Impact of Regulatory Agencies on the Efficiency of Publicly-Owned Utilities

Jean-Thomas Bernard, Mohamed Nouhi and Michel Roland*
Departement d'economique
Universite Laval
Quebec, Qc
Canada, G1K 7P4
e-mail: jtber@ecn.ulaval.ca and mrol@ecn.ulaval.ca

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Abstract

We compare the economic efficiency of a publicly-owned utility directly controlled by the government with a publicly-owned utility regulated by a public utility commission (PUC). Regulation by a PUC is modelled as a Nash equilibrium of a game between two principals, the government and the PUC, each of them having control over a subset of decision variables determining the utility performance. A utility manager, who has private information over a productivity parameter, is the agent. Comparisons of both regulatory regimes are made with respect to output, choice of inputs, manager's information rent and firm's profit. Reasons for which the government should prefer one regulatory regime over the other are discussed. The recent

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regulatory reform of electricity markets in the province of Quebec (Canada) provides an illustration of the model.

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1 Introduction

In recent years, technological progress has considerably reduced the extent of activities which are considered to be natural monopolies. As a result, entry restrictions were relaxed in many industries, such as telecommunications, cable television, natural gas, electricity or mail services. However, in all these industries, sector-specific regulation remains, either because parts of their operations still are natural monopolies or because they are deemed essential, in which case subsidized prices are insured by regulation for equity purposes.[1] Such services continue to be protected from entry. As there can exist scope economies between competitive and protected services, price regulation must often apply to firms that supply both types of services.

In such a regulatory framework, prices set for protected services are likely to be routinely contested by both the protected service provider and competitors on the ground that they involve cross-subsidies at their disadvantage. In many countries, such charges can be exarcebeted by the fact that the former monopoly incumbent is a public enterprise, as presumptions of political interferences with market operations become difficult to eschew. For this reason, governments in these countries often combine deregulation and measures which signal their commitment to keep public enterprises at arm's lenght from political interventions:[2] these can go from simple accounting rules, such as accounting "separation" of competitive activities and protected services, to outright privatization.

[1]For instance, liberalization of telecommunications and postal services are generally accompanied with some form of universal service obligations to insure that high cost customers still get a minimal service level. Distribution and transport/transmission of natural gas and electricity stay natural monopolies whether or not competition is allowed in production and supply.

[2]Furthermore, such measures can be encouraged or imposed by trade agreements.

One of these measures, adopted by the government of Quebec for electricity markets, is to delegate the monitoring of the industry in general and of the public enterprise in particular to a so-called independent regulatory agency, or public utility commission (PUC),[3] similar to the ones that traditionally oversaw private natural monopolies in US. This framework has the advantage of being relatively easy to implement. However, as the government owns the public enterprise and sets up the agency which regulates the latter, it is not readily clear whether and how this regulatory framework differs from one where government solely controls the public enterprise.

This paper presents a microeconomic model which allows to make efficiency comparisons between two regulatory frameworks applied to protected markets of public enterprises: direct government control, which refers to the case where government has the power over all decision variables that affect the performance of the public enterprise, and regulation by a PUC. We first develop a principal-agent model to analyze allocative and productive efficiencies of a public enterprise which is directly controlled by government. Regulatory reform is then viewed as the transfer of some decision variables from government to the PUC. A solution is derived for a game played by the two principals, i.e. the government and the PUC. A utility manager, who has private information about labor productivity, acts as a self-interested agent who maximizes her information rent.

In this model, the government can pursue an objective that differs from utilitarian welfare maximization and use its public enterprise as a policy instrument to reach its goal. This is in fact why market liberalization requires a signal that the industry will be regulated at arm's length. In order to highlight the impact of PUC regulation on the efficiency of the public enterprise, we first consider that the government's objective remains the same under both regulatory regimes. In these circumstances, the government prefers direct control, since it can maximize its objective function using all decision variables. As a result, creation of the PUC must be caused by external pressure, such as trade agreements. We then look at

[3] Because the regulatory agency acts as a principal in our model, hereafter, we refer to it as the public utility commission.

the possibility that both regimes be operated under different objective functions. This is to reflect a case where the government is forced to change its announced objective function, but is free to select the regulatory framework. The question is then whether the PUC becomes a way to circumvent this external pressure.

Our allocation of decision variables between the government and the PUC follows the distinction made by Laffont and Tirole[7] between internal control and external control. According to these authors, “internal control is the control of the firm’s inputs and cost minimization process”[4] while “external control is the control of all variables that link the firm with outsiders: consumers (regulation of prices, quality, product selection, etc.)...”.[5] They view a regulated private firm as a firm whose internal control is exercised by shareholders, and external control, by government. For public enterprises, both external and internal controls are exercised by government. A natural extension of this analysis to the case of a regulated public enterprise is to let the PUC exert external control while the government exerts internal control. This is the way separation of control over decision variables between the two principals is made in our model.

We assume that all sectors of the economy other than the protected sector, including the competitive segments of the regulated industry, are perfectly contestable. However, pricing of the protected service can induce distortions in other markets. In order to abstract from the explicit ways these distortions are created (e.g. cross-subsidies, taxation of competitor’s service) and to focus on a partial equilibrium for the protected service, we assume that the public enterprise is entirely financed by government, on the base of the appropirate shadow price of public funds, and that it is a price-taker on its competitive segments.

The main results of the model are as follows. When the same objective function is used under both regulatory regimes, the action of the PUC leads to an increase of the public enterprise output and to a profit decrease if demand is inelastic. Creation of a PUC could then potentially be justified if the price of the

[4] Laffont and Tirole [7], p. 86. They cite “influence on managerial inputs through managerial incentive schemes, intervention in the decisions concerning employment, level and type of investments, borrowing etc.”, as examples of internal control.

[5] Laffont and Tirole [7], p. 86.

protected service was originally higher than the welfare-maximizing price. But if government preferences are such that the price of the protected service is originally lower than the welfare-maximizing price, the tendency of the PUC to increase further the output can be used strategically by the government: it can help circumvent a change of objective function imposed by external pressures in order to decrease output.

Although, to our knowledge, there exists no economic model which analyzes explicitly the performance of publicly-owned monopolies under various regulatory regimes, models have already been built in order to compare the efficiency of directly controlled publicly-owned monopolies to the efficiency of regulated private monopolies.[6] Our treatment of direct government control closely follows Pint's model[10] with two exceptions. First, our specification of the manager's compensation scheme is less elaborate than in Pint. This simplifies the model without losing any insight on productive or allocative efficiency. The model could be extended to include Pint's compensation scheme without modifying the results. Second, contrary to Pint, the government does not value employment wages in its objective function; i.e. it does not wish to use its public enterprise to spur employment. This also allows to simplify considerably the presentation without modifying the structure and the basic logic of the model. However, it should be noticed that the results derived here would change if a sufficiently high weight were given to labor wages in the government's objective function: the PUC would tend to decrease output and, with an inelastic demand, to increase profit.[7]

Note also that in our model, contrary to most models in the literature, we assume that the PUC does not improve the government's information on the firm's cost or productivity. This allows us to focus on the impact of separating decision variables between the government and the PUC. This assumption can be justified by the fact that, as a shareholder, the government already has the right to conduct inquiries into its enterprise as it sees fit. As a result, getting better information

[6] See Laffont and Tirole[7], Pint[10], De Fraja [5],and Schmidt[11]. There is also a large empirical literature on this topic, see Bernard and Weiner[4] and references therein.

[7] Nouhi [9] presents the same model as the one developped in this paper, with the addition of a labor wage in the government's objective function.

from the firm does not require an independent body as it is the case for a private firm; it can be done, for instance, by increasing the staff of the department which monitors the enterprise.

The next section describes the parts of the model which are common to both types of regulatory regimes. Sections 3 and 4 then turn to determination of output and inputs under direct government control and under regulation by a PUC, respectively, assuming that the government objective function stays the same. Section 5 looks at the ways the government can use regulation by a PUC to reach goals that differ from an objective function that is imposed by external pressure. We illustrate this case with electricity markets in Quebec. By way of conclusion, we discuss some extensions that could be brought to the model.

2 Basic Model

2.1 Technology, Welfare and Government's Objective

The government is the sole owner of an enterprise which produces a good according to the following Cobb-Douglas technology:

$$q \leq K^{\alpha}(\theta L)^{\beta} \tag{1}$$

where q is output, K is capital, L is labor, and θ is a random variable affecting input productivity. A high θ is thus associated with high input productivity. In order to insure decreasing marginal productivities for capital and labor, we assume that $\alpha < 1$ and $\beta < 1$. At this stage, no assumption is required on returns to scale, i.e. on whether $\alpha + \beta$ is greater than, equal to, or less than 1.

Realizations of the random variable θ, as well as the amount of labor employed, are privately known by the manager of the firm.[8] However, the density

[8]This assumption is justified as follows by Pint [10] (p. 134-135): "outsiders observe the number of workers, but not their quality or the numbers of hours they work." Efficient usage of labor can be considered as a management problem. Generally, the existence of a public enterprise

function f and the distribution function F, defined over the interval $[\theta^-, \theta^+]$, are common knowledge. From (1), we obtain the labor requirement function, i.e. the minimum amount of labor that is required to produce q with capital input K and productivity parameter θ:

$$L(q, K, \theta) = \theta^{-1} q^{1/\beta} K^{-\alpha/\beta} \tag{2}$$

The fact that θ cannot be directly observed by government or the PUC allows the utility's manager to extract an information rent. This rent takes the form of a payment (or transfer) $V(\theta)$ which varies with the reported productivity.[9] Because such payment reduces the profitability of the public enterprise, the government wishes to keep it as small as possible. Other manager's compensations which are not related to the productivity parameter, such as a fixed salary, are set equal to zero without loss of generality. Similarly, the manager's reservation utility, which can be assimilated to her outside opportunities, is also taken to be zero.

Output, capital and profit are observable by the principal(s). For given values of the observable and the private information variables, consumer surplus and profit are then defined by:

$$CS(q) \equiv \int_0^q p(x)dx - p(q)q \tag{3}$$
$$\pi(q, K, L, V) \equiv p(q)q - rK - wL - V \tag{4}$$

where $p(\cdot)$ is the inverse demand function, r is the price of capital, and w is the wage rate (all exogenous to the model). Note that the information rent is deducted directly from profit. This accounting convention is adopted because the information rent constitutes an incentive payment to the manager and thus reduces the benefits of owning the enterprise. However, as long as the same weight is given to the information rent and other input costs, it would be equivalent to keep separate accounting for the information rent and "gross" profit $\pi(\cdot, \cdot, \cdot, V) + V$.

is justified by the fact that the government has neither the time nor the knowledge to tackle such problems. This amounts to acknowledging an information asymmetry between government and the public enterprise's managers.

[9] This rent can thus be interpreted as a performance-based bonus.

