed by Riordan and Sappington (1987a) will be considered. In their model the regulator is

[89] The Loeb and Magat mechanism was proposed as a non-Bayesian mechanism, since the beliefs of the regulator about the firm's costs have no role in the form of either the regulatory policy or the auction. That is, price is equated to marginal cost for any beliefs the regulator might have about the marginal cost of the selected firm. As indicated above, this is a consequence of the specification of the welfare function that weights consumer and producer surplus equally so that distributional considerations are irrelevant to the design of the mechanism.

[90] See Vickrey (1961) and Milgrom and Weber (1982).

[91] The franchise payment must be redistributed in a manner that does not affect demand.

assumed to be able to commit to both the selection and the regulation policies to be implemented.

Their model includes a set of possible bidders each of which has private, but imperfect, information about the marginal costs that it will incur once it has been selected and has sunk its fixed costs.[92] The firm thus has ex ante private information about its possible marginal costs. Ex post, once selection has occurred and fixed costs are sunk, but before production has begun, the firm will privately observe its actual marginal cost. Since production takes place after the firm observes its marginal cost, the mechanism can base the price, and hence output, on a report on marginal cost.

Let θ_2 denote the marginal cost the firm will incur once it has sunk a cost K in the construction of its facilities. This marginal cost is known neither to the regulator nor the firm at the time of selection but will be privately observed by the firm before production commences. Prior to selection, the firm has private information, denoted by θ_1, that conditions the distribution function $F_2(\theta_2|\theta_1)$ of θ_2, where a higher θ_1 corresponds to higher marginal costs in the sense of first-degree stochastic dominance; i.e. if $\theta_1^1 > \theta_1^2$, then $F_2(\theta_2|\theta_1^1) \leq F_2(\theta_2|\theta_1^2)$, $\forall\theta_2$, with the strict inequality holding for some θ_2. Potential supplier i thus has a parameter θ_1^i that is drawn independently from a distribution $F_1(\theta_1)$ that is common knowledge. Each bidder thus knows its own θ_1^i, the distribution of the θ_1^j of the other firms, and $F_2(\theta_2|\theta_1)$. The regulator knows only the distribution $F_1(\theta_1)$, the number n of firms, and the distribution function $F_2(\theta_2|\theta_1)$.

The bidding mechanism specifies a function $\Upsilon(\hat{\theta}_1)$ that determines the payment by the selected firm for the franchise as a function of its report $\hat{\theta}_1$. The winning bidder is the firm that reports the lowest $\hat{\theta}_1$, and if the mechanism induces truthful reports, the lowest cost supplier will be chosen. Since the marginal cost θ_2 will be known to the selected firm prior to production, the regulator at the time of selection commits to a regulatory policy that requires the selected firm to make a report $\hat{\theta}_2$ once its marginal cost has been realized. That report thus conditions the price $p(\hat{\theta}_1, \hat{\theta}_2)$ and the fixed charges $T(\hat{\theta}_1, \hat{\theta}_2)$. The sequence of actions and events is thus that firms learn their θ_1^i's, the regulator commits to the selection–regulation mechanism $M = \{(\Upsilon(\hat{\theta}_1), p(\hat{\theta}_1, \hat{\theta}_2), T(\hat{\theta}_1, \hat{\theta}_2)), \hat{\theta}_2 \in [\theta_2^-, \theta_2^+], \hat{\theta}_1 \in [\theta_1^-, \theta_1^+]\}$, each firm "bids" a $\hat{\theta}_1^i$, and the firm with the lowest $\hat{\theta}_1^i$ is selected. That firm then sinks K, realizes θ_2, and reports $\hat{\theta}_2$ which completes the determination of the price $p(\hat{\theta}_1, \hat{\theta}_2)$ and the fixed charges $T(\hat{\theta}_1, \hat{\theta}_2)$. The equilibrium sought is a Bayesian Nash equilibrium in which each firm i chooses its strategy $\hat{\theta}_1^i(\theta_1^i)$ given the strategies $\hat{\theta}_1^j(\theta_1^j) = \theta_1^j$, $j = 1, \ldots, i-1, i+1, \ldots, n$, of the other firms and given that reporting $\hat{\theta}_2^i = \theta_2^i$ is a dominant strategy once the winner has been determined.

[92] This model thus corresponds to the case in which the firm must build a new plant rather than to the case in which the firm already has a plant in place and knows its costs.

The equilibrium in the Riordan and Sappington model may be characterized by viewing the choice of a regulatory policy and the selection of a firm as two phases of the regulatory process. Suppose initially that the regulator faced only one potential supplier with private information θ_1 that conditions the distribution function $F_2(\theta_2|\theta_1)$ of the marginal cost θ_2. In the context of the theory of commitment presented in Subsection 6.2, the model may be thought of as having two periods. The first period extends from the time the contract is offered to just prior to the sinking of the fixed cost and thus involves the revelation of θ_1 but no production. The second period commences with the sinking of the fixed cost and involves the revelation of θ_2 and the production of a quantity $Q(p(\theta_1, \theta_2))$. The optimal price is thus that given in (6.12), or

$$p(\theta_1, \theta_2) = \theta_2 - (1-\alpha)\frac{\partial F_2(\theta_2|\theta_1)/\partial\theta_1}{f_2(\theta_2|\theta_1)}\frac{F_1(\theta_1)}{f_1(\theta_1)}, \tag{7.1}$$

which depends on the marginal cost and on the informativeness of θ_1 about θ_2.[93] As will be indicated below, this price will also be optimal when the selection phase is incorporated. Consequently, the regulatory policy does not depend on the number n of firms.

The remaining problem for the regulator is to select a firm and to determine the bid function $\Upsilon(\theta_1)$. Viewed from the point in time at which the bidding takes place, the expected profit earned in the second period by the selected firm is given in (6.3), so the value $V(\hat{\theta}_1; \theta_1)$ of the opportunity to bid is

$$V(\hat{\theta}_1; \theta_1) = \left[\int_{\theta_2^-}^{\theta_2^+} Q(p(\hat{\theta}_1, \theta_2))F_2(\theta_2|\hat{\theta}_1)\,\mathrm{d}\theta_2 - \Upsilon(\hat{\theta}_1)\right](1 - F_1(\hat{\theta}_1))^{n-1}, \tag{7.2}$$

where $(1 - F(\hat{\theta}_1))^{n-1}$ is the probability that the other $n-1$ firms have values of θ_1 above $\hat{\theta}_1$ and $\Upsilon(\hat{\theta}_1)$ is the amount the firm pays for the franchise if it is selected. To ensure that the firms bid $\hat{\theta}_1 = \theta_1$, the function $\Upsilon(\theta_1)$ is specified as

$$\begin{aligned}\Upsilon(\theta_1) = {} & \int_{\theta_2^-}^{\theta_2^+} Q(p(\theta_1, \theta_2))F_2(\theta_2|\theta_1)\,\mathrm{d}\theta_2 \\ & + \int_{\theta_1}^{\theta_1^+}\left(\frac{(1-F_1(\theta_1^0))^{n-1}}{(1-F_1(\theta_1))^{n-1}}\right)\int_{\theta_2^-}^{\theta_2^+} Q(p(\theta_1^0, \theta_2))\frac{\partial F_2(\theta_2|\theta_1^0)}{\partial\theta_1}\,\mathrm{d}\theta_2\,\mathrm{d}\theta_1^0.\end{aligned} \tag{7.3}$$

[93] The fixed charges function that implements this pricing policy is given in (6.20).

