Incentives for Quality Provision and Environmental Innovations by Water Supply Utilities

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Primes accordées à la qualité et à l'innovation en matière d'environnement par les services des eaux

Résumé — Cet article traite de la régulation par les services publics des eaux. En particulier nous nous concentrons sur des prestations de qualité et de recherche et développement (R&D) en présence d'informations asymétriques: l'eau, qui est polluée par les secteurs industriels et agricoles, doit être filtrée par les services publics en utilisant des méthodes d'épuration qui sont exigeantes en R&D. Les services publics des eaux sont responsables de l'épuration et de la distribution de l'eau avec une extension de l'abattement dépendant aussi bien du volume exogène de la pollution que du niveau de la qualité prescrit par le régulateur.

En présence d'un mécanisme optimum de régulation, nous convenons que la structure d'information est asymétrique, parce que nous supposons que le régulateur est confronté à l'incertitude quant à l'efficacité du service et en conséquence quant aux coûts d'abattement et aux effets du progrès technique, lesquels réduisent les coûts. Le prix du service est calculé indépendamment de la qualité, mais en retour il dépend du niveau d'efficacité, ce qui incite les services à surévaluer les vrais coûts. Par conséquent les coûts de la fourniture de qualité peuvent être utilisés par les services comme un outil pour obtenir des rentes d'information.

Des services optimisent leurs coûts d'abattement au moyen d'investissements dans le progrès technique (innovations de procédés). Il faut noter que la cession des décisions quant à la R&D et quant à la qualité des services n'assure pas du tout une deuxième-meilleure solution, si bien que le régulateur est à même, non seulement d'effectuer une régulation des prix, mais peut en outre imposer un programme de qualité, de R&D et de transfert. Ainsi nous essayons de caractériser des mécanismes endogènes qui soient compatibles avec des incitations assurant une deuxième-meilleure solution.

Dans notre essai, la pollution de l'eau est d'origine non ponctuelle et comprend la pollution résiduelle après les essais d'épuration des pollueurs ponctuels. Par conséquent nous nous intéressons plus précisément aux modalités d'usage optimales de la technologie «en bout de canalisation», utilisée dans le processus d'épuration.

Mots-clés:
régulation, informations asymétriques, eau, services publics, progrès technique

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Summary *– This paper deals with optimal regulatory policies to provide for quality of service and innovations in abatement technology by water supply utilities. The main focus of the analysis is on the relationship among price, quality, pollution and abatement technology. Allowing for asymmetric information about abatement costs and costs of quality service we try to characterize incentive compatible mechanisms, where price, quality and technical progress are optimally regulated to assure for a second-best solution. We find price to be higher, quantity and investment in abatement technology to be lower than in the full information solution.*

Key-words:
regulation, asymmetric information, technological change, water

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WATER has been considered as one very important, if not the most important resource mankind needs to ensure its future survival. While in many developing countries the quantity of available drinking water poses the greatest problems, it is the quality of the available water that causes great concern in all nations. Thus, regulation of the water supply utilities becomes an important task for policy makers in order to guarantee for drinking water quality and for the technical progress required to deal with evermore new pollutants. In the European Community e.g. national drinking water standards have been supplemented by EC wide standards which require the regulatory promotion of investments (see Rees, Vickers 1995)[1].

In this paper we deal with the regulation of water suppliers, concentrating on the provision of quality and R&D in the presence of asymmetric information: water which is polluted by the industrial and agricultural sector has to be filtered by the water suppliers using R&D intensive purification methods. Water supply utilities are in charge of water purification and distribution with the extension of abatement depending on the exogenous volume of pollution as well as on the quality level set by the regulator.

When designing the optimal regulatory mechanisms, we take the information structure to be asymmetric, assuming that the regulator is faced by uncertainty about the efficiency of the firm and thus abatement costs and cost reducing effects of technical progress. The price of water is modeled to be independent of quality, but to depend on the efficiency level instead which gives firms an incentive to overstate true costs. Thus the costs of providing quality can be used by the firms as an instrument for extracting information rents.

Firms optimize their abatement costs by investing in technical progress (process innovations). It is worth noting that leaving decisions on R&D and quality up to the firm does not assure for a second-best solution at all so that in addition to price regulation the regulator is able to impose a quality, R&D and transfer schedule as well. Hence, we try to characterize endogenous incentive compatible mechanisms to assure for a second-best solution. Our analysis falls in the range of the mechanism design literature to follow the approaches by Baron, Myerson (1982), Baron (1989) and Laffont, Tirole (1993).