We assume that consumers' utility functions are separable in the public enterprise's good and income (which represents "all other goods") and that they take the following quasi-linear form:

$$U^i(q_i, y_i) = u^i(q_i) + y_i \tag{5}$$

where i is the consumer index, q_i is the quantity of public enterprise's good purchased by consumer i, and y_i is its income. Because of this quasi-linear form, u^i corresponds to individual consumer's surplus. Each consumer will see its income affected by the utility's profit (deficit) because government acts as a residual claimant: such profit (deficit) will reduce (increase) taxes levied by government and, considering that each dollar of taxation creates a deadweight loss of λ, aggregate income increases (decreases) by $(1 + \lambda)\pi$. We also assume that the firm's manager is part of the constituency, so that her information rent enters into the social welfare function. With each consumer getting a given share of profit (taxes), summing individual utility functions leads to the following utilitarian welfare function:

$$W(q, \pi, V) = \frac{CS + V}{(1 + \lambda)} + \pi \tag{6}$$

where normalization with respect to $(1 + \lambda)$ is made only for ease of presentation of calculations made below.

The government may have political motivations and use the public enterprise as a policy instrument to reach goals other than welfare maximization. Specifically, government gives a weight γ to aggregate consumer surplus that differs from $1/(1 + \lambda)$:[10]

$$\Gamma(CS, \pi, V) = \gamma CS + \pi + (1 + \lambda)^{-1} V \tag{7}$$

[10] Baron [1] shows that such a function can be viewed as a majority-rule equilibrium of a legislature whose members have utility functions that are linear in consumer surplus and profit. He also shows how to connect these utility functions to constituent interests.

2.2 Manager Behavior

The manager seeks to maximize her utility. This amounts to maximizing the information rent, since all other components of her compensation are fixed.

In virtue of the revelation principle, a direct mechanism is used.[11] The manager is thus asked to report parameter θ. Depending on her report $\hat{\theta}$, she will have to meet a production and profit target $\{q(\hat{\theta}), \pi(\hat{\theta})\}$ with the amount of capital made available to her, $\{K(\hat{\theta})\}$. If she reports $\hat{\theta}$ while the true value of the parameter is θ, the rent $\hat{V}(\hat{\theta}, \theta)$ that she obtains is:

$$\hat{V}(\hat{\theta}, \theta) = p(q(\hat{\theta}))q(\hat{\theta}) - rK(\hat{\theta}) - wL(q(\hat{\theta}), K(\hat{\theta}), \theta) - \pi(\hat{\theta}) \tag{8}$$

Then, in order to make the manager truthfully report parameter θ (and insure that output and profit targets are met), the menu of contracts $\{q(\theta), \pi(\theta), K(\theta)\}$ must be designed in such a way that

$$\hat{V}(\hat{\theta}, \theta) \leq \hat{V}(\theta, \theta) \equiv V(\theta) \quad \forall \hat{\theta}, \theta \tag{9}$$

This is the incentive compatibility (IC) constraint. The following two lemmas, borrowed from Pint (1992), provide operational necessary and sufficient conditions for satisfying this constraint. In the second lemma and later developments, it is useful to refer to the following function:

$$\Lambda(q, K) = q^{1/\beta} K^{-\alpha/\beta} \tag{10}$$

whose value can be interpreted as the amount of *effective* labor, or *work*, which is required to produce output q with K units of capital.[12]

Lemma 1 *The necessary condition for a menu of contracts* $\{q(\theta), \pi(\theta), K(\theta)\}$ *to satisfy local incentive compatibility is*

$$\frac{\partial V(\theta)}{\partial \theta} = w\theta^{-2} q(\theta)^{1/\beta} K(\theta)^{-\alpha/\beta} = w\theta^{-1} L(q(\theta), K(\theta), \theta) \tag{11}$$

[11] We will discuss later how the direct mechanism solution can be implemented.

[12] This measure of labor, which is independent of the productivity parameter, is to be contrasted with the required *nominal* amount of labor $L(q, K, \theta) = \Lambda(q, K)/\theta$, which of course decreases for given q and K as the productivity parameter increases.

Proof. See Appendix A ■

Lemma 2 *Necessary and sufficient conditions for menu of contracts* $\{q(\theta), \pi(\theta), K(\theta)\}$ *to satisfy global incentive compatibility are:*

$$(i)\;\; V(\theta) = V(\theta^-) + w\int_{\theta^-}^{\theta} x^{-2} q(x)^{1/\beta} K(x)^{-\alpha/\beta} dx$$
$$= V(\theta^-) + w\int_{\theta^-}^{\theta} x^{-2}\Lambda(q(x), K(x))dx$$

(ii) $\Lambda(q(\theta), K(\theta))$ *is non decreasing in* θ.

Proof. See Appendix B ■

Menu $\{q(\theta), \pi(\theta), K(\theta)\}$ must also respect the individual rationality constraints $V(\theta) \geq 0, \forall\theta$. Since it can be seen from (11) that the rent must be increasing in θ and because the government always prefers to minimize the rent payment, these individual rationality (IR) constraints collapse to

$$V(\theta^-) = 0 \tag{12}$$

To understand intuitively why the government must grant an information rent instead of conceding only the reservation utility, note that the manager, when faced with the true parameter value θ, can always announce a lower productivity parameter value $\hat{\theta} < \theta$ and still meet contract targets $\{q(\hat{\theta}), \pi(\hat{\theta}), K(\hat{\theta})\}$, without making her lie apparent. This is so because labor actually employed is unobservable by government and because the lower is the productivity parameter, the higher is the amount of labor required to meet given contract targets. As a result, by making the government believe that more labor is required than what is actually needed, the manager can ensure herself a budget that can be used for her own benefit. More precisely, if government made a priori no provision for an information rent, it can be seen from (8) that announcing a value $\hat{\theta}$ lower than the true value θ would give the manager the following "self-granted" compensation:

$$\hat{V}(\hat{\theta}, \theta) - \hat{V}(\theta, \theta) = w\left[L(q(\hat{\theta}), K(\hat{\theta}), \hat{\theta}) - L(q(\hat{\theta}), K(\hat{\theta}), \theta)\right] > 0 \tag{13}$$

Taking the limit as $\hat{\theta} \to \theta$, we obtain the rate at which this compensation increases with θ, which is exactly equation (11). In other words, in the truthful direct mechanism, the government concedes exactly the amount that the manager can otherwise get by her own means. As its name indicates, the information rent is then exactly the value to the manager of her superior information.

3 Direct Government Control

3.1 Direct Mechanism

Under a regime of direct control, the government determines, for each contingency θ, the value of output and capital. It seeks to maximize the expected value of its objective function (7) under IC and IR constraints with available technology. Letting $\nu \equiv \lambda/(1+\lambda)$, its problem reads as:

$$\max_{\{q(\theta),K(\theta)\}} \int_{\theta^-}^{\theta^+} \left\{ \gamma \left[\int_0^{q(\theta)} p(x)dx - p(q(\theta))q(\theta) \right] + p(q(\theta))q(\theta) \right. \\ \left. -rK(\theta) - wL(q(\theta),K(\theta),\theta) - \nu V(\theta) \right\} dF \tag{14}$$

$$\text{s.t.} \qquad \frac{\partial V(\theta)}{\partial \theta} = w\theta^{-1}L(q(\theta),K(\theta),\theta) \tag{15}$$

$$V(\theta^-) = 0 \tag{16}$$

$$\dot{\Lambda}(q(\theta),K(\theta)) \geq 0 \tag{17}$$

This is an optimal control problem where $V(\theta)$ represents a state variable.

For the moment we neglect constraint (17) and we will check later whether it is satisfied or not. Appending costate variable $\mu(\theta)$ to constraint (15), we form the Hamiltonian function H^D as follows:[13]

$$H^D = \left[\gamma \int_0^{q(\theta)} p(x)dx + (1-\gamma)p(q(\theta))q(\theta) \right. \\ \left. -rK(\theta) - w\theta^{-1}q^{1/\beta}(\theta)K^{-\alpha/\beta}(\theta) - \nu V(\theta) \right] f(\theta) \\ +\mu(\theta)\, w\theta^{-2}q^{1/\beta}(\theta)K^{-\alpha/\beta}(\theta) \tag{18}$$

[13]Hereafter, superscript D refers to Direct government control.

where $L(q, K, \theta)$ was replaced by its value given in (2). Let $(q^D(\theta), K^D(\theta), V^D(\theta), \mu^D(\theta))$ be an interior solution[14] and $L^D(\theta) \equiv L(q^D(\theta), K^D(\theta), \theta)$. This solution then satisfies the following necessary conditions:[15]

$$\dot{\mu}^D = -\frac{\partial H^D}{\partial V} = \nu f \tag{19}$$

$$\frac{\partial H^D}{\partial q} = \left[\gamma p(q^D) + (1-\gamma)(p'(q^D)q^D + p(q^D)) - \frac{wL^D}{\beta q^D}\right] f + \mu^D \frac{wL^D}{\theta\beta q^D} = 0 \tag{20}$$

$$\frac{\partial H^D}{\partial K} = \left[-r + w\frac{\alpha L^D}{\beta K^D}\right] f - \mu^D w \frac{\alpha L^D}{\theta\beta K^D} = 0 \tag{21}$$

$$\mu^D(\theta^+) = 0 \tag{22}$$

$$\left(q^D(\theta), K^D(\theta)\right) \text{ maximizes } H^D\left(q(\theta), K(\theta), V^D(\theta), \theta\right) \tag{23}$$

Condition (23) in turn implies the following second-order condition:[16]

$$H^D_{qq} = \left[(1-\gamma)\left[p''q^D + 2p'\right] + \gamma p' + wL_{qq}(q^D, K^D, \theta)\right] f - \mu^D \theta^{-1} L_{qq}(q^D, K^D, \theta) < 0 \tag{24}$$

Transversality condition (22) comes from the fact that $V(\theta^+)$ is free in this problem: recall that the endpoint individual constraint $V(\theta^+) \geq 0$ was not included because it is never binding due to equations (16) and (15). Then, from (19) and (22), we get:

$$\mu^D(\theta) = \mu^D(\theta^+) - \int_{\theta}^{\theta^+} \nu f(\theta) dx = -\nu(1 - F(\theta)) \leq 0 \tag{25}$$

[14]Since both inputs are essential, any solution with $q > 0$ is necessarily an interior solution. Note however that an optimal solution may not exist: for instance, if γ is sufficiently high and if demand elasticity is one, the objective function continuously increases as $q \to \infty$.

[15]We omit argument θ whenever there is no confusion. It can be shown that if $\alpha + \beta \leq 1$, these conditions become sufficient for a maximum. We do not wish, however, to impose this decreasing returns to scale condition, since regulated enterprises that are publicly-owned are often considered to be natural monopolies.

[16]It also implies that $H^D_{KK} < 0$ and that $H^D_{qq}H^D_{KK} - (H^D_{qK})^2 > 0$, $\forall\theta$. The former condition can be shown to be always satisfied with $\alpha < 1$ and $\beta < 1$. The latter has to checked for each problem at hand, but we do not write it explicitly, and refer instead to (23), because it does not convey any interesting economic interpretation.

To interpret this equation, note that (15) represents the rate at which the manager's information rent increases with θ. Now, suppose that the manager is able to extract one additional dollar of rent when the parameter value is θ. Since the manager can always "mimic" a firm of productivity θ if the productivity parameter is higher than θ, this additional dollar of rent must also be granted to the manager whenever the productivity parameter exceeds θ. As the net cost to government of each dollar of rent is ν, the expected loss to government is $\nu(1 - F(\theta))$.