The value $V(\theta_1) \equiv V(\theta_1; \theta_1)$ of the opportunity to bid is then

$$V(\theta_1) = \int_{\theta_1}^{\theta_1^+} \int_{\theta_2^-}^{\theta_2^+} Q(p(\theta_1^0, \theta_2)) \frac{\partial F_2(\theta_2 | \theta_1^0)}{\partial \theta_1} \mathrm{d}\theta_2 (1 - F_1(\theta_1^0))^{n-1} \mathrm{d}\theta_1^0. \quad (7.4)$$

This value is a strictly decreasing function of the number n of firms, so more competitors reduces the rents of the selected firm. If θ_1 were uninformative about θ_2, the value $V(\theta_1)$ would be zero, since all firms would make the same "bid". The regulator then may select one at random. The franchise fee in this case equals the expected profit under the regulatory policy, so $V(\theta_1) = 0$.

The regulator will select the firm that reports the lowest θ_1, and viewed ex ante the probability distribution of the winning bid is that of the lowest order statistic θ_1^* which has a density function $f_1^*(\theta_1^*)$ given by

$$f_1^*(\theta_1^*) \equiv n(1 - F_1(\theta_1^*))^{n-1} f_1(\theta_1^*).$$

The expected welfare thus is

$$\begin{aligned} W = n\int_{\theta_1^-}^{\theta_1^+} \int_{\theta_2^-}^{\theta_2^+} \Bigg\{ & \left[\int_{p(\theta_1, \theta_2)}^{\infty} Q(p^0)\,\mathrm{d}p^0 + (p(\theta_1, \theta_2) - \theta_2) Q(p(\theta_1, \theta_2)) - K \right] \\ & \times f_2(\theta_2|\theta_1) f_1(\theta_1) \\ & + \left[(1-\alpha) F_1(\theta_1) Q(p(\theta_1, \theta_2)) \frac{\partial F_2(\theta_2|\theta_1)}{\partial \theta_1} \right] (1 - F_1(\theta_1))^{n-1} \Bigg\} \mathrm{d}\theta_2\, \mathrm{d}\theta_1. \end{aligned} \quad (7.5)$$

Maximizing with respect to $p(\theta_1, \theta_2)$ yields (7.1).[94]

An important feature of this mechanism is the separation of selection and regulation. This separation results because the firm does not learn its marginal cost until after the selection has been made and because the regulator is able to commit to the pricing policy that will be implemented once selection has been completed.

Riordan and Sappington (1987b) also consider the case in which the regulator is unable to commit to the pricing policy that will be offered to the firm chosen in the selection phase of the mechanism. After selection, the information of the regulator is represented by $F_2(\theta_2|\theta_1)$, and the firm can only expect that the

[94] The Loeb and Magat mechanism obtains as a special case when $\alpha = 1$ in which case the price is set equal to marginal cost.

regulator will fully exploit the information available to it. The price $p_2^*(\theta_1, \theta_2)$ is thus given by

$$p_2^*(\theta_1, \theta_2) = \theta_2 + (1 - \alpha)\frac{F_2(\theta_2|\theta_1)}{f_2(\theta_2|\theta_1)}. \tag{7.6}$$

Even though commitment is not possible in this case, the equilibrium is separating, since the firm only has one opportunity to produce and thus cannot employ the strategy identified in Subsection 6.3.

To compare the policy without commitment to the regulatory policy with commitment, consider the example in (6.13) in which $\tilde{\theta}_2$ is a convex combination of $\tilde{\theta}_1$ and $\tilde{\varepsilon}$, which are uniform on [0, 1]. The price $p_2(\theta_1, \theta_2)$ with commitment is then

$$p_2(\theta_1, \theta_2) = \theta_2 + (1 - \alpha)\gamma\theta_1, \quad \text{for } \theta_2 \in [\gamma\theta_1, 1 - \gamma + \gamma\theta_1],$$

and the price $p_2^*(\theta_1, \theta_2)$ without commitment is

$$p_2^*(\theta_1, \theta_2) = \theta_2 + (1 - \alpha)(\theta_2 - \gamma\theta_1), \quad \text{for } \theta_2 \in [\gamma\theta_1, 1 - \gamma + \gamma\theta_1].$$

It is straightforward to demonstrate that the price with commitment is lower than the price without commitment if and only if $\theta_2 > 2\gamma\theta_1$. Consequently, if θ_1 is not very informative (low γ), commitment leads to a lower price, and if θ_1 is highly informative (high γ), commitment leads to a higher price. Since any policy feasible in the absence of commitment is also feasible with commitment (but not vice versa), the regulator is, of course, better off with commitment even though the price may be higher.

In a related model McAfee and McMillan (1986) consider a selection model in which the selected firm makes an unobservable effort which affects an observable cost. They restrict attention to policies that are linear in the observable cost, but they allow the firms to be risk averse with a utility function exhibiting constant absolute risk aversion. Because of these two assumptions the effort taken by the selected firm depends only on the share of the cost reimbursed by the regulator. They provide a characterization of the optimal regulatory policy for the case in which a first-price, sealed-bid auction is employed for selection. The regulator prefers to employ a fixed-price pricing policy to induce effort by the firm, but prefers to use a cost-plus pricing policy to reduce the information rents due to the firm's private information. McAfee and McMillan demonstrate that the closer the policy is to cost-plus, the lower are the initial bids, since the rents appropriable by the firms are lower under such a policy.

In an extension of their observable cost model, Laffont and Tirole (1987) consider the optimal selection and regulatory mechanism for the case in which potential supplier i of an indivisible good has a cost function of the form:

$$C^i = \theta^i - a^i, \quad i = 1, \ldots, n,$$

where a^i is effort. The optimal mechanism selects the most efficient firm, the one with the lowest θ^i, and provides a regulatory policy of the same form as that when there is only one firm. That is, the regulatory policy depends only on the report of the selected firm. The franchise fee, however, may depend on all the bids. As the number of firms increases, the price specified in the regulatory policy approaches the first-best price, since the information rents captured by the firm, and hence the distortion made to reduce the marginal information rents, approach zero. Laffont and Tirole demonstrate that this mechanism can be implemented in dominant strategies through an auction in which the franchise fee depends on the lowest and the next lowest bids (a Vickery auction) using payment functions that are linear in the observed cost as in (5.6). The selected firm captures rents based on the difference between its θ^i and the θ^j of the next most efficient firm.

8. Ex post competition

In the models considered in the previous section, the regulator utilizes an auction as a means of creating an ex ante competion that identifies the most efficient firm. If a firm is already the subject of regulation, the regulator no longer has the opportunity to utilize ex ante competition. It may, however, be able to utilize ex post competition to reduce the information rents and to improve efficiency. For example, the regulator may be able to use the threat of entry or the opportunity to switch to an alternative supplier as a means of improving performance.

Caillaud (1986) considers the case of the regulation of a single firm when there is an unregulated competitive fringe of firms that can also supply the good. This might correspond to the case of a regulated railroad and a competitive trucking industry or to a regulated AT & T and a competitive fringe of long-distance carriers not subject to price or profit regulation. His mechanism utilizes the competitive fringe as a means of controlling the information rents of the regulated firm. The regulated firm has private information about its marginal costs θ as in the model considered in Section 4, and the marginal cost v of the competitive fringe is private information. The regulator can use its prior information about v in its regulatory policy, but the regulator does not have the authority to regulate the fringe and hence cannot induce the fringe to reveal its information ex ante. Ex post, however, consumers can buy from either the regulated firm or the fringe and will do so based on their respective prices.

Consequently, the price that will prevail for the good is the minimum of v and the price established for the regulated firm.