In our paper we do not deal with the aspect of deregulation and / or privatization of the water sector. Since the water sector shows consider-

[1] For a discussion of institutional questions of the regulation and deregulation of the water sector see e.g. Dick (1991) for Germany and Vickers, Yarrow (1988) for Great-Britain.

able aspects of a natural monopoly as argued in Klein, Irwin (1996), the scope for deregulation is limited. For a further discussion of this aspect, see e.g. Klein (1997), Spulber, Sabbaghi (1994) and Beesley (1992).

The pollution of the raw water in our paper results from non-point-source pollution including the pollution which pertains in the water, subsequent to purification efforts of point-source polluters. Consequently we take a closer look at the conditions for an optimal use of end of the pipe technology applied in the purification process. The internalization of point-source pollution by green taxes, marketable permits and quantitative restrictions is out of the scope of our paper.

The paper is organized as follows. In the first section the basic model is introduced and the regulator's optimization regulation problem is formalized. After having analyzed the full-information solution we try to derive the second-best solution when information is asymmetric. The optimal price, transfer, quality and R&D schedules are presented and analyzed.

THE BASIC MODEL

Consider a water supply utility which is faced with some external water pollution activity taken by households as well as the industrial and agricultural sector. We model this activity in a rather simple way by assuming an exogenous and deterministic pollution load denoted e^+. In order to assure for the health of the population, the regulatory agency requires the water supplier to meet a water quality standard s where an increase in s implies higher quality. In order to be able to deliver water of the quality required, the utility has to apply a purification process leading to a reduction of the load of discharges and consequently an increase in the quality level s.

Consumer demand for water is given by:

$$q(p) \quad , q_p < 0 \tag{2.1}$$

Quality is not reflected in the price, since we consider water neither as a search nor as an experience good. Although water quality may be observable to a certain extent indicated by smell, taste or discoloration, many of the discharges like metals, pesticides or germs in general cannot be detected by the consumer. This unobservable aspect of water quality gives rise to governmental intervention to control for quality. While quality is thus assumed to be observable and verifiable by public authorities, consumers have to rely on the regulatory agency to assure for quality s. The desired or required level of quality implicitly determines the abatement activity of the utility. Furthermore, a decrease in water quality may cause damages to the consumers represented by a convex damage function $D(s)$ which has to be taken into account by the regulator.

Usually consumers cannot choose between water of higher or lower quality at different prices, they are delivered with drinking water at the given price. Although one can imagine horizontally differentiated water supply utilities which provide water of different quality standards for industrial and household use, we don't consider this possibility in our paper.

For purification, capital and R&D intensive production processes have to be applied, reflected in the following convex cost function:

$$C(q, R, s, \theta) = c(R, s, \theta)q + R + K \tag{2.2}$$

where marginal costs are assumed to be constant in q and increasing in the level of quality ($c_s > 0$). We consider utilities to be able to invest in R&D leading to process innovations with diminishing returns ($c_R < 0$, $c_{RR} > 0$). Water supply utilities which have to increase their level of abatement may therefore want to compensate the induced increase in marginal costs at least partly by investing in technical progress. The factor price of R&D is normalised to one. Process innovations are modelled as deterministic, which may be justified because the water supply agency can purchase mains systems and purification plants from the capital investment industry (mechanical engineering and chemical industry).

In our paper we deal with vertically integrated water supply utilities which provide not only for the purification of the water but also for its subsequent distribution. Since our cost function is not necessarily separable with respect to purification and distribution, the impact of technical progress on both cannot be differentiated.

Fixed costs K are originating from the mains system on the one hand and the purification plants on the other.

θ is an efficiency parameter, referred to as the type of the firm. The higher θ the less efficient the agency produces, so that marginal cost increase in θ ($c_\theta > 0$).

Information asymmetries are introduced by assuming that the firm has private knowledge of its type θ, whereas the regulator has only (common) knowledge of the density function $f(\theta)$ and the distribution $F(\theta)$ defined on the support

$$\theta \in [\theta^-, \theta^+]$$

(The associated monotone hazard rate

$$F(\theta) \,/\, f(\theta)$$

is assumed to be strictly increasing to assure for an unique solution to our maximization problem.)

Although the regulator is able to monitor R and s resp. e^{-}, he is not able to infer the type θ of the firm. Thus the efficiency of R as well as the cost increasing effect of s are not observable. These are the sources for the rent seeking activities taken by the utility.