From (21) and (25), we get the marginal rate of substitution of labor for capital at an optimal solution:

$$MRS_{LK}^{D} \equiv \frac{\beta K^D(\theta)}{\alpha L^D(\theta)} = \frac{w}{r}\left[1 + \nu \frac{1 - F(\theta)}{\theta f(\theta)}\right], \ \ \forall\theta \tag{26}$$

If the government maximized expected welfare $E_\theta W(q, \pi, V)$ without constraint, this MRS would be equal to w/r. However, the government implicitly values labor differently from market wage w. To see why, suppose it is decided that one additional unit of labor is to be used in the event that the productivity parameter lies in the interval $[\theta, \theta + d\theta]$. This event occurs with probability $f(\theta)d\theta$. From (15), this unit adds $w\theta^{-1}d\theta$ to the information rent (and thus reduces the objective function by $\nu w\theta^{-1}d\theta$) whenever the parameter value is equal to or greater than θ, i.e. with probability $1 - F(\theta)$. The net marginal cost of labor at θ, or the value of labor to government, is thus $w[f(\theta)d\theta + \nu(1 - F(\theta))d\theta/\theta]$. Since the unit cost of capital is $rf(\theta)d\theta$, condition (26) simply states that the MRS should, as usual, be equalized to the ratio of input values, where the value of labor differs from its market price because of information constraints. Because the term $\nu(1 - F(\theta))/\theta f$ is unambiguously related to information constraints, hereafter, we refer to it as the information term.

Turning to allocative efficiency, we substitute (25) and (26) into (20) and divide the result by $f(\theta)$ to obtain:

$$\begin{aligned} p(q^D(\theta))\left[1 + \frac{1-\gamma}{\varepsilon(p(q^D(\theta)))}\right] &= \frac{wL^D(\theta)}{\beta q^D(\theta)}\left[1 + \nu\frac{1 - F(\theta)}{\theta f(\theta)}\right] \\ &= \frac{rK^D(\theta)}{\alpha q^D(\theta)}, \ \ \forall\theta \end{aligned} \tag{27}$$

where $\varepsilon(p)$ is the price elasticity of demand. The left-hand side of this equation represents the marginal benefit of output to the government, conditional on θ. If $\gamma = 0$, this marginal benefit simply corresponds to marginal revenue. Increasing γ increases the marginal benefit of a given level of output over marginal revenue. If the government gives more weight to consumer surplus than to profit ($\gamma > 1$), a case which is likely in practice, the marginal benefit is even higher than price. Note that in such a case the marginal benefit is positive even if $\varepsilon > -1$, so that it is possible that the public enterprise sells in the inelastic portion of demand.

To provide an interpretation to both terms on the right-hand side of (27), note that if the public enterprise minimized the cost of producing q, its marginal cost of production $MC(q, \theta; w, r)$ would be given by:

$$\begin{aligned} MC(q, \theta; w, r) &= \frac{w\tilde{L}(q, \theta; w, r)}{\beta q} = \frac{r\tilde{K}(q, \theta; w, r)}{\alpha q} \\ &= \theta^{-\frac{\beta}{\alpha+\beta}} \left[\frac{w}{\beta}\right]^{\frac{\beta}{\alpha+\beta}} \left[\frac{r}{\alpha}\right]^{\frac{\alpha}{\alpha+\beta}} q^{\frac{1}{\alpha+\beta}-1} \end{aligned} \tag{28}$$

where $\tilde{L}$ and $\tilde{K}$ represent input demand functions.[17] However, from (26), the government acts as if the price of labor were $w\left[1 + \nu(1-F)/\theta f\right]$, which we call the implicit price of labor. Letting $MB(q;\gamma) \equiv p(q)\left[1 + (1-\gamma)\varepsilon^{-1}\right]$ represent the (conditional) marginal benefit of output to government and $\phi(\theta) \equiv 1 + \nu(1 - F(\theta))/\theta f$ represent the factor by which government implicit labor wage differs from the market wage, the pricing condition (27) can be written as:

$$MB\left(q^D(\theta);\gamma\right) = MC\left(q^D(\theta), \theta; w\phi(\theta), r\right),\ \forall\theta \tag{29}$$

[17]These input demand functions are given by:

$$\begin{aligned} \tilde{L}(q, \theta; w, r) &= \theta^{-\frac{\beta}{\alpha+\beta}} \left[\frac{\beta r}{\alpha w}\right]^{\frac{\alpha}{\alpha+\beta}} q^{\frac{1}{\alpha+\beta}} \\ \tilde{K}(q, \theta; w, r) &= \theta^{-\frac{\beta}{\alpha+\beta}} \left[\frac{\beta r}{\alpha w}\right]^{-\frac{\beta}{\alpha+\beta}} q^{\frac{1}{\alpha+\beta}} \end{aligned}$$

They are obtained from the problem of minimizing cost subject to the Cobb-Douglas function (1). The first line of (28) is intuitive because $\beta q/\tilde{L}$ and $\alpha q/\tilde{K}$ represent the marginal productivities of labor and capital.

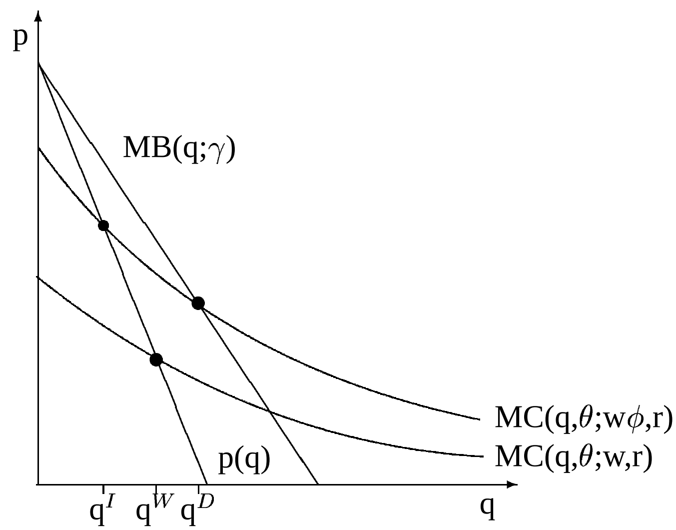
Similarly, second order condition (24) can be written in the following intuitive form:

$$MB_q\left(q^D(\theta);\gamma\right) < MC_q\left(q^D(\theta),\theta;w\phi(\theta),r\right),\ \forall\theta \tag{30}$$

Equation (29) can then be used to determine intuitively whether more or less output is produced in comparison to the welfare-maximizing solution, with or without private information constraints. For example,[18] if government weighs consumer surplus more heavily than profit ($\gamma > 1$), marginal benefit of output in (29) is always superior to price; this implies that output $q^D(\theta)$ will be greater than the welfare-maximizing solution where information constraints are taken into account. However, the output can be greater or less than the welfare-maximizing solution without constraints. This is illustrated in Figure 1 where technology is assumed to display increasing returns to scale, q^I is the welfare-maximizing output subject to information constraints and q^W is the welfare maximizing output without information constraints. In this case, we have $q^D > q^W$ and we see that q^D is necessarily greater than q^I.

[18] In what follows, we assume $\lambda = 0$ for ease of presentation of the graphic. The same analysis can be performed with $\lambda \neq 0$, but it would add a marginal benefit function in the figure, as the marginal benefit function associated with welfare-maximization would differ from the demand curve.

FIGURE 1
COMPARISON BETWEEN THE DIRECT CONTROL AND WELFARE
MAXIMIZATION FOR A GIVEN θ WITH $\gamma > 1$



One can thus easily perform comparative statics for different weights γ using graphics such as Figure 1.

3.2 Monotonicity Constraint and Implementation

We now show that the solution developed in the previous sub-section satisfies monotonicity constraint (17) under the fairly general and usual assumption that the hazard rate $f(\theta)/(1 - F(\theta))$ is increasing with θ. We proceed by proving first that, in conformity with intuition, this solution insures that the higher is input productivity, the higher is output. We then show that such output monotonicity is sufficient for the satisfaction of (17). Output monotonicity allows also to implement the direct mechanism solution by setting up the menu of contracts in terms of output rather than in terms of the productivity parameter.

Proposition 1 *Let* $\{q^D(\theta), K^D(\theta)\}$ *be a solution of problem (14)-(16). If the hazard rate is increasing in* θ*, then* $\dot{q}^D(\theta) > 0, \forall\theta$.

Proof. We first note that a monotone increasing hazard rate implies that $\phi'(\theta) < 0, \forall\theta$. Second, a solution of problem (14)-(16) must satisfy conditions (29) and (30). Differentiating (29) yields:

$$\dot{q}^D(\theta) = \frac{MC_\theta + MC_w w\phi^{'}}{MB_q - MC_q} \tag{31}$$

The numerator is negative since $MC_\theta < 0$, $MC_w > 0$, and $\phi^{'} < 0$. The denominator is negative in virtue of the second-order condition (30). ■

Corollary 1 *Under the assumptions of Proposition 1, constraint (17) is satisfied. In other words, necessary condition (ii) for incentive compatibility is satisfied.*

Proof. From the definition of Λ, we have:

$$\begin{aligned}\Lambda(q^D(\theta), K^D(\theta)) &= \theta L(q^D(\theta), K^D(\theta), \theta) = \theta\tilde{L}(q^D(\theta), \theta; w\phi(\theta), r) \\ &= \theta^{\frac{\alpha}{\alpha+\beta}} \left[\frac{\beta r}{\alpha w}\right]^{\frac{\alpha}{\alpha+\beta}} \phi^{-\frac{\alpha}{\alpha+\beta}} \left(q^D(\theta)\right)^{\frac{1}{\alpha+\beta}} \end{aligned} \tag{32}$$

Totally differentiating with respect to θ, we obtain:

$$\begin{aligned}\dot{\Lambda}(q^D(\theta), K^D(\theta)) = &\frac{\alpha}{\alpha+\beta}\theta^{\frac{-\beta}{\alpha+\beta}} \left[\frac{\beta r}{\alpha w}\right]^{\frac{\alpha}{\alpha+\beta}} \phi^{-\frac{\alpha}{\alpha+\beta}} \left(q^D\right)^{\frac{1}{\alpha+\beta}} \\ &-\frac{\alpha}{\alpha+\beta}\theta^{\frac{\alpha}{\alpha+\beta}} \left[\frac{\beta r}{\alpha w}\right]^{\frac{\alpha}{\alpha+\beta}} \phi^{\frac{-2\alpha-\beta}{\alpha+\beta}} \left(q^D\right)^{\frac{1}{\alpha+\beta}} \phi' \\ &+\frac{1}{\alpha+\beta}\theta^{\frac{\alpha}{\alpha+\beta}} \left[\frac{\beta r}{\alpha w}\right]^{\frac{\alpha}{\alpha+\beta}} \phi^{-\frac{\alpha}{\alpha+\beta}} \left(q^D\right)^{\frac{1}{\alpha+\beta}-1} \dot{q}^D \end{aligned} \tag{33}$$

which is positive for all θ since $\phi'(\theta)$ is negative by assumption and $\dot{q}^D(\theta)$ is positive in virtue of Proposition 1. ■

The solution found for the relaxed problem (14)-(16) thus satisfies constraint (17). Once this solution is found, one is confronted with implementing it in practice: it seems unrealistic to expect that the government would ask the public utility's managers to "announce their productivity parameter". Managers should rather have to commit publicly on reaching a target on one of the observable variables, such as profit. In the problem considered here, since output increases monotonically with the efficiency parameter θ, the direct mechanism solution can simply be implemented by asking the manager to announce the output level that the firm promises to supply, or equivalently, the price at which output will be sold.