Caillaud demonstrates that the nature of the optimal regulatory policy depends importantly on the relationship between v and θ. In the case in which they are independent, the competitive fringe can be viewed as an option that consumers may exercise if the price established for the regulated firm is higher than the price in the competitive industry. This option is more valuable to consumers the higher is the reported marginal cost of the regulated firm. Viewed from the perspective of the regulator, this option allows the regulator to control better the information rents of the firm through greater distortions of the regulated price from marginal cost. The regulator can set a higher price because the higher is that price the more likely it is that consumers will be able to avoid that price by exercising their option by purchasing from the competitive fringe.

The regulated price in this case is determined as in Section 4 with the modification that the quantity $q(\theta)$ the firm produces satisfies:

$$\begin{aligned} &q(\theta) \text{ s.t. } p(\theta) = E\left[\min\{v, P(q(\theta))\}\right], && \text{if } p(\theta) < E[v], \\ &q(\theta) = 0, && \text{if } p(\theta) \geq E[v], \end{aligned} \tag{8.1}$$

where $P(q)$ denotes the inverse demand function and E denotes expectation. The quantity is thus based on the expected price that will prevail for the good. The quantity is nonincreasing in θ, and if the price $p(\theta)$ exceeds the expected price of the competitive fringe, the regulated firm is not allowed to produce.

Caillaud also analyzes the case in which the marginal cost in the competitive fringe is perfectly correlated with the marginal cost of the regulated firm. A truthful report by the firm of its marginal cost thus identifies for the regulator the marginal cost of the competitive industry. Since the marginal costs are perfectly correlated, the price that will prevail in the market equals $\min\{v, P(q(\theta))\}$. The revenue function of the firm thus has a "kink", and the programming problem of the regulator is nonconvex. Caillaud is able to characterize the optimal regulatory mechanism and show that the regulator may prefer that the competitive industry produce for some θ because the threat that they will produce diminishes the incentive of the firm to overstate its costs and thus reduces the information costs to the regulator. The quantity produced by the regulated firm is a nonincreasing function of θ but may be discontinuous. When the competitive fringe does not produce, the price is that for the optimal static mechanism given in (4.19). On other intervals, the price may be lower or higher than that in (4.19).

Demski, Sappington and Spiller (1986) consider the case in which a regulated firm has private information about its costs which are correlated with the costs of another firm that the regulator could allow to enter the market. The regulator does not know the cost of either firm and thus designs a regulatory mechanism that specifies how much each firm will be allowed to produce. The regulator uses the possibility of entry both as a means of obtaining information from the cost report of the potential entrant, which may be correlated with the private information of the regulated firm, and as an alternative source of output. The information serves to reduce the rents of the regulated firm in the same manner as an audit as considered in Subsection 5.2. The possibility that the potential entrant may be allowed to produce also improves the efficiency of the regulatory mechanism. They show that the reduction in information rents resulting from entry may be sufficient that the mechanism specifies that the entrant produce even though it has higher costs than the regulated firm.

Anton and Yao (1987) consider the case in which a regulator, the Department of Defense in their setting, contracts with a primary source that has private information about its marginal cost. The regulator is able to commit to an initial procurement policy but is unable to commit to a policy for the period after the initial procurement phase has been completed. The regulator then may at that time switch to a second-source supplier, so the regulator makes the reprocurement decision after it has learned the marginal cost of the primary source. Although the regulator cannot commit to a reprocurement policy, it can commit to the mechanism, an auction, to be used to determine if production in the second period will be assigned to the primary source or to the second source. In their model, costs are characterized by a learning curve with no spillover, so the primary source has a cost advantage over a second source. This gives the primary source some assurance that it will be selected as the supplier in the second period. The possibility that a second source may be selected, however, serves to control the strategic advantage of the primary source.

9. Two-sided private information

9.1. *Ex ante private information*

In the models considered above, the private information in the regulatory relationship is "one-sided" in the sense that the firm's type is unknown to the regulator but the regulator's type is known to the firm. The regulator, however, may also have private information that may be of interest to the firm.[95] For example, the regulator may have information about demand that would affect the firm's preferences regarding its selection of a regulatory policy from those comprising the mechanism offered by the regulator. Similarly, the regulator may

[95] Myerson (1983) initiated the study of this class of models which he labeled "informed principal" models.

have private information about its preferences, which may be thought of as corresponding to private information about the weight α it assigns to profit in its welfare function. When private information is two-sided in this sense, the mechanism design may become more complicated because the regulator may be concerned that its announcement of a mechanism will reveal to the firm information that the firm will use to the regulator's disadvantage.

Maskin and Tirole (1986) consider a model in which the regulator has private information which is not an argument of the firm's preference function.[96] For example, if the regulator's private information is about the weight α on profits in the regulator's welfare function this condition is satisfied since the firm's preferences do not depend on α. If, however, the regulator knows the demand function but the firm does not, the regulator's information directly affects the profit of the firm. Their theory pertains to the former and not the latter case.

If the preferences of the regulator and the firm are linear in the revenue $p(\theta)Q(p(\theta)) + T(\theta)$, Maskin and Tirole show that the regulator will employ the same mechanism when it has private information about its type as it would if its type were known to the firm.[97] Consequently, if the regulator knew α but the firm did not, the equilibrium mechanism is that characterized in Subsection 4.2. The regulator thus loses nothing by revealing its information to the firm. Furthermore, the equilbrium mechanism is the same for whatever information the firm may have about α.

More generally, when the preferences of the regulator and the firm are not linear in the payment, the regulator may prefer to conceal its type rather than to have it revealed by the mechanism it offers.[98] The regulator's preferences are represented in general as $W(p, T, \tau^i)$, where τ^i, $i = 1, \ldots, n$, is one of a finite number of types, and the firm's preferences are represented as $V(p, T, \theta^j)$, $j = 1, \ldots, m$, where θ^j is one of a finite number of values. The game considered by Maskin and Tirole involves three stages. In the first stage the regulator offers a mechanism to the firm, and in the second stage the firm either accepts or rejects it.[99] In the third stage both parties announce their types.[100] At the beginning of the first period the firm has prior beliefs, represented by probabilities $(\rho_i, i = 1, \ldots, n)$, about the possible types $(\tau^i, i = 1, \ldots, n)$ of the regulator. Upon announcement of the mechanism the firm may revise its beliefs, but if all types of

[96] They label this case as "independent values" and the case in which the firm does care about the regulator's type as "dependent values". The independent values case pertains to adverse selection settings, since if moral hazard is present due to imperfect observability the regulator's information affects the firm's beliefs which then enters into preferences.

[97] The firm is assumed to have one of a finite number of types, and the prior information of the regulator is assumed to be such that the probability of each possible types is positive.

[98] Myerson (1983) refers to this as the principle of inscrutability.

[99] The regulator is assumed to be able to commit to a mechanism, but the firm does not commit to participate.

[100] Attention is restricted here to direct revelation mechanisms.

the regulator prefer in equilibrium to offer the same mechanism, the firm's posterior beliefs will be the same as its prior beliefs. The equilibrium sought is a perfect Bayesian Nash equilibrium in which each player acts optimally at each stage of the game and beliefs are updated according to Bayes' rule and are consistent with the equilbrium strategies and the observed actions.[101] Maskin and Tirole show that a perfect Bayesian Nash equilibrium exists and furthermore that an equilibrium exists in which all types of the regulator offer the same mechanism.[102] If the firm's preferences satisfy the usual sorting condition,[103] there are only a finite number of equilibria in the regulatory game.