In this setup of a Bayesian-Nash-Game with the regulator and firm as actors we will identify the set of optimal regulatory schemes for each type $\hat{\theta}$ reported by the firm. The regulator is assumed to use a revelation approach in order to induce firms to report their level of efficiency truthfully. The timing of the game generally contains three stages: on a first stage the utility learns its type θ chosen by nature. Subsequently the regulator offers a menu of regulatory schemes to the firm, which then chooses the profit-maximizing contract followed by the investment and production stage.

As a standard assumption we take the water supplier to pursue profit maximization over its strategic variable $\hat{\theta}$ so that we are able to rule out moral hazard which is not in the scope of our paper. We deal with an adverse-selection problem instead, arising from the asymmetric cost information mentioned above.

The regulatory agency on the other hand is maximizing expected social welfare. We model social welfare as the weighted sum of consumer and producer surplus:

$$W = CS - D - T + \alpha\Pi, \alpha \leq 1 \tag{2.3}$$

following the approach taken by Baron (1989). When transfers are given to the water suppliers, this formulation implicates welfare losses which can be interpreted as implicitly arising social costs of public funds[(2)].

Regulatory mechanisms are endogenous, the regulator has to base regulation on the efficiency report made by the firm $\hat{\theta} \in [\theta^{-}, \theta^{+}]$. The regulatory scheme consists of:

- a price schedule $p(\hat{\theta})$ to reduce monopoly rents,
- a transfer schedule $T(\hat{\theta})$ to cover possible losses[(3)] due to below average cost pricing and to transfer information rents,
- a water quality schedule $s(\hat{\theta})$ as s can be observed and enforced by the regulator, thereby determining the level of abatement.
- and regulated investment in technical progress $R(\hat{\theta})$ as water suppliers are forced to reveal their investment in abatement technology in order to be eligible for subsidies or increases in regulated prices. Ob-

(2) For a detailed discussion see Laffont / Tirole (1993).

(3) Baron, Myerson (1982).

viously it is relatively easy for the regulator to control investment of public enterprises in the case of large projects. Anyhow, leaving R&D investment under the control of the firm would not lead to a second-best solution as we will see later.

Altogether, the regulator faces the following optimization problem:

$$\max_{p,T,R,s} W = \int_{\theta^-}^{\theta^+} \left\{ \int_{p(\theta)}^{\infty} q(p^0)\, dp^0 - D(s(\theta)) - T(\theta) + \alpha \Pi(\theta) \right\} f(\theta)\, d\theta \quad (2.4)$$

subject to[4] for all $\hat{\theta}, \theta \in [\theta^-, \theta^+]$

$$\Pi(\theta \mid \theta) \geq \Pi(\hat{\theta} \mid \theta) \quad (2.5)$$

$$\Pi(\theta \mid \theta) \geq 0 \quad (2.6)$$

where

$$\Pi(\hat{\theta} \mid \theta) = q(p(\hat{\theta}))\, [p(\hat{\theta}) - c\,(R(\hat{\theta}), s(\hat{\theta}), \theta)] + T(\hat{\theta}) - R(\hat{\theta}) - K \quad (2.7)$$

In designing incentive compatible regulatory mechanisms the regulator has to assure that the utilities realize non-negative profits for all types of θ (individual rationality constraint (2.5)) while providing the firms with incentives to report their true type θ (incentive compatibility constraint (2.6)). Equation (2.7) defines the firm's profit function.

OPTIMAL REGULATION OF R&D AND QUALITY

Before we derive the optimal price, quality and investment in R&D under the scenario described above, we consider the full information optimum as a benchmark solution. Assuming that the regulator has perfect information about the type of firm ($\hat{\theta} = \theta$) and assuming that he runs a publicly owned firm to produce the service ($\alpha = 1$), the first order conditions for an optimal regulatory schedule of price, investment and quality include as can be easily proved:

Lemma 1: Full Information Optimum:

$$p^*(\theta) = c\,(R^*(\theta), s^*(\theta), \theta) \quad (3.1)$$

$$-c_R\,(R^*(\theta), s^*(\theta), \theta)\, q(p^*(\theta)) = 1 \quad (3.2)$$

$$-D_s\,(s^*(\theta)) = -c_s\,(R^*(\theta), s^*(\theta), \theta)\, q(p^*(\theta)) \quad (3.3)$$

[4] The second order condition for the (local) maximization of profit can be shown to be fulfilled assuming the hazard