To see this, let θ^D be the inverse function of q^D, i.e. θ^D is such that $\theta^D(q^D(\theta)) = \theta, \ \forall \theta \in \left[\theta^-, \theta^+\right]$. Instead of using the direct mechanism, government can ask the manager to choose output in the following menu of contracts:

$$\left\{q, \pi^D(\theta^D(q)), K^D(\theta^D(q))\right\}_{q \in \left[q^D(\theta^-), q^D(\theta^+)\right]} \tag{34}$$

Since this menu simply translates the direct revelation menu in function of output, it should be clear that the choice of the manager will not be modified: whenever the productivity parameter is θ, she will announce $q^D(\theta)$, *i.e.* the quantity that corresponds to θ in the original menu. This is formally shown in the following proposition.

Proposition 2 *The menu of contracts (34) implements the direct mechanism solution.*

Proof. Let $\hat{V}^D(\hat{\theta}, \theta) \equiv p(q^D(\hat{\theta}))q^D(\hat{\theta}) - rK^D(\hat{\theta}) - wL(q^D(\hat{\theta}), K^D(\hat{\theta}), \theta) - \pi^D(\hat{\theta})$ represent the information rent under the direct revelation mechanism. Suppose that the manager faces menu of contracts (34) and announces output $\hat{q} \neq q^D(\theta)$, where θ is the true parameter. Letting $\hat{\theta} \equiv \theta^D(\hat{q})$ and using the fact that the direct mechanism is incentive compatible, we have:

$$\hat{V}^D(\theta^D(\hat{q}), \theta^D(q^D(\theta))) = \hat{V}^D(\hat{\theta}, \theta) < \hat{V}^D(\theta, \theta) = \hat{V}^D\left(\theta^D(q^D(\theta)), \theta^D(q^D(\theta))\right)$$

i.e. announcing $\hat{q} \neq q^D(\theta)$ gives to the manager an information rent that is lower than the one associated with $q^D(\theta)$. This is in contradiction with the fact that the manager seeks to maximize her information rent. ■

It turns out that output is the only observable variable that is necessarily monotone with respect to the productivity parameter. This is because that, although effective labor Λ is increasing with θ, labor usage L could decrease following a productivity improvement. As a result, capital usage, which is observable, could decrease as well as increase with θ. Similarly, although we can derive conditions under which profit is a monotone increasing function of θ, the monotonicity of the profit path cannot be warranted in general. It thus seems that output (or price) would be the variable around which the menu of contracts should be designed. This is in line with actual practice, since price is usually the instrument that governments use to regulate their public enterprises.[19]

4 Pricing via a PUC

The creation of a PUC is modeled as an allocation of decision variables between two principals, the government and the PUC. The PUC is handed control over the utility's price (output), which, in the terminology of Laffont and Tirole [7], represents the only external control variable in our model. In choosing the price, the PUC has the mandate to give the same weights to consumer and producer surplus than those formerly given by the government under direct control.[20] However, the PUC does not have to pay any attention to information rents, which remain the government's prerogatives. It is assumed that the PUC is dedicated to fulfilling its mandate faithfully, i.e. that it does not have a private agenda of its own that could make it diverge from its stated objective. The government and the PUC play a Nash game, i.e. both principals take decisions of the other as given. We thus search for equilibrium values of decision variables.

4.1 Government's Problem

The stated objective of the government is the same as under direct control, i.e. the government still wants to maximize a weighted sum of consumer surplus, producer surplus and information rent. However, since it relinquished control

[19] Governments also issue service or quality standards while setting price, but this is beyond the scope of this paper as we have (implicitly) assumed a given and homogeneous quality of output.

[20] Comparing results between direct control and PUC regulation will allow us, in the next section, to infer whether government has an interest in modifying the weights when it creates a PUC.

over output, this is equivalent to minimize output cost, including the net cost to government of the information rent. Its problem then becomes:

$$\max_{\{K(\theta)\}} E_\theta \left\{ - \left[rK(\theta) + wL(q(\theta), K(\theta), \theta) + \nu V(\theta) \right] \right\} \tag{35}$$

$$\text{s.t.} \quad \frac{\partial V(\theta)}{\partial \theta} = w\theta^{-1} L(q(\theta), K(\theta), \theta) \tag{36}$$

$$V(\theta^-) = 0 \tag{37}$$

$$\dot{\Lambda}(q(\theta), K(\theta)) \geq 0 \tag{38}$$

We ignore for the moment constraint (38) and will check later whether it is satisfied or not at equilibrium once we have solved the PUC problem. With H^G as the Hamiltonian for this problem and η as the costate variable, first-order conditions for an interior solution are:[21]

$$\eta' = -\frac{\partial H^G}{\partial V} = \nu f \tag{39}$$

$$\frac{\partial H^G}{\partial K} = \left[-w\frac{\alpha L}{\beta K} - r \right] f - \eta w \frac{\alpha L}{\theta \beta K} = 0 \tag{40}$$

$$\eta(\theta^+) = 0 \tag{41}$$

These, of course, represent the same conditions than those for the corresponding variables in the direct control problem (14)-(16). This means that, if the government keeps the same weights in its objective function, giving up the output decision to a PUC does not modify productive efficiency.

4.2 PUC's Problem and Equilibrium

Given the capital-labor ratio determined by the government, the mandate of the PUC is to maximize the weighted sum of consumer and producer surplus. Since

[21] Since the second derivative of L with respect to K is positive, $\forall(q, K, \theta)$, the objective function of the government's problem is concave in K and V. Moreover, the labor requirement function in the state equation is convex in K (and V, since L is independent of V) while the costate variable η is negative. As a result, first-order conditions are sufficient for a maximum.

the government remains in charge of managerial incentives, the PUC pays no attention to the distribution of the information rent between the manager and the government. The PUC's problem is then:

$$\max_{\{q(\theta)\}} E_\theta \left\{ \gamma \left[\int_0^{q(\theta)} p(x)dx - p(q(\theta))q(\theta) \right] + [p(q(\theta))q(\theta) - wL(q(\theta), K(\theta), \theta)] \right\} \tag{42}$$

Let H^R be the Hamiltonian function for this problem. We obtain the necessary conditions:

$$\frac{\partial H^R}{\partial q} = \left[\gamma p(q) + (1-\gamma)(p'(q)q + p(q)) - \frac{wL}{\beta q} \right] f = 0 \tag{43}$$

$$\frac{\partial^2 H^R}{\partial q^2} = [(1-\gamma)\left(p''q + p'\right) + \gamma p' - wL_{qq}] f \leq 0 \tag{44}$$

A Nash equilibrium is obtained when conditions (39)-(41) of the government's problem and condition (43)-(44) of the PUC's problem are satisfied simultaneously. If such is the case, we obtain from (43) and (40):

$$p(q^R(\theta)) \left[1 + \frac{1-\gamma}{\varepsilon(p(q^R(\theta)))} \right] = \frac{wL^R(\theta)}{\beta q^R(\theta)} = \frac{r\phi\,(\theta)^{-1}\,K^R(\theta)}{\alpha q^R(\theta)} \tag{45}$$

where $\left\{q^R(\theta), K^R(\theta)\right\}$ represents a Nash equilibrium and $L^R(\theta) \equiv L(q^R(\theta), K^R(\theta), \theta)$. In terms of the marginal benefit and marginal cost functions defined above, this condition can be written in the following form:

$$MB\left(q^R(\theta); \gamma\right) = MC\left(q^R(\theta), \theta; w, r\phi(\theta)^{-1}\right) \tag{46}$$

Similarly, second-order condition (44) is translated in a more intuitive form as:

$$MB_q\left(q^R(\theta); \gamma\right) \leq MC_q\left(q^R(\theta), \theta; w, r\phi(\theta)^{-1}\right) \tag{47}$$

From (29) and (46), it can be seen that the difference between the two regulatory regimes comes from the way that inputs are valued by government. Under direct control, the choice of output by government was determined taking into account an implicit price of labor of $w\phi$. Here, the PUC determines output with no consideration of information rents, i.e. the PUC considers that the price of labor is w. The only instrument in the hands of government, quantity of capital, must then be used to cope with the "externalities" of PUC decisions on information rent. Since the PUC uses w as the price of labor and since adding one unit of capital will reduce labor usage by $1/MRS_{LK}^R$ unit of labor, the value of capital is w/MRS_{LK}^R for government. From the equilibrium marginal rate of substitution, this implies an implicit value of capital of $r\phi^{-1}$. This is the price of capital used for choosing output in (47). As a result, relative input prices are the same under both regulatory regimes, but their *absolute* prices differ. As shown in section 4.4, this will have an impact on the choice of output.

4.3 Monotonicity Constraint

The fact that government does not directly control output also has an impact on the possibility of satisfying the monotonicity constraint. Under direct control, government could restrain information rent by restraining output, since lower output requires less labor for given capital and productivity parameter. The higher was the productivity parameter, however, the lesser was the role of output as a rent restriction device since the cost of 1 dollar of rent conceded at event θ, that is $\nu(1 - F(\theta))$, decreases with θ. Combined with the fact that output was less costly to produce, this led to an increase of production.[22] As government does not directly control output under PUC regulation, containment of the information rent must be made through the choice of capital. Since the need for rent reduction is reduced as θ increases, it is possible that capital supplied to the firm is reduced with increases of θ. This can have the perverse effect of having output reductions with increases of the productivity parameter. Such output reduction can in turn provoke a violation of the monotonicity constraint (17).

[22]This can be seen from equation (31).

To formalize this idea, we totally differentiate equation (46) and obtain:

$$\dot{q}^R = \frac{MC_\theta - MC_r r\phi^{-2}\phi'}{MB_q - MC_q} \quad (48)$$

where $MC_\theta < 0$ and $MC_r > 0$, $\forall(q, \theta)$ and where it is assumed that necessary condition $MB_q - MC_q < 0$ is satisfied and that $\phi' < 0$. The first term of the RHS, $MC_\theta/(MB_q - MC_q)$, is a productivity effect: higher input productivity reduces cost and favors an increase of production. The second term is an information rent effect: the decrease of the information term (ϕ') reduces the value of a unit of capital, or equivalently, increases its price ($r\phi^{-1}$). This tends to reduce output. The sign of $\dot{q}^R(\theta)$ is thus indeterminate. Intervals of θs over which the hazard rate increases steeply, so that the information term ϕ decreases rapidly, could well display output reduction with productivity improvement.

An output reduction with productivity does not violate any constraint as such. However, it could lead to a reduction in effective labor Λ, i.e. to a violation of (38), as can be seen from (33). Then, the Nash equilibrium (39)-(41) and (43) would not be incentive compatible and would have to be modified over ranges of productivity parameters for which Λ is decreasing. For this purpose, we first note that whenever Λ is decreasing, both output and capital are also decreasing.