Maskin and Tirole's results for two-sided private information are important because if the firm can reasonably be taken to be risk neutral and the regulator employs a surplus measure of welfare the regulator will prefer to reveal its information about α truthfully even when both parties have private information. The firm thus need not consider more sophisticated strategies than to report its type truthfully in response to the announced mechanism. The mechanisms characterized in the previous section then are optimal for whatever information the firm may have about α.

9.2. *Ex ante and ex post two-sided private information*

In the Maskin and Tirole model both the regulator and the firm have private information at the beginning of the regulatory relationship. In some settings, however, the firm may have private information ex ante, and the regulator may privately observe ex post a parameter that affects either performance or the desirability of alternative strategies. For example, suppose that ex ante the firm knows its marginal cost θ but at the time the regulatory mechanism is announced neither the firm nor the regulator knows the weight α that will be employed by the regulator. That weight will be determined prior to the time at which the pricing policy is to be established and will be privately observed by the regulator. This might correspond to the case in which the firm must construct a plant prior to knowing the basis on which the regulator will establish the regulatory mechanism. The process by which α is determined will not be modeled but instead will be represented by a density function $g(\alpha)$ which is assumed to be positive on $[0, 1]$. The regulatory policy is based on both the ex ante and the ex post

[101] To support the equilibrium, beliefs off, as well as on, the equilibrium path are required. The reader is referred to Maskin and Tirole for the specification of the off-the-equilibrium-path beliefs that support the equilibrium.

[102] Their method of analysis involves the ingenious device of constructing a fictitious economy in which the possible types of the regulator trade "slack" in the individual rationality and incentive compatibility constraints. The equilibrium in the game is shown to correspond to the equilibrium in the fictitious economy.

[103] For the specification of costs in (4.13), this sorting condition is satisfied.

information, so a policy $(p(\hat{\theta}, \hat{\alpha}), T(\hat{\theta}, \hat{\alpha}))$ is specified as a function of reports by both the firm and the regulator. The regulator is assumed to be able to commit to the mechanism M defined as

$$M = \{(p(\hat{\theta}, \hat{\alpha}), T(\hat{\theta}, \hat{\alpha})), \hat{\theta} \in [\theta^-, \theta^+], \hat{\alpha} \in [0,1]\}.$$

Because the firm does not observe the ex post private information α, the regulator must assure the firm that it will not be exploited by the regulator misreporting its information in order to obtain a more favorable policy. The regulator thus must structure the regulatory policy so that the firm can be confident that the regulator will implement the policy anticipated in equilibrium by the firm. Since the revelation principle continues to apply to this situation, the regulator will structure its policy so that it has an incentive to report truthfully the information it will receive. At the beginning of the relationship, the firm, in choosing its report, thus can rely on this incentive for assurance about the policy that will be implemented. Riordan and Sappington (1987b) present a theory applicable to this situation. Methodologically, the nested revelation principle approach addressed in Subsection 6.2 forms the basis for the characterization of the equilibrium.

For any report $\hat{\theta}$ by the firm, the regulator will report truthfully $\hat{\alpha} = \alpha$ if the policy is such that

$$\begin{aligned} W(\alpha|\hat{\theta}) &\equiv \int_{p(\hat{\theta}, \alpha)}^{\infty} Q(p^0)\,\mathrm{d}p^0 - T(\hat{\theta}, \alpha) + \alpha\pi(\hat{\theta}, \alpha; \theta) \\ &\geq W(\hat{\alpha}; \alpha|\hat{\theta}) \equiv \int_{p(\hat{\theta}, \hat{\alpha})}^{\infty} Q(p^0)\,\mathrm{d}p^0 - T(\hat{\theta}, \hat{\alpha}) + \alpha\pi(\hat{\theta}, \hat{\alpha}; \theta), \\ &\qquad \forall \hat{\alpha}, \forall \alpha \in [0,1], \forall \hat{\theta}, \theta \in [\theta^-, \theta^+], \end{aligned} \tag{9.1}$$

where $\pi(\hat{\theta}, \alpha; \theta)$ denotes the profit of the firm when the regulator implements the policy corresponding to α. A price $p(\hat{\theta}, \hat{\alpha})$ is implementable if

$$\frac{\mathrm{d}W(\alpha|\hat{\theta})}{\mathrm{d}\alpha} = \pi(\hat{\theta}, \hat{\alpha}; \theta),$$

and the welfare given a truthful report by the firm is thus

$$W(\alpha|\theta) = W(1|\theta) - \int_{\alpha}^{1} \pi(\theta|\alpha^0)\,\mathrm{d}\alpha^0, \tag{9.2}$$

where $\pi(\theta, \alpha) \equiv \pi(\theta, \alpha; \theta)$. The fixed charges function $T(\theta, \alpha)$ that implements

$p(\theta, \alpha)$ can then be obtained from (9.1) and (9.2). Any policy satisfying (9.2) will thus (locally) assure the firm that once the regulator has learned α it will implement the policy corresponding to that α.

The policy will be incentive compatible from the firm's perspective if

$$\pi(\theta;\theta) \geq \pi(\hat{\theta};\theta), \quad \forall\hat{\theta}, \forall\theta \in [0,1], \tag{9.3}$$

where

$$\pi(\hat{\theta};\theta) \equiv \int_0^1 \big[p(\hat{\theta},\alpha)Q\big(p(\hat{\theta},\alpha)\big) + T(\hat{\theta},\alpha) - \theta Q\big(p(\hat{\theta},\alpha)\big) - K\big]g(\alpha)\,\mathrm{d}\alpha. \tag{9.4}$$

Incentive compatibility requires (locally) that the analog of (4.8) (or (4.7)) be satisfied, so a price function $p(\theta, \alpha)$ is implementable by fixed charges $T(\theta, \alpha)$ such that

$$\int_0^1 T(\theta,\alpha)g(\alpha)\,\mathrm{d}\alpha$$

satisfies the analog of (4.11) and (9.4). The function $T(\theta, \alpha)$ thus must make the policy incentive compatible for both the firm an the regulator.[104] Substitution of $\pi(\theta, \alpha) \equiv \pi(\theta, \alpha; \theta)$, which is the integrand in (9.4), into $W(\alpha|\theta)$ and substitution of the expression analogous to (4.8) indicates that the optimal price is $p(\theta, \alpha) = y_\alpha(\theta)$. The same price will be implemented as in the case in which the welfare weight α is common knowledge. This result is analogous to that obtained by Maskin and Tirole, although the timing of the arrival of information is different. Ex post private information of the regulator about α thus has no effect on the pricing policy. The resulting welfare will be affected, however, since the regulator must satisfy the constraints in (9.1).

10. Non-Bayesian mechanisms

The above mechanisms are based on an underlying information or probability structure that forms the basis for a Bayesian game. The equilibrium mechanism is thus sensitive to the prior information available to the regulator. From a Bayesian perspective this sensitivity is desirable because the regulator is fully utilizing all available information about the firm. From a non-Bayesian perspec-

[104] This analysis is based on local representations of the incentive compatibility conditions, so the resulting policies must be checked to determine if global incentive compatibility is satisfied.

tive, however, the designer of a regulatory institution might prefer a regulatory mechanism that is invariant to the subjective assessments of whoever occupies the position of the regulator. A non-Bayesian mechanism might also be employed if the information structure has sufficiently many dimensions that the optimal mechanism defies analytical characterization. In such situations, a regulator may seek a mechanism that, although not optimal from a Bayesian perspective, has certain desirable properties. Finsinger and Vogelsang (1982) have considered a variety of iterative, non-Bayesian mechanisms with the properties that they converge to marginal cost pricing when the regulator is able to observe ex post either the expenditures or the profit of the firm in each period.[105]

In their model the firm is allowed to choose price and is required to satisfy all demand at that price. The firm is assumed to be fully strategic and to maximize the discounted sum of its net income under the mechanism offered by the regulator. The regulator is assumed to be able to commit to the mechanism and is able to observe the profit of the firm as well as the price and quantity. The regulator does not know the demand and/or cost functions of the firm, however, which are private information of the firm but are known to remain the same in each period. The net compensation or income I_i of the owners or managers of the firm in period i is specified as

$$I_i = \pi_i - \pi_{i-1} + q_{i-1}(p_{i-1} - p_i) + \delta, \tag{10.1}$$

where $\pi_i = P(q_i)q_i - C(q_i)$, $p_i = P(q_i)$, δ is a constant base income, and π_0, p_0, and q_0 are initial parameters specified by the regulator. This compensation function is a linear approximation of the change in total surplus resulting from a change in price from p_{i-1} to p_i, so the firm finds its interests to be aligned with those of aggregate welfare.

The objective of the firm is to maximize the discounted present value I of its income or

$$I = \sum_{i=1}^{\infty} \frac{1}{(1+\rho^i)} I_i,$$

where ρ is the discount rate.[106] The firm will choose q_i to satisfy the necessary

[105]In addition to the mechanism presented here, Vogelsang and Finsinger (1979) have considered mechanisms that either are not immune to strategic behavior by the firm, as demonstrated by Sappington (1980), or require that the firm act myopically. Tam (1981) also provides a mechanism that converges to efficient pricing, but it is myopic in that it requires the firm to maximize current period income rather than the discounted present value of income. See Finsinger and Vogelsang (1985) for an analysis of the Tam mechanism.

[106]Note that the regulator need not know the discount rate used by the firm.

condition:

$$\frac{\rho}{1+\rho}[P'(q_i)q_i + P(q_i) - C'(q_i)] - q_{i-1}P'(q_i)$$

$$+ \frac{1}{1+\rho}[P(q_i) - P(q_{i+1}) + P'(q_i)q_i] = 0. \tag{10.2}$$

Because the interests of the regulator and the firm are aligned, in each successive period the firm's choice results in an increase in aggregate welfare. This mechanism leads to efficiency in the limit, as can be seen by noting that at the steady state in which $q_{i-1} = q_i = q_{i+1}$ only a price equal to marginal cost satisfies (10.2).

The strength of this mechanism is that it produces a welfare improvement in each successive period and converges to marginal cost pricing. The mechanism, however, has a number of limitations. First, it is not clear how this mechanism would perform for a nonstationary model in which either the cost function or demand changes over time or in which profit is affected by randomness. Second, measurement or monitoring noise may reduce the efficiency of the mechanism. Third, the mechanism does not utilize either prior information or the information from the observation of profit in each period to improve the form of the mechanism. For example, in each period the regulator observes the profit of the firm and if the firm had private information about its constant marginal cost, the regulator would be able to determine the marginal cost from the observed profit. The regulator could then exploit that information in future periods. The firm would, of course, recognize this and act strategically. The Vogelsang and Finsinger mechanism, however, is based on the assumption that the regulator is able to commit not to exploit this information, but that may not be optimal.[107] Another potential weakness of the mechanism is the determination of the initial parameters π_0, p_0, q_0, and δ. For example, if the firm has increasing returns to scale, the regulator would not know how to set the constant payment δ. Similarly, the firm could participate even if it were inefficient to do so, if δ were set too high. Finally, as with the multiperiod Bayesian mechanisms considered in Section 6, the regulator must be able to commit credibly to the mechanism.

Sappington and Sibley (1988) propose a non-Bayesian mechanism that improves on the Vogelsang and Finsinger mechanism by providing a payment that equals the exact change in consumer surplus from one period to the next. In contrast to the Finsinger and Vogelsang mechanism, this mechanism requires that the regulator and the firm have symmetric information about the demand

[107] Although the Bayesian approach of Baron and Besanko addressed in Subsection 6.2.1 demonstrates that in the case of perfect correlation the regulator never exploits the information, this may not be the case in a non-Bayesian mechanism.

function. Their mechanism is intended to maximize consumer surplus and to deal with any incentive the firm might have to waste resources. The firm is allowed in each period to retain its current profits π_i and receives a payment S_i given by

$$S_i = \int_{p_i}^{p_{i-1}} Q(p)\,\mathrm{d}p - q_{i-1}(p_{i-1} - p_i) + C(q_{i-1}) - q_{i-1}p_i. \tag{10.3}$$

Substituting the expression for operating profit,

$$\pi_{i-1} = p_{i-1}q_{i-1} - C(q_{i-1}),$$

and simplifying yields the income I_i in period i as[108]

$$I_i = \pi_i - \pi_{i-1} + \int_{p_i}^{p_{i-1}} Q(p)\,\mathrm{d}p. \tag{10.4}$$

This expression is analogous to that in Finsinger and Vogelsang's mechanism with the exception that the change in welfare is represented exactly.

Instead of viewing this mechanism as analogous to that of Finsinger and Vogelsang, the Sappington and Sibley mechanism can be more appropriately viewed as an extension of the Loeb and Magat mechanism to a dynamic context. In a static model the only means available to deal with the distribution of surplus is an auction. In a dynamic setting, however, distribution may be dealt with by intertemporal transfers between consumers and the firm. Thus, the firm can be given an incentive for efficiency and the distributive issue can be resolved by taking away in the current period the profit earned by the firm in the previous period. This is apparent in the statement of the firm's net income in (10.4).

To interpret the Sappington and Sibley mechanism, rewrite the last term in (10.4) as the difference between consumer surplus at the prices p_i and p_{i-1}. The income is then

$$\begin{aligned} I_i &= \pi_i + \int_{p_i}^{\infty} Q(p)\,\mathrm{d}p - \pi_{i-1} - \int_{p_{i-1}}^{\infty} Q(p)\,\mathrm{d}p \\ &= TS_i(p_i) - TS_{i-1}(p_{i-1}), \end{aligned} \tag{10.5}$$

where $TS(p_i)$ denotes total surplus. The income of the firm in each period thus is the difference between the total surplus in the current period and the total surplus in the prior period. Maximizing the present value of net income induces the firm immediately to choose price equal to marginal cost and to choose the

[108] Note that when $I_i = 0$ this is also the difference between the profit $\pi(\theta_i)$ and $\pi(\theta_{i-1})$ in (4.8a). The incentive properties of the mechanism thus are the same as that characterized in Section 4.

minimum cost (no waste). The firm will agree to participate in the mechanism if it will earn a nonnegative profit in the first period, and in subsequent periods it will earn zero profits and thus will be willing to participate.[109] This mechanism is thus the dynamic extension of the Loeb and Magat mechanism. Even though Sappington and Sibley state the regulator's objective as the maximization of consumer surplus, the ability to redistribute costlessly provides an equivalence between consumer surplus and total surplus maximization. Except for the problem of establishing the policy in the initial period, the prior information of the regulator is irrelevant to the mechanism design as it is to the Loeb and Magat mechanism.

In the case in which the regulator does not know the discount rate employed by the firm, the mechanism results in rents to the firm in the first period and zero rents thereafter when it is common knowledge that the firm has the same cost function in every period. If the regulator knew the discount rate, those rents could be eliminated. The Sappington and Sibley mechanism also gives the firm the incentive to be efficient in every period and to choose efficiently among investments that can lower costs in future periods. Randomness in the firm's costs also does not result in inefficiency if the discount rate is known. This indicates the power resulting from the ability to observe expenditures in each period and to be able to commit to policies. The difficulties associated with ensuring commitment have been addressed in Section 6.