Lemma 3 *If $\phi'(\theta) < 0$ (increasing hazard rate), and $\dot{\Lambda}(q^R(\theta), K^R(\theta)) < 0$, then $\dot{q}^R(\theta) < 0$ and $\dot{K}^R(\theta) < 0$*

Proof. The fact that $\dot{q}^R(\theta) < 0$ can be directly seen from (33). Now, writing $\dot{\Lambda}$ in terms of capital instead of output, one gets:[23]

$$\dot{\Lambda}(q^R(\theta), K^R(\theta)) = \dot{K}\theta\left(\frac{\beta r}{\alpha w}\right)\phi^{-1} + K\left(\frac{\beta r}{\alpha w}\right)\phi^{-1} - K\theta\left(\frac{\beta r}{\alpha w}\right)\phi^{-2}\phi' \quad (49)$$

Since the last two terms are positive, $\dot{\Lambda}$ can be negative only if $\dot{K}$ is negative.
■

Now, consider an interval $\left[\bar{\theta}_1, \bar{\theta}_2\right]$ for which constraint $\dot{\Lambda}(q^R(\theta), K^R(\theta)) \geq 0$ in government's problem is not satisfied. Then the solution has to be adjusted

[23] To write Λ in terms of capital only, we substitute K^R to q^R by taking the inverse of the capital demand function with respect to output. We then totally differentiate with respect to θ to get $\dot{\Lambda}$.

so that Λ becomes constant over an interval $[\theta_1, \theta_2]$ where $\theta_1 \leq \bar{\theta}_1 \leq \bar{\theta}_2 \leq \theta_2$. Let $\{q^{CR}(\theta), K^{CR}(\theta)\}$ be such a solution, so that $\Lambda(q^{CR}(\theta), K^{CR}(\theta)) = \bar{\Lambda}$ over $[\theta_1, \theta_2]$. It is shown in Appendix C that it must satisfy:

$$\int_{\theta_1}^{\theta_2} \left[w\theta^{-1}\bar{\Lambda} - \frac{r\beta}{\alpha} K^{CR} + \nu \frac{(1-F)}{f} w\theta^{-2}\bar{\Lambda} \right] dF = 0 \tag{50}$$

Then, from (43), we get an implicit condition for output q^{CR},

$$MB(q^{CR}(\theta); \gamma) = \frac{w\theta^{-1}\bar{\Lambda}}{\beta q^{CR}(\theta)} \tag{51}$$

and $K^{CR}(\theta)$ must be chosen in order to meet this output, i.e. must be such that:

$$\Lambda(q^{CR}(\theta), K^{CR}(\theta)) = \bar{\Lambda} \tag{52}$$

Note that labor usage will decrease over this interval because of higher productivity: $L^{CR}(\theta) = \theta^{-1}\bar{\Lambda}$. Since $\dot{\Lambda} = 0$, it is also clear from (49) that capital decreases over this interval. Similarly, we get from (33) that output is decreasing.[24]

To summarize, an incentive Nash equilibrium is given by conditions (39)-(41) and (43) whenever $\dot{\Lambda} \geq 0$ and by conditions (50)-(52) for interval of constant effective labor.

4.4 Comparisons with Direct Government Control

In order to compare solutions of both regulatory regimes, we will first concentrate on the $\{q^R(\theta), K^R(\theta)\}$ path and check thereafter how results are affected when the constraint $\dot{\Lambda} \geq 0$ is binding. In the following propositions, we assume that the marginal cost function MC always crosses the marginal benefit function MB from below for all (q, θ). This is a slight reinforcement of second-order necessary conditions (30) and (47), which only requires that $MB_q < MC_q$ be satisfied in a neighborhood of the solution point. We assume that the condition would be met whatever is the solution to allow for comparative statics.

[24] If the initial solution $\{q^R(\theta), K^R(\theta)\}$ allows for several segments of declining Λ, this so-called "ironing" procedure would have to be repeated for each of these segments.

Proposition 3 *If $MB_q < MC_q$, $\forall(q,\theta)$, then $q^R(\theta) \geq q^D(\theta)$, $\forall\theta$.*

Proof. Since $w\phi(\theta) \geq w$ and $r\phi(\theta)^{-1} \leq r$, we have $MC(q,\theta;w\phi,r) \geq MC(q,\theta;w,r\phi^{-1})$, $\forall(q,\theta)$. We proceed by contradiction. Suppose $q^R(\theta) < q^D(\theta)$. Then,

$$\begin{aligned} MB(q^R;\gamma) - MC(q^R,\theta;w,r\phi^{-1}) &> MB(q^R;\gamma) - MC(q^R,\theta;w\phi,r) \\ &> MB(q^D;\gamma) - MC(q^D,\theta;w\phi,r) = 0 \end{aligned}$$

But this is in contradiction with optimal pricing condition (46) of the PUC problem. ■

Turning to input usage, the fact that the marginal rates of substitution are the same under both regulatory regimes imply that both regimes use the same expansion path. As a result, the regime who provides more output also employs more of both inputs.

Corollary 2 *If $MB_q < MC_q$, $\forall(q,\theta)$, then $L^R(\theta) \geq L^D(\theta)$ and $K^R(\theta) \geq K^D(\theta)$, $\forall\theta$.*

Proof. This follows from the fact that both regulatory regimes produce on the same expansion path and, from Proposition 3, that $q^R(\theta) \geq q^D(\theta)$, $\forall\theta$. ■

We now show that Proposition 3 extends to the cases where, under PUC regulation, the monotonicity constraint is binding over intervals of productivity parameters. This result follows from the fact that, with an increasing hazard rate, output always increases with θ under direct governmental control, while it *decreases* with θ when the monotonicity constraint is binding under PUC regulation.

Proposition 4 *Let θ_1 and θ_2 be such that $q^{CR}(\theta_1) = q^R(\theta_1)$, $q^{CR}(\theta_2) = q^R(\theta_2)$ and $\dot{\Lambda}(q^{CR}(\theta), K^{CR}(\theta)) = 0,\ \forall\theta \in (\theta_1,\theta_2)$. Assume that $MB_q < MC_q$, $\forall(q,\theta)$ and that the hazard rate is increasing for all θ. Then $q^{CR}(\theta) \geq q^D(\theta)$, $\forall\theta \in [\theta_1,\theta_2]$.*

Proof. By Proposition 3, $q^D(\theta_2) \leq q^R(\theta_2) = q^{CR}(\theta_2)$. Since, under an increasing hazard rate, $\dot{q}^D(\theta) > 0$, $\forall\theta$ and $\dot{q}^{CR}(\theta) < 0\ \forall\theta \in (\theta_{1,}\theta_2)$, it follows that $q^D(\theta) \leq q^{CR}(\theta)$, $\forall\theta \in [\theta_{1,}\theta_2]$. ■

The next proposition simply combines the preceding results on cases of non-binding and binding monotonicity constraint in order to compare the complete output paths of the two regulatory regimes.

Proposition 5 *Assume that* $MB_q < MC_q$, $\forall(q,\theta)$ *and that the hazard rate is monotone increasing for all* θ. *Then* $q^{CR}(\theta) \geq q^D(\theta)$, $\forall\theta$.

Proof. This follows from the combination of Propositions 3 and 4, using Proposition 3 whenever $q^{CR}(\theta) = q^R(\theta)$ and Proposition 4 whenever $\dot{\Lambda}(q^{CR}(\theta), K^{CR}(\theta)) = 0$. ■

However, Corollary 2 remains true only for labor usage. Results on capital are not maintained because regulatory regimes do not operate on the same expansion path when the monotoncity constraint is binding.

Corollary 3 *Assume that* $MB_q < MC_q$, $\forall(q,\theta)$ *and that the hazard rate is monotone increasing for all* θ. *Then* $L^{CR}(\theta) \geq L^D(\theta)$, $\forall\theta$.

Proof. Whenever $q^{CR}(\theta) = q^R(\theta)$, the result follows directly from Corollary 2. Consider now an interval $[\theta_1, \theta_2]$ for which $\dot{\Lambda}(q^{CR}(\theta), K^{CR}(\theta)) = 0$. By definition of Λ and in virtue of Corollary 2, $\Lambda(q^{CR}(\theta_2), K^{CR}(\theta_2)) = \theta_2 L^{CR}(\theta_2) \geq \theta_2 L^D(\theta_2) = \Lambda(q^D(\theta_2), K^D(\theta_2))$. Since $\dot{\Lambda}(q^{CR}(\theta), K^{CR}(\theta)) = 0$ and $\dot{\Lambda}(q^D(\theta), K^D(\theta)) \geq 0$, $\forall\theta \in [\theta_{1,}\theta_2]$, it follows that

$$L^{CR}(\theta) = \theta^{-1}\Lambda(q^{CR}(\theta), K^{CR}(\theta)) \geq \theta^{-1}\Lambda(q^D(\theta), K^D(\theta)) = L^D(\theta), \ \forall\theta \in [\theta_{1,}\theta_2]$$

■

Because we are not able to derive similar results for the capital paths, we cannot infer general results on whether expected costs of production is higher or lower under one regulatory regime compared to the other. Consequently, we cannot compare both regimes in terms of profit. The difficulty arises when the monotonicity constraint is binding; otherwise, the results on labor paths would carry over capital paths, as was shown in Corollary 2. However, intervals of binding monotonicity constraints also bring implementation problems, as we discuss in the next sub-section. Tackling these implementation issues, as we do in sections 4.5 and 4.6, will turn out to allow meaningful comparisons between capital paths and as a result, between values of the government's objective function.

4.5 Implementation

Because an incentive compatible Nash equilibrium does not warrant monotonicity of either the output path $\left\{q^{CR}(\theta)\right\}$ or the capital usage path $\left\{K^{CR}(\theta)\right\}$, neither of these variables can be used to implement the direct mechanism outcome. The only variable that can be used is the information rent of the manager. In principle then, the menu of contracts could be designed in terms of the information rent, i.e. the manager could be asked to announce her information rent. This could be considered as an agreement on the performance-based bonus given to the manager. The menu would then be $\{q(V^{CR}(\theta)), \pi(V^{CR}(\theta)), K(V^{CR}(\theta))\}$.

However, the solution could be politically difficult to implement for two reasons. First, it seems odd to have a regulatory agency focusing hearings on the determination of the overall compensation of managers, especially when internal control is considered the prerogative of government. Second, the resulting menu could allow for output reductions with productivity improvements. This would typically encounter political resistance and it is dubious that the government or the PUC could make a credible commitment to such a solution: once it is known that the utility operates under a relatively high productivity parameter, the PUC would certainly be pressured by consumer groups to keep the output price at least as low as when the productivity parameter is low. In other words, it appears unacceptable to sustain a situation where consumers turn out to lose from the firm's productivity improvements.

For these reasons, the next section analyzes a solution where output is constrained to increase with the productivity parameter. This is sufficient (but not necessary) to meet constraint (38). Forcing the output function to be monotonic will also allow the PUC to write the menu of contracts in terms of output, or price, which seems more realistic than using manager's compensation.