11. Extensions and applications

This section identifies an additional set of issues that have been studied in the context of theory addressed here.

11.1. Multiple regulators

The above models pertain to regulatory settings with a single regulator, but regulatory jurisdictions may be overlapping or different regulators may have control over different aspects of a firm's performance.[110] Baron (1985b) considers the case of a firm such as an electric utility that is subject to regulation by a public utility commission (PUC) responsible for the pricing policy and an environmental regulator (EPA) responsible for controlling a pollution externality. The firm is assumed to have private information about the effectiveness of

[109] The first-period profit results from the choice of the initial parameters.

[110] Bernheim and Whinston (1986) have considered a model with multiple principals in which information is symmetric but the actions of the agent are unobservable.

abatement technologies applied to its production process. The regulators are modeled as having conflicting objectives with the PUC maximizing a weighted sum of consumer surplus and profit and the EPA minimizing a weighted sum of the environmental damage and the abatement burden on the firm. Since the EPA has authority to act unilaterally to deal with the pollution problem and since the PUC has the responsibility to provide the firm with a fair return, the EPA is in a position to act as a Stackelberg leader. Furthermore, since the pricing procedures employed by the PUC are in the public domain, the EPA can anticipate the response of the PUC to any pollution control policy it chooses.

Because of the conflicting objectives of the regulators, both cooperative and noncooperative equilibria are of interest. In the noncooperative equilibrium the EPA sets the maximum allowable emissions fee and mandates an abatement standard that is more stringent than that which the regulators would choose in a cooperative equilibrium. The PUC is forced to respond with prices that are higher than would be set under cooperation. The firm prefers that the regulators not cooperate because it then earns greater rents on its private information. Under plausible conditions the EPA prefers noncooperative regulation because it is better able to serve its own mandate than if it had to take into account the PUC's interests. The PUC prefers cooperative to noncooperative regulation as would be expected.

11.2. Multiple firms

With the exception of those in Sections 7 and 8, the models considered in previous sections pertain to the regulation of a single firm. If the regulator has authority over a set of firms each of which has private information, the regulator may be able to use the information obtained from one firm to improve the regulation of other firms. In the context of the revelation of preferences for public goods, d'Aspremont and Gerard-Varet (1979) provide a modification of a mechanism developed by Groves (1973) that results in an equilibrium in which each agent reports its demand truthfully.[111] If the private information of the firms is correlated and the firms are risk neutral, Cremer and McClean (1985) demonstrate in a bidding model that the regulator may be able to extract all the rents from the firms and to implement the first-best outcome. Demski and Sappington (1984) obtain a similar result in a one-principal, two-agent model with ex ante private information where the agents take unobservable actions. When the agents are risk neutral and their private information is correlated, they show that the first-best outcome is attainable. When the agents are risk averse, the first-best outcome is attained and the principal prefers an equilibrium in which one of the

[111] The individual rationality constraints are not necessarily satisfied in their mechanism.

agents has truthful reporting as a dominant strategy and the other has truthful reporting as a best response to the other agent's strategy. In the context of an agency model with symmetric ex ante information and incomplete observability, Mookherjee (1984) examines the use of relative performance measures when the performance of the agents is correlated.

11.3. Hierarchical relationships

The models analyzed above involve a regulator and a firm and thus represent a hierarchical relationship with one level. Many regulatory relationships involve more levels, however. For example, a cabinet officer or a legislature may supervise the regulatory agency that regulates the firms. Similarly, an agency may regulate a firm whose owners must formulate a contract to motivate managers to serve their interests. These hierarchical relationships involve broader opportunities for strategic behavior than present in the single-level models considered above.[112]

Tirole (1986b) has analyzed a model in which two parties in the hierarchy may collude to the detriment of the third party. For example, the regulator and the firm might collude to serve their own interests rather than follow the agency's mandate or the preferences of the cabinet officer. This, for example, might correspond to capture of the regulator by the firm (or vice versa). The top of the hierarchy would, of course, recognize this possibility and would structure the regulatory relationship to deal as efficiently as possible with this collusion. Tirole's analysis suggests that more complex models may reveal more sophisticated and more realistic behavior on the part of the both the regulator and the firm. For example, the possibility of collusion between the regulator and the firm suggests that the legislature or the executive may wish to change regularly the administrator or the membership on the regulatory commission to diminish the likelihood of collusion. The gains from lessening the likelihood of collusion would have to be balanced against the loss of information associated with regulatory turnover.

11.4. Regulation and bargaining power

The models considered in previous sections assume that the regulator has all the bargaining power in the sense that it is able to offer a mechanism to the firm on a take-it-or-leave-it basis, and the firm has no opportunity to bargain with the regulator over the form of the mechanism. If bargaining power is distributed

[112] Stiglitz (1975), Sah and Stiglitz (1986), and Demski and Sappington (1986) also present models of hierarchical relationships.

differently, the equilibrium mechanism will be affected. Spulber (1988) has characterized mechanisms for differing degrees of bargaining power for the case in which the firm has private information about its costs and consumers have private information about their demand.[113] The regulator then designs a mechanism in response to the distribution of bargaining power. In the case in which the regulator has all the bargaining power, the equilibrium mechanism is a special case of that characterized in Section 4. In the case in which the firm has all the bargaining power, the equilibrium mechanism is that which obtains for an unregulated monopolist as considered by Maskin and Riley (1984).

12. Research directions

The perspective taken in this chapter is basically normative with the regulator modeled as maximizing a welfare function based on consumer and producer surplus and the firm acting strategically given the mechanism adopted by the regulator. The characteristics of regulatory mechanisms and institutions is thus viewed as endogenous to the relationship between the regulatory commission and the firm.[114] The design of regulatory mechanisms in this setting is complicated by incentive problems arising from informational asymmetries, incomplete observability of actions and performance, imperfect monitors of observable variables, and differing risk preferences. The substantial body of theoretical research on these issues has clarified the interrelationships among the incentive problems inherent in regulation and has identified the tradeoffs among the possible responses to them. Important theoretical issues remain particularly pertaining to the dynamics of regulation, to the regulation of several firms, to richer informational structures, and to more descriptive models. At least in the near future, however, this work is likely to be based on the methods employed herein and on the recent advances in game theory and microeconomic theory.

This section is intended to address other directions of research associated with the design of regulatory institutions in the presence of incentive problems. Two directions will be considered: applications to actual regulatory settings and the empirical study of regulatory performance in the presence of incentive problems.

At a conceptual level the theory of regulatory mechanism design is a useful guide to reasoning about applications and about the tradeoffs among the possible responses to incentive problems. The application of these principles, however, is only beginning and can be expected to involve a range of practical complications

[113] The private information in this formulation is an additive component of cost and demand, respectively.

[114] A broader issue would be to explain the locus of regulation in an economy. The explanation undoubtedly rests on theories of market failure but perhaps more importantly on theories of political choice.

that may make precise calculations difficult. In the near term at least this line of theory development may be more directly applicable to the design of institutional features and procedures, such as the fairness condition considered in Subsection 6.3.3. That is, in addition to formulating complex incentive mechanisms, applications may center on the design of institutional properties intended to deal with issues of commitment, ratcheting, monitoring, and performance evaluations.