4.6 Constraint on Output Monotonicity

The technique used to solve the PUC problem with an output monotonicity constraint $\dot{q}(\theta) \geq 0$ is the same as the one presented for the labor monotonicity constraint in the preceding section and in Appendix C. Appendix D presents detailed calculations. It is shown that for an interval $[\theta_1, \theta_2]$ over which the constraint is binding (so that $q(\theta) = \bar{q}$, $\forall \theta \in [\theta_1, \theta_2]$), the first order condition reads as:

$$MB(\bar{q}; \gamma)\,[F(\theta_2) - F(\theta_1)] = \frac{w}{\beta \bar{q}} \int_{\theta_1}^{\theta_2} L(\bar{q}, K(\theta), \theta) dF \tag{53}$$

Satisfying simultaneously (39)-(41) and (53), a Nash equilibrium $(\bar{q}^{OR}, K^{OR}(\theta))$ over this interval is such that:

$$MB(\bar{q}^{OR}; \gamma)\,[F(\theta_2) - F(\theta_1)] = E_\theta MC(\bar{q}^{OR}, \theta; w, r\phi^{-1}(\theta)) \tag{54}$$

Over intervals for which output is increasing, we simply have $(q^{OR}(\theta), K^{OR}(\theta)) = (q^R(\theta), K^R(\theta))$. We can then restate Proposition 5 for the case where an output monotonicity constraint is imposed.

Proposition 6 *Assume that $MB_q < MC_q$, $\forall (q, \theta)$, and that the hazard rate in increasing for all θ. Then $q^{OR}(\theta) \geq q^D(\theta)$, $\forall \theta$.*

Proof. If θ is such that $\dot{q}^{OR}(\theta) > 0$, $q^{OR}(\theta) = q^R(\theta)$ and the result is obtained from Proposition 3. Consider now an interval $[\theta_1, \theta_2]$ such that $q^{OR}(\theta_1) = q^R(\theta_1) = q^{OR}(\theta_2) = q^R(\theta_2)$ and $\dot{q}^{OR}(\theta) = 0$, $\forall \theta \in (\theta_1, \theta_2)$. By Proposition 3, $q^D(\theta_2) \leq q^R(\theta_2) = q^{OR}(\theta_2)$. Since, under an increasing hazard rate, $\dot{q}^D(\theta) > 0$, $\forall \theta$ and $\dot{q}^{OR}(\theta) = 0\ \forall \theta \in (\theta_{1,}\theta_2)$, it follows that $q^D(\theta) \leq q^{OR}(\theta)$, $\forall \theta \in [\theta_{1,}\theta_2]$. ■

Contrary to the case where the monotonicity constraint is imposed on effective labor, first-order conditions (39)-(41) remain unchanged whether the output monotonicity constraint is binding or not. As a result, the marginal rate of substitution under PUC regulation will be the same as under direct government control, whatever is the productivity parameter. This feature allows us to obtain stronger results on capital paths, and consequently, on profit.

Corollary 4 *Assume that $MB_q < MC_q$, $\forall(q,\theta)$, and that the hazard rate is increasing for all θ. Then $L^{OR}(\theta) \geq L^D(\theta)$ and $K^{OR}(\theta) \geq K^D(\theta)$, $\forall\theta$.*

Proof. This follows from the fact that both regulatory regimes produce on the same expansion path and, from Proposition 6, that $q^{OR}(\theta) \geq q^D(\theta), \forall\theta$. ■

Since information rents are directly related to labor usage, it follows from Corollary 4 that they are higher with PUC regulation than under direct control. Together with the fact that more of both inputs are used, this means that expected cost of production is higher with the presence of a PUC. If demand is elastic, profit will be lower only if the gain of revenue is less than the cost increase. However, if government gives more weight to consumer surplus than to profit (i.e. if $\gamma > 1$), it is possible that the production takes place in the inelastic portion of demand. In such a case, profit would unambiguously decrease. This is shown in the next proposition.

Proposition 7 *If $MB_q < MC_q$, $\forall(q,\theta)$, $\phi'(\theta) < 0, \forall\theta$, $\gamma > 1$, and $\varepsilon(p(q)) > -1$, $\forall q \in \left[q^D(\theta), q^{OR}(\theta)\right]$, then $\pi^{OR}(\theta) \leq \pi^D(\theta)$, where $\pi^{OR}(\theta)$ and $\pi^D(\theta)$ are profits under regulation by a PUC and under direct control, respectively.*

Proof. Under the assumption that demand is inelastic over the range $[q^D, q^{OR}]$, a decrease in price brings a decrease in revenue. We thus have

$$p(q^{OR}(\theta))q^{OR}(\theta) \leq p(q^D(\theta))q^D(\theta) \tag{55}$$

From Corollary 4 and incentive compatibility constraints of problems (14) and (35), we have:

$$V^{OR}(\theta) = \int_{\theta^-}^{\theta} wx^{-1}L^{OR}(x)dx \geq \int_{\theta^-}^{\theta} wx^{-1}L^D(x)dx = V^D(\theta) \tag{56}$$

where V^{OR} and V^D are the manager's information rents under PUC regulation and direct government control, respectively. Then, (4), (55), Corollary 4 and (56) yield $\pi^{OR}(\theta) \leq \pi^D(\theta), \forall\theta$. ■

In general, the relative performance of both regimes are driven only by the fact that the government and the PUC have different perceptions of the *absolute* prices of labor and capital. Under direct control, government considers implicitly that the prices of labor and capital are $w\phi(\theta)$ and r, respectively, while the PUC rather uses w and $r\phi(\theta)^{-1}$. Relative prices being the same, this does not impact on productive efficiency. The high implicit labor price of direct control tends to decrease output,[25] while the low implicit capital price of PUC regulation tends to increase it.

5 Choice of Regulatory Regime by Government

In the previous section, comparisons of regulatory regimes were made under the assumption that the weights given to consumer surplus and profit in the government's objective function were the same under both regimes. Under such an assumption, it is clear that the government prefers direct control over PUC regulation: with direct control, it can maximize its objective function using all decision variables, while it loses control over output under PUC regulation. PUC regulation should thus be observed only if the government cannot freely pursue its objective.

Governments can be restrained in the regulation of a given economic sector either by the country's constitution, by national laws governing economic activities in general, or by bilateral and multilateral trade agreements. Trade agreements, in particular, have limited significantly the power of governments to intervene in markets for the last 10 or 15 years. In our model, such external constraints can be interpreted as an obligation for government to explicitly or implicitly put a weight on consumer surplus that differs from the one that it would choose to use, i.e. to adopt an objective function that does not represent its true preferences. In this section, we illustrate two cases where the creation of the PUC is susceptible to follow from external pressure, such as trade agreements, on government. We then illustrate the model with the regulatory reform of electricity markets in Quebec.

[25] Whether output is too high or too low compared to first best solution also depends, however, on the marginal benefit function.

5.1 PUC as a Constraint on Government

As the PUC tends to increase the production of the industry, its creation can increase welfare in the case where the government puts a weight γ on consumer surplus which is lower than $1/(1+\lambda)$. This would be the case where the government wants to use the protected sector of its public enterprise to finance other governmental activities or competitive activities of the same enterprise.[26] If external pressure cannot impose an objective function to government, it can then ask for the creation of an independent regulatory body, such as the PUC. Alternatively, if government cannot credibly commit to increase its weight on consumer surplus while holding control of the public enterprise, creation of the PUC can signal such a commitment.

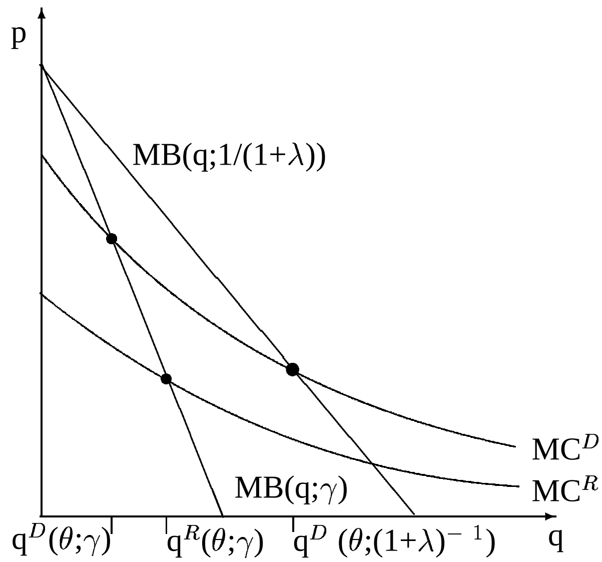
Figure 2 illustrates[27] this point. If government is free to choose its objective function, it puts a weight equal to γ on consumer surplus and opts for direct control. Government preferred output is then $q^D(\theta;\gamma)$. With the same information constraints, however, welfare-maximizing output is $q^D(\theta;(1+\lambda)^{-1})$. A PUC would operate as if marginal cost was given by the MC^R curve and output would be $q^R(\theta;\gamma)$. If, as shown in the figure, $q^R(\theta;\gamma) < q^D(\theta,(1+\lambda)^{-1})$ and if the welfare function is strictly concave, welfare would unambiguously increase. This is a case where external pressure would prefer regulation by a PUC than direct control for this precise value of θ.

[26] For example, provincial governments in Canada own public monopolies in alcohol distributions. Some of these public enterprises have been accused of subsidizing its activities in competitive sectors of the industry, such as wine bottling, with the surpluses generated in the protected distribution sector.

[27] For ease of presentation, in this figure, marginal cost curves are labeled in the following way: $MC^D \equiv MC(q,\theta;w\phi,r)$ and $MC^R \equiv MC(q,\theta,w,r\phi^{-1})$

FIGURE 2

DIRECT CONTROL VS. PUC WITH $\alpha + \beta > 1$ AND $\gamma < (1+\lambda)^{-1}$



However, regulation by a PUC could "overshoot" the welfare-maximizing target by having $q^R(\theta, \gamma) > q^D(\theta, (1+\lambda)^{-1})$, in which case it is not clear whether welfare is greater under regulation by a PUC or not. This overshooting is the likeliest the closer is γ to $(1+\lambda)^{-1}$. This is intuitive: the closer are government's preferences to welfare maximization, the less likely the distortions created by the PUC are beneficial. Overall, regulation by a PUC should be preferred when $E_\theta\left[\gamma CS(q^R(\theta;\gamma)) + \pi(q^R(\theta;\gamma))\right] > E_\theta\left[\gamma CS(q^D(\theta;\gamma)) + \pi(q^R(\theta;\gamma))\right]$

5.2 PUC as an Instrument for Softening Constraints

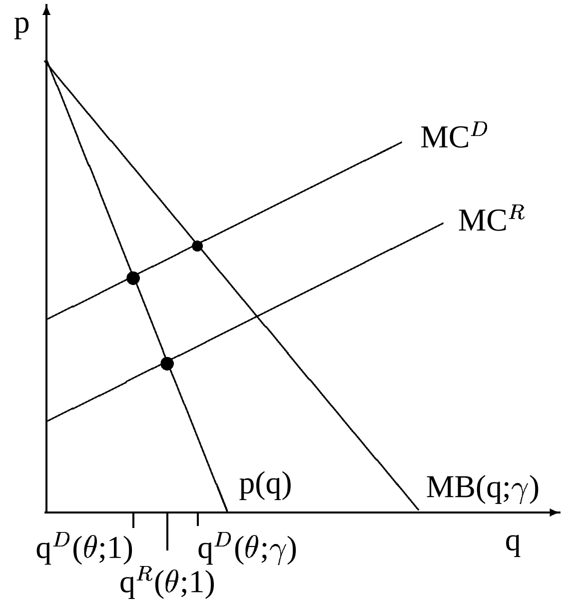
We now illustrate the case where the government initially values consumer surplus with a weight $\gamma > 1$. In such a case, the protected sector is subsidized under direct control as the price is lower than marginal cost. We assume that external pressure is able to require government to keep its weight on consumers' surplus equal to or less than 1,[28] but that it cannot impose the regulatory framework. To insure that the objective function of the government is strictly concave, we also assume that the enterprise experiences decreasing returns to scale. The same results hold with increasing returns to scale with the caveat that one has to check whether "moving" from one output level towards the government's preferred output really increases government's objective function: this is not always the case because the function is not necessarily everywhere concave.