The application of incentive mechanisms of this nature has a long history in regulation.[115] Many of these mechanisms were introduced during periods of rapid inflation, significant technological change, or a changing regulatory environment such as that created by the antitrust accord that restructured AT&T and the telecommunications industry. For example, even though fuel-adjustment clauses had been used as early as World War I, the rapid increases in fuel prices in the 1970s stimulated a variety of design experiments intended to adjust electricity prices in response to changes in fuel costs.[116] In 1986 and 1987 a number of regulatory commissions began to adopt incentive mechanisms to govern the profits of the regional telephone companies operating in their jurisdistictions. Similarly, regulatory commissions are beginning to take more seriously the deregulation of the electric power industry, and if that transpires, a number of incentive experiments would be designed to deal with the resulting mixture of regulated and unregulated units of power companies.

Experiments such as these provide an opportunity for empirical work of two types. First, researchers may have the opportunity to study the efficiency consequences of various incentive mechanisms using cross-sectional data.[117] Such studies, however, will be complicated by the difficulties in dealing with incomplete information. When information is incomplete, regulation involves mechanisms or schedules of policies, so empirical work must focus both on policies, such as rate-setting formulas and other procedures that specify how reported information is to be used to revise prices, and on how procedures are revised as a function of performance data. Second, researchers may be able to study the institutions established to implement these policies. In particular, institutional properties, such as the ability of regulators to commit to multiperiod policies, may be investigated with the objective of identifying their efficiency consequences.

Empirical studies will be complicated by the difference between the data the econometrician observes and the information available to the parties at the time they took their actions. Even in static contexts the econometrician must be able

[115]See Morgan (1923) for an analysis of early experiments with incentive regulation and Joskow and Schmalensee (1986) for a recent analysis.

[116]These clauses may have been adopted more to respond to cash flow problems of electric utilities due to inflation and regulatory lag than to a desire to promote economic efficiency by basing prices on costs on a continuous basis.

[117]Joskow (1987, 1988) has conducted studies of this nature involving a cross-section of long-term coal supply contracts for electric utilities.

to formulate, or at least make inferences about, the informational asymmetries that were present. Furthermore, care must be taken in the analysis, since in the presence of informational asymmetries the conclusions one might draw from the data may be the opposite of those that would be drawn if information were symmetric. For example, suppose that, after the fact, the econometrician had data on actual costs and the price that had been set in a period. If the price were equal to the actual marginal cost yet information had been incomplete at the time the price had been set, the conclusion that should be drawn is that regulation was inefficient, since price should have been above marginal cost (except in the case of the lowest conceivable cost). Similarly, if the price had been above actual marginal cost, the econometrician could not conclude that regulation had been inefficient. Distinguishing between these two cases may be possible using other data. For example, the econometrician could use data on the profits (rents) of the firm to judge whether regulation had been efficient. That is, profits should be higher under inefficient regulation than under efficient regulation given the same actual costs and information structure. Profits are useful here because, unlike prices, they do not depend directly on the information available to the regulator at the time that prices were established.[118]

Empirical analysis is more complicated in a dynamic setting because it is necessary to determine when information became available. With time series data, however, it may be possible to use the paths of prices and costs to assess the efficiency of regulation. To illustrate this, consider the dynamic model with commitment analyzed in Section 6. If, at the time a regulatory mechanism was adopted, the type of the firm had been known to be persistent (perfect correlation), then a price path that was constant over time would indicate efficient regulation with commitment even if prices remained above costs. If prices ratcheted downward over time, either inefficiency or a limited degree of commitment, such as that characterized by fairness in Subsection 6.3.3, would be consistent with the observation. To complement such an analysis, the extent to which commitment was possible may be assessed by examining whether regulatory procedures had been revised. Other cases could be analyzed in a similar manner as a function of information about the state of the regulator's knowledge at the time the procedures were implemented.

It may also be possible to make inferences from the data about the nature of the regulatory relationship. With the maintained hypothesis that regulators are acting optimally given the information available to them, suppose that the econometrician observed that in each period the regulator employed a pricing mechanism such as that characterized in Section 4 and that prices fluctuated across periods. Then, if marginal costs varied over time yet the firm did not earn rents after the initial period, the data would be consistent with the regulator having the ability to make credible commitments and the type of the firm being

[118]The profit depends, however, on the upper bound θ^+ of possible marginal costs.

random. If, however, the firm earned rents in each period, the data would be consistent with the type being random and the regulator being unable to make credible commitments to multiperiod policies.

As suggested here, even though considerable progress has been made on the theory of the design of regulatory mechanisms and institutions, a wide range of theoretical, applied, and empirical research remains to be conducted.

Appendix A

This appendix presents the control theoretic approach to the solution of the regulator's problem. In this approach the profit function $\pi(\theta)$ is treated as a state variable and the controls are $p(\theta)$, $T(\theta)$, and $\mathrm{d}\pi(\theta)/\mathrm{d}\theta$. The objective function is that in (4.16) which is to be maximized subject to two constraints: (1) that the derivative of the state variable satisfies (4.7) and (2) that the state variable is non-negative for all θ. The Lagrangian $\mathscr{L}$ formed from the Hamiltonian is

$$\mathscr{L}=\left(\int_{p(\theta)}^{\infty} Q(p^0)\,\mathrm{d}p^0 - T(\theta) + \alpha\pi(\theta)\right)f(\theta) + \mu(\theta)(-Q(p(\theta)))$$
$$+\lambda(\theta)(p(\theta)Q(p(\theta)) - \theta Q(p(\theta)) - K - \pi(\theta)) + \tau(\theta)\pi(\theta), \tag{A.1}$$

where $\mu(\theta)$ is the costate variable associated with $\mathrm{d}\pi(\theta)/\mathrm{d}\theta = -Q(p(\theta))$ in (4.7), $\lambda(\theta)$ is a multiplier, and $\tau(\theta)$ is a non-negative multiplier. The necessary optimality conditions are

$$\frac{\partial\mathscr{L}}{\partial p(\theta)} = -Q(p(\theta))f(\theta) - \mu(\theta)Q'(p(\theta))$$
$$+\lambda(\theta)(Q(p(\theta)) + p(\theta)Q'(p(\theta)) - Q'(p(\theta))) = 0, \tag{A.2}$$

$$\frac{\partial\mathscr{L}}{\partial T(\theta)} = -f(\theta) + \lambda(\theta) = 0, \tag{A.3}$$

$$\frac{\partial\mathscr{L}}{\partial \pi(\theta)} = -\mu'(\theta) = \alpha f(\theta) - \lambda(\theta) + \tau(\theta), \tag{A.4}$$

$$\tau(\theta) \geq 0, \tag{A.5}$$

$$\pi(\theta) = p(\theta)Q(p(\theta)) + T(\theta) - \theta Q(p(\theta)) - K. \tag{A.6}$$

From (A.3) the multiplier $\lambda(\theta)$ on the definition of the state variable equals the density function $f(\theta)$, so substituting into (A.4) and integrating yields:

$$\mu(\theta) = \mu(\theta^-) + (1-\alpha)F(\theta) + \int_{\theta^-}^{\theta}\tau(\theta^0)\,\mathrm{d}\theta^0. \tag{A.7}$$

Since the state variable is constrained only to be non-negative, the end points $\pi(\theta^+)$ and $\pi(\theta^-)$ are also to be chosen. From (4.7) the value $\mu(\theta^-) = 0$, since the state variable is a strictly decreasing function of θ. The end point $\pi(\theta^+)$ of the state variable satisfies the transversality condition:

$$\tau(\theta^+)\pi(\theta^+) = 0.$$

To show that the state variable equals zero at θ^+ when $\alpha < 1$, assume that it is positive. This then implies that $\mu(\theta^+) = 0$ which from (A.7) implies that

$$0 = (1 - \alpha)F(\theta^+) + \int_{\theta^-}^{\theta^+} \tau(\theta^0)\,\mathrm{d}\theta^0.$$

Since $F(\theta^+) = 1$ and $\tau(\theta) \geq 0$, a contradiction is obtained when $\alpha < 1$. If $\alpha = 1$, then no contradiction is obtained and $\pi(\theta^+)$ can be chosen arbitrarily. Thus, $\pi(\theta) = 0$ for all α satisfies the necessary conditions. Consequently, $\tau(\theta) = 0$ for all $\theta < \theta^+$. From (A.7) this implies that the costate variable satisfies:

$$\mu(\theta) = (1 - \alpha)F(\theta). \tag{A.7a}$$

Substituting this and $\lambda(\theta)$ into (A.2) yields (4.19). The transfer $T(\theta)$ is then determined by integrating the state equation and using (4.10).