In Figure 3 below, if government is free to choose its objective function, it puts a weight $\gamma > 1$, which corresponds to its preferences, and opts for direct control. For a given value of θ, this leads to output $q^D(\theta; \gamma)$, its preferred solution. Forcing the government to change the weight on consumers' surplus to $\gamma = 1$ is equivalent to force it to consider the inverse demand curve as its marginal benefit curve. Under direct control, government would then choose to decrease production to $q^D(\theta; 1)$. If it chooses to switch to PUC regulation, the enterprise would produce $q^R(\theta; 1) > q^D(\theta; 1)$. If, as in the figure, $q^R(\theta; 1) < q^D(\theta; \gamma)$, government prefers PUC regulation for this particular θ since the objective function is strictly concave and PUC regulation allows to get "closer" to the preferred output. If $q^R(\theta; 1) > q^D(\theta; \gamma)$, it is not clear which regulatory regime would be preferred for this θ, since one of them leads to overproduction compared to the government's preferred solution, while the other leads to underproduction.

[28] Trade agreements generally include provisions for precluding outright subsidization of industries.

FIGURE 3

DIRECT CONTROL VS. PUC WITH $\alpha + \beta < 1$ AND $\gamma > 1$



Government would then choose PUC regulation if it is advantageous on average, i.e. if $E_\theta \left[\gamma CS(q^R(\theta;1)) + \pi(q^R(\theta;1))\right] > E_\theta \left[\gamma CS(q^D(\theta;1)) + \pi(q^D(\theta;1))\right]$. This depends on the actual parameters of the problem. However, it is clear that the higher is γ, i.e. the "farther apart" is the marginal benefit curve from the demand curve, the more likely is PUC regulation as a way to circumvent external constraints.

5.3 Illustration: Electricity Markets in Quebec

In December 1996, the provincial government of Quebec adopted a law creating a public utility commission which received the mandate, among other things, to regulate electricity rates in Quebec. Most of electricity used in Quebec is produced by a publicly-owned utility, Hydro-Quebec. However, to help Hydro-Quebec get a licence to participate in the US competitive wholesale markets, the

Government of Quebec has opened access to the utility's transmission grid for transborder wholesale transactions. Hydro-Quebec also introduced separate accounting for generation, transmission and distribution and delegated management of its transmission assets to a division, whose activities are deemed independent from the rest of the corporation. This division is legally forbidden to practice price discrimination, in the sense that it must charge the same unit price[29] for all transmission services, regardless of the specific user. Hydro-Quebec maintains its monopoly in distribution and in domestic wholesale supply. However, government delegated pricing authority to the PUC for these protected sectors[30] as well as for the transmission network.

Before this regulatory reform, there was no independent regulatory overview of Hydro-Quebec and rates were directly approved by the government after a public examination by a commission of the public legislature. Combined with access to hydro resources, this regulatory framework has made Hydro-Quebec's rates among the lowest in the world. Accordingly, rates of return on equity have been dismal: from 1989 to 1995 the nominal rates of return ranged from 3.3 per cent to 8.4 per cent, rates that are roughly equal to treasury bill rates of return. In fact, Quebec has the capacity to keep low electricity rates without having accounting deficits: this is because 95% of electric energy is produced from hydraulic resources and production sites have been developed in ascending order of costs. Through ownership of Hydro-Quebec, the government could thus enjoy an important Ricardian rent, but has always dissipated it through electricity rates below marginal cost. Bernard and Chatel [2] have estimated that the application of marginal cost pricing instead of the observed price, approximately based on average cost, would have increased social welfare by C$270 to C$530 million per year, in constant 1980 Canadian dollars. Bernard and Roland [3] have shown that this propensity to dissipate rent is consistent with a majority-rule equilibrium.

[29]This price is to be set by the PUC.

[30]This is to be contrasted with France which, as a way to comply with an EU directive on third-party access to transmission network, had announced the creation of a PUC which will regulate only the price of transmission. Distribution prices for protected services will continue to be part of a service agreement between the publicly-owned utility and the government.

Such pricing policy and its ensuing welfare loss shows that the government did not maximize welfare and rather preferred to favor the electricity customers at the expense of the public utility profit. In terms of our model, this hints at a relatively high weight γ in the government's objective function. However, one can wonder why such a politically popular policy has not been maintained. In fact, in spite of the worldwide trend of electricity market restructuring, there was no internal pressure for reform. The government's motivation was rather to insure that Hydro-Quebec met US regulators' criteria to be an eligible seller on US wholesale markets, while minimizing the impact on the domestic market. This was shown, in particular by efforts made by the government to convince domestic consumers that prices would be maintained low in Quebec[31] and that there was no plan for privatizing Hydro-Quebec in whole or in part.

Nevertheless, US regulators required only warranties for non-discriminatory access to Quebec's transmission network. There was then no formal obligation to create the PUC. Furthermore, if the aim of creating the PUC were strictly to signal non-intervention in transmission pricing, the mandate of the PUC could have been limited to the transmission segment of the market. As experience shows that government of Quebec puts a weight greater than 1 on consumer surplus and since the Quebec hydro-electric system operates under decreasing returns to scale, it seems that Figure 3 would apply to Quebec electricity markets. This would suggest that the PUC was created in order to maintain the lowest prices possible in domestic markets.

6 Conclusion

When the presence of the PUC does not improve information to government, splitting decision variables between two principals increases the cost of limiting the information rent to the firm's manager. As a result, the information rent will be

[31] While the government delegated price authority to the PUC, both the government and Hydro-Québec made the commitment to freeze rates for a period of 4 years, i.e. to refrain from asking the PUC to increase rates over the period.

allowed to be greater with a PUC than under direct control and, since this information rent is positively correlated to output, this will also lead to an increase of output. There is thus an inherent inefficiency in PUC regulation, and the government would never resort to it if its objective were to maximize welfare.

However, this tendency of PUC regulation to increase output could prove attractive when the government's objective differs from welfare maximization and when the government is not entirely free of its choices for any reasons, such as constitutional restrictions or trade agreements. We used two cases to illustrate this point. First, if the government's objective is such that output is lower than the welfare-maximizing one, creation of a PUC could be externally imposed on the government in order to rectify its bias for low output. On the contrary, if the government prefers an higher output than the welfare-maximizing one, the creation of the PUC could be used to soften constraints that would be externally imposed.

A number of extensions should be brought to our analysis. First, as Pint (1991) already made comparisons between a directly controlled public monopoly and a regulated private monopoly, there remains the task of comparing a regulated public monopoly with a private one. From the results of Pint, it can already be inferred that, under regulation by a PUC, a public enterprise would differ from a private one not only with respect to allocative efficiency, but also in productive efficiency.

Second, in line with most of the principal-agent literature, it would be interesting to consider that the PUC *(i)* improves the information available to government, but *(ii)* has interests of its own that differ from those of the government. Consequently, the PUC would try to benefit from the information it gathers and would be able to extract an information rent in the same way the manager does. This could eventually result in coalition between the PUC and the utility. Such an extension could possibly draw on the work of Laffont and Tirole [6].

Appendices

A Proof of Lemma 1[32]

Letting $V(\theta) \equiv \hat{V}(\theta, \theta)$, we get from (8):

$$\hat{V}(\hat{\theta}, \theta) = V(\hat{\theta}) + w\left[L(q(\hat{\theta}), K(\hat{\theta}), \hat{\theta}) - L(q(\hat{\theta}), K(\hat{\theta}), \theta)\right] \tag{57}$$

Incentive compatibility means that the manager has an interest in truthfully reporting the parameter θ. This can be true only if the utility of the manager is greater when she is honest than when she lies. From (57) and (2), this implies that

$$V(\theta) \geq \hat{V}(\hat{\theta}, \theta) = V(\hat{\theta}) + w\left[\hat{\theta}^{-1} q(\hat{\theta})^{1/\beta} K(\hat{\theta})^{-\alpha/\beta} - \theta^{-1} q(\hat{\theta})^{1/\beta} K(\hat{\theta})^{-\alpha/\beta}\right] \tag{58}$$

Reversing the roles of θ and $\hat{\theta}$ in (58), we obtain:

$$V(\hat{\theta}) \geq \hat{V}(\theta, \hat{\theta}) = V(\theta) + w\left[\theta^{-1} q(\theta)^{1/\beta} K(\theta)^{-\alpha/\beta} - \hat{\theta}^{-1} q(\theta)^{1/\beta} K(\theta)^{-\alpha/\beta}\right] \tag{59}$$

Combining (58) and (59) yields:

$$\begin{aligned} & w\left[\hat{\theta}^{-1} q(\hat{\theta})^{1/\beta} K(\hat{\theta}) - \theta^{-1} q(\hat{\theta})^{1/\beta} K(\hat{\theta})^{-\alpha/\beta}\right] \\ \leq \;& V(\theta) - V(\hat{\theta}) \\ \leq \;& w\left[\hat{\theta}^{-1} q(\theta)^{1/\beta} K(\theta)^{-\alpha/\beta} - \theta^{-1} q(\theta)^{1/\beta} K(\theta)^{-\alpha/\beta}\right] \end{aligned} \tag{60}$$

Dividing by $\hat{\theta} - \theta$ and taking the limit as $\hat{\theta} \to \theta$ we get:

$$-\frac{\partial V(\theta)}{\partial \theta} = -w\theta^{-2} q(\theta)^{1/\beta} K(\theta)^{-\alpha/\beta} = -w\theta^{-1} L(q(\theta), K(\theta), \theta) \tag{61}$$

[32] Appendices A and B are based upon Pint[10].

B Proof of Lemma 2

(Necessity) From (60)

$$w(\hat{\theta}^{-1} - \theta^{-1})\Lambda(q(\hat{\theta}), K(\hat{\theta})) \leq w(\hat{\theta}^{-1} - \theta^{-1})\Lambda(q(\theta), K(\theta)) \tag{62}$$

which reduces to

$$\Lambda(q(\hat{\theta}), K(\hat{\theta})) \leq \Lambda(q(\theta), K(\theta)) \text{ for } \hat{\theta} \leq \theta \tag{63}$$

which is equivalent to condition (ii).