This approach yields a "first-order" solution, since the state equation guarantees only that the incentive compatibility constraints hold locally. The incentive compatibility constraints thus must either be verified directly or compared to the conditions established in (4.12) and (4.15).

Appendix B

This appendix presents a derivation of the optimal regulatory policy for the Laffont and Tirole model. Their approach to determining the optimal mechanism is based on a "concealment set", but instead of presenting that approach, the control theoretic approach of Appendix A will be used in conjunction with the formulation in Baron and Besanko (1987b). The objective of this appendix is to demonstrate that when the firm is risk neutral the marginal cost of responding to the adverse selection problem is exactly offset by the marginal cost of responding to the moral hazard problem in equilibrium.

The uncertain cost $\tilde{C}$ of the firm is assumed to be given by a generalization of (5.5) where

$$\tilde{C} = C(\theta, a, q) + \sqrt{\nu}\,\tilde{\varepsilon}. \tag{B.1}$$

The distribution of $\tilde{\varepsilon}$ induces a distribution on $\tilde{C}$, and the resulting density function will be denoted by $h(C|C(\theta, a, q))$. Only the fixed charges $T(\theta, C)$ and the cost depend on C, so the expected profit of the firm may be written as

$$\pi(\hat{\theta};\theta)=p(\hat{\theta})Q(p(\hat{\theta}))-K-\psi(a)$$
$$+\int_{\Gamma}\left[T(\hat{\theta},C)-C\right]h\left(C|C\left(\theta,a,Q(p(\hat{\theta}))\right)\right)\mathrm{d}C. \tag{B.2}$$

Given an incentive compatible policy, the derivative of the state variable $\pi(\theta)$ is

$$\pi'(\theta)=C_{\theta}(\theta,a,Q(p(\theta)))\int_{\Gamma}\left[T(\hat{\theta},C)-C\right]h_2\left(C|C\left(\theta,a,Q(p(\hat{\theta}))\right)\right)\mathrm{d}C, \tag{B.3}$$

where h_2 denotes the partial derivative of h with respect to its conditioner. The firm will choose its effort $a(\theta)$ to satisfy:

$$\frac{\partial\pi(\theta)}{\partial a(\theta)}=C_a(\theta,a(\theta),Q(p(\theta)))\int_{\Gamma}\left[T(\hat{\theta},C)-C\right]$$
$$\times h_2\left(C|C\left(\theta,a(\theta),Q(p(\hat{\theta}))\right)\right)\mathrm{d}C-\psi'(a(\theta))=0. \tag{B.4}$$

The regulator maximizes the objective in (4.16) subject to the constraints in (B.3) and (B.4). The Lagrangian corresponding to (A.1) is

$$\begin{aligned}
\mathscr{L}=&\left(\int_{p(\theta)}^{\infty}Q(p^0)\,\mathrm{d}p^0\right.\\
&\left.-\int_{\Gamma}T(\theta,C)h(C|C(\theta,a(\theta),Q(p(\theta))))\,\mathrm{d}C+\alpha\pi(\theta)\right)f(\theta)\\
&+\mu(\theta)\Big[C_{\theta}(\theta,a(\theta),Q(p(\theta)))\int_{\Gamma}\left[T(\hat{\theta},C)-C\right]\\
&\qquad\times h_2(C|C(\theta,a(\theta),Q(p(\theta))))\,\mathrm{d}C\Big]\\
&+\xi(\theta)\Big[C_a(\theta,a(\theta),Q(p(\theta)))\int_{\Gamma}\left[T(\theta,C)-C\right]\\
&\qquad\times h_2(C|C(\theta,a(\theta),Q(p(\theta))))\,\mathrm{d}C-\psi'(a(\theta))\Big]\\
&+\lambda(\theta)\Big[p(\theta)Q(p(\theta))-K-\psi(a(\theta))\\
&\qquad+\int_{\Gamma}\left[T(\theta,C)-C\right]h(C|C(\theta,a(\theta),Q(p(\theta))))\,\mathrm{d}C-\pi(\theta)\Big]\\
&+\tau(\theta)\pi(\theta),
\end{aligned} \tag{B.5}$$

where the multipliers are the same as in (A.1) with the addition of the multiplier $\xi(\theta)$ corresponding to the moral hazard constraint in (B.4).

A necessary optimality condition is obtained by differentiating $\mathscr{L}$ with respect to $T(\theta,C)$ pointwise on (θ, C) or

$$\begin{aligned}\frac{\partial \mathscr{L}}{\partial T(\theta, C)} = &-f(\theta)h(C|C(\theta, a(\theta), Q(p(\theta))))\\ &+\lambda(\theta)h(C|C(\theta, a(\theta), Q(p(\theta))))\\ &+[\mu(\theta)C_\theta(\theta, a(\theta), Q(p(\theta)))\\ &\quad+\xi(\theta)C_a(\theta, a(\theta), Q(p(\theta)))]\\ &\times h_2(C|C(\theta, a(\theta), Q(p(\theta)))) = 0, \quad \forall C, \forall\theta. \qquad \text{(B.6)}\end{aligned}$$

Dividing by h indicates that the first two terms on the right-hand side are independent of C, so the last two terms must also be independent of C. Since h_2/h varies with C, (B.6) can be satisfied only if

$$\mu(\theta)C_\theta(\theta, a(\theta), Q(p(\theta))) + \xi(\theta)C_a(\theta, a(\theta), Q(p(\theta))) = 0, \quad \forall\theta. \qquad \text{(B.7)}$$

Consequently, the marginal cost $\mu(\theta)C_\theta$ of responding to the moral hazard problem exactly offsets the marginal cost $\xi(\theta)C_a$ of responding to the adverse selection problem. This also implies that

$$\lambda(\theta) = f(\theta), \quad \forall\theta. \qquad \text{(B.8)}$$

The derivative of the Lagrangian with respect to $p(\theta)$ is

$$\begin{aligned}\frac{\partial \mathscr{L}}{\partial p(\theta)} = &-Q(p(\theta))f(\theta) + C_q\int_\Gamma[-T(\theta, C)]h_2\,\mathrm{d}Cf(\theta)\\ &+[\mu(\theta)C_a + \xi(\theta)C_\theta]C_q\int_\Gamma[T(\theta, C) - C]h_2\,\mathrm{d}C\\ &+\lambda(\theta)\Big[p(\theta)Q'(p(\theta)) + Q(p(\theta))\\ &\qquad+C_q\int_\Gamma[T(\theta, C) - C]h_2\,\mathrm{d}C\Big] = 0. \qquad \text{(B.9)}\end{aligned}$$

Substituting (B.7) and (B.8) into (B.9) implies:

$$p(\theta) - C_q \int_\Gamma Ch_2 \, \mathrm{d}C = p(\theta) - C_q = 0, \tag{B.10}$$

so price equals expected marginal cost.

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