Now, dividing all terms in (60) by $\hat{\theta} - \theta$ and taking the limit as $\hat{\theta} \to \theta$ we obtain:

$$\frac{\partial V(\theta)}{\partial \theta} = w\theta^{-2}\Lambda(q(\theta), K(\theta)) \tag{64}$$

Integrating yields

$$V(\theta) = V(\theta^{-}) + \int_{\theta^{-}}^{\theta} wx^{-2}\Lambda(q(x), K(x)) \tag{65}$$

which is condition (i)

(Sufficiency) Let $\hat{\theta} \leq \theta$. From (8) and the definition of Λ:

$$\begin{aligned} \hat{V}(\hat{\theta}, \theta) &= V(\hat{\theta}) + w\left[L(q(\hat{\theta}), K(\hat{\theta}), \hat{\theta}) - L(q(\hat{\theta}), K(\hat{\theta}), \theta)\right] && (66) \\ &= V(\hat{\theta}) + w(\hat{\theta}^{-1} - \theta^{-1})\Lambda(q(\hat{\theta}), K(\hat{\theta})) && (67) \end{aligned}$$

Substituting for $V(\hat{\theta})$ from condition (i)

$$\hat{V}(\hat{\theta}, \theta) = V(\theta^{-}) + w\int_{\theta^{-}}^{\hat{\theta}} x^{-2}\Lambda(q(x), K(x))dx + w(\hat{\theta}^{-1} - \theta^{-1})\Lambda(q(\hat{\theta}), K(\hat{\theta})) \tag{68}$$

Substituting for $V(\theta^-)$ from condition (i)

$$\begin{aligned}
\hat{V}(\hat{\theta},\theta) &= V(\theta) - w\int_{\theta^-}^{\theta} x^{-2}\Lambda(q(x),K(x))dx \\
&\quad + w\int_{\theta^-}^{\hat{\theta}} x^{-2}\Lambda(q(x),K(x))dx + w(\hat{\theta}^{-1}-\theta^{-1})\Lambda(q(\hat{\theta}),K(\hat{\theta})) \\
&= V(\theta) - w\int_{\hat{\theta}}^{\theta} x^{-2}\Lambda(q(x),K(x))dx + w(\hat{\theta}^{-1}-\theta^{-1})\Lambda(q(\hat{\theta}),K(\hat{\theta})) \\
&= V(\theta) - w\int_{\hat{\theta}}^{\theta} x^{-2}\Lambda(q(x),K(x))dx + w\int_{\hat{\theta}}^{\theta} x^{-2}\Lambda(q(\hat{\theta}),K(\hat{\theta}))dx \\
&= V(\theta) + w\int_{\hat{\theta}}^{\theta} x^{-2}\left[\Lambda(q(\hat{\theta}),K(\hat{\theta})) - \Lambda(q(x),K(x))\right]dx \qquad (69)
\end{aligned}$$

Under condition (ii), this last integral is negative so that $\hat{V}(\hat{\theta},\theta) < V(\theta)$.

C Binding Labor Monotonicity Constraint

In this Appendix, we explicitly take into account constraint (38) while solving problem (35). As the solution over intervals of θ for which the constraint is not binding is explicitly derived in the main text, we focus here on intervals for which the constraint is binding.

The treatment here differs from the one in main text in two respects: first, since the constraint applies on effective labor Λ rather than nominal labor L, we solve this problem in terms of Λ. The solution for L is then simply given by $L = \theta^{-1}\Lambda$. Second, rather than solving for capital K and deduct required labor for producing q from function $\Lambda(q,\cdot)$ defined in (10), we solve for Λ and then deduct the required capital for producing output q. This is again because the constraint applies directly on Λ, while capital usage is unconstrained. The capital requirement function is obtained by inverting $\Lambda(q,\cdot)$:

$$K(q,\Lambda) = \Lambda^{-\frac{\beta}{\alpha}} q^{\frac{1}{\alpha}} \qquad (70)$$

The constraint applying on the derivative of Λ, we treat $\Lambda(\theta)$ as a state variable and define a new variable $\delta(\theta) \equiv \dot{\Lambda}(\theta)$, which becomes the control variable.

Problem (35) can then be written under the following form:[33]

$$\max_{\delta(\theta)} \int_{\theta_0}^{\theta_1} - \left[w\theta^{-1}\Lambda(\theta) + rK(\Lambda(\theta), q(\theta)) + \nu V(\theta) \right] dF(\theta) \tag{71}$$

$$\text{s.t.} \qquad \dot{V}(\theta) = w\theta^{-2}\Lambda(\theta) \tag{72}$$

$$V(\theta^{-}) = 0 \tag{73}$$

$$\dot{\Lambda}(\theta) = \delta(\theta) \tag{74}$$

$$\delta(\theta) \geq 0 \tag{75}$$

Letting superscript CR denote the "constrained" government problem under PUC regulation and denoting by ζ the costate variable associated with constraint (75), we form the Hamiltonian:

$$H^{CR} = \left[-w\theta^{-1}\Lambda(\theta) - rK(\Lambda(\theta), q(\theta)) - \nu V(\theta) \right] f(\theta) + \eta(\theta) w\theta^{-2}\Lambda(\theta) + \zeta(\theta)\delta(\theta)$$

First-order conditions are then given by:

$$\dot{\zeta}(\theta) = -\frac{\partial H^{CR}}{\partial \Lambda} = \left[w\theta^{-1} + rK_{\Lambda} \right] f - \eta w\theta^{-2} \tag{76}$$

$$\dot{\eta} = -\frac{\partial H^{CR}}{\partial V} = \nu f \tag{77}$$

$$\frac{\partial H^{CR}}{\partial \delta} = \zeta(\theta) \leq 0 \qquad \zeta(\theta)\delta(\theta) = 0 \qquad \delta(\theta) \geq 0 \tag{78}$$

Calculating K_{Λ} from (70) and substituting into (76), we get:

$$\dot{\zeta}(\theta) = \left[w\theta^{-1} - r\frac{\beta K}{\alpha \Lambda} \right] f - \eta w\theta^{-2} \tag{79}$$

[33] The treatment here follows Laffont and Tirole [8], section A1.5.

Consider now an interval $[\theta_1, \theta_2]$ for which $\Lambda(\theta) = \bar{\Lambda}$. Since $\zeta(\theta_1) = \zeta(\theta_2) = 0$, we obtain, after multiplying both sides of the last expression by $\bar{\Lambda}$, substituting $\nu(1 - F(\theta))$ to $\eta(\theta)$, and integrating:

$$\int_{\theta_1}^{\theta_2} \left[w\theta^{-1}\bar{\Lambda} - \frac{r\beta}{\alpha}K + \frac{\nu(1-F)}{f} w\theta^{-2}\bar{\Lambda} \right] dF = 0 \tag{80}$$

Substituting $L(q(\theta), K(\theta), \theta) = \theta^{-1}\Lambda(q(\theta), K(\theta)) = \theta^{-1}\bar{\Lambda}$, this can be written as:

$$\int_{\theta_1}^{\theta_2} \left[wL - \frac{r\beta}{\alpha}K + \frac{\nu(1-F)}{\theta f} L \right] dF = 0 \tag{81}$$

Note that this condition can easily be related to condition (40): while this latter required that the integrand of (81) be equaled to zero for each θ, here it is only required to be zero on "average" on the interval $[\theta_1, \theta_2]$, over which effective labor is fixed.

D Binding Output Monotonicity Constraint

In this Appendix, we include an output monotonicity constraint in the PUC problem and solve the problem by following the technique used in Appendix C. Output $q(\theta)$ is taken as a state variable and we introduce $\kappa(\theta) \equiv \dot{q}(\theta)$ as the control variable. The PUC problem then becomes:

$$\max_{\{\kappa(\theta)\}} \quad E_\theta \left\{ \gamma \left[\int_0^{q(\theta)} p(x)dx - p(q(\theta))q(\theta) \right] + [p(q(\theta))q(\theta) - wL(q(\theta), K(\theta), \theta)] \right\}$$

$$\text{s.t.} \quad \dot{q}(\theta) = \kappa(\theta) \tag{82}$$

$$\kappa(\theta) \geq 0 \tag{83}$$

Letting $\xi(\theta)$ be the co-state variable associated with (82), we can write the Hamiltonian for this problem as follows:

$$H^{OR} = \gamma \left[\int_0^{q(\theta)} p(x)dx - p(q(\theta))q(\theta)) \right] + [p(q(\theta))q(\theta) - wL(q(\theta), K(\theta), \theta)] + \xi(\theta)\kappa(\theta)$$

First-order conditions are:

$$\dot{\xi}(\theta) = -\frac{\partial H^{OR}}{\partial q(\theta)} = \left[\gamma p + (1-\gamma)(p'q + p) - \frac{wL}{\beta q} \right] f \tag{84}$$

$$\frac{\partial H^{OR}}{\partial \kappa(\theta)} = \xi(\theta) \leq 0 \qquad \xi(\theta)\kappa(\theta) = 0 \qquad \kappa(\theta) \geq 0 \tag{85}$$

Consider now an interval $[\theta_1, \theta_2]$ over which constraint $q(\theta) = \bar{q}$. Since $\xi(\theta_1) = \xi(\theta_2) = 0$, we from (84):

$$\int_{\theta_1}^{\theta_2} \left[\gamma p + (1-\gamma)(p'\bar{q} + p) - \frac{wL}{\beta \bar{q}} \right] dF = 0 \tag{86}$$

This can be written as:

$$MB(\bar{q}; \gamma) \left[F(\theta_2) - F(\theta_1) \right] = \frac{w}{\beta \bar{q}} \int_{\theta_1}^{\theta_2} L(\bar{q}, K(\theta), \theta) dF \tag{87}$$

which is equation (53) in the main text.

References

[1] BARON, D. P.: "Regulation and Legislative Choice", *Rand Journal of Economics*, 19 (1988), 467-477.

[2] BERNARD, J.-T. and J. CHATEL: "The application of Marginal Cost Pricing Principals to a Hydro-Electric System: The Case of Hydro-Quebec", *Resource and Energy Economics*, 7 (1985), 353-375.

[3] BERNARD, J.-T. and M. ROLAND: "Rent Dissipation through Electricity Prices of Publicly-Owned Utilities", *Canadian Journal of Economics*, 30 (1997), 1204-1219.

[4] BERNARD, J.-T. and R. J. WEINER: "Export Pricing in State Owned and Private MNE's: Evidence form the International Petroleum Market", *International Journal of Industrial Organization*, 14 (1996), 647-668.

[5] DE FRAJA G.:"Productive Efficiency in Public and Private Firms", *Journal of Public Economics*, 50 (1993), 15-30.

[6] LAFFONT, J.-J and J. TIROLE: "The Politics of Government Decision Making: Regulatory Institutions", *Journal of Law, Economics and Organizations*, 7 (1990) 1-31.

[7] LAFFONT, J.-J and J. TIROLE: "Privatization and Incentives", *Journal of Law, Economics and Organization*, 7 (1991), 84-105.

[8] LAFFONT, J.-J and J. TIROLE: "A Theory of Incentives in Procurement and Regulation", MIT Press, 1993.

[9] NOUHI, M.: "Impact d'une agence de reglementation sur l'efficacite des compagnies publiques d'electricite", M.A. thesis, Departement d'economique, Universite Laval, 1999.

[10] PINT, E. M.: "Nationalization vs. Regulation of Monopolies: The Effects of Ownership on Efficiency", *Journal of Public Economics*, 44 (1991), 131-164.

[11] SCHMIDT, K. M.: "Incomplete Contracts and Privatization", Discussion Paper A-480, Universität Bonn, 1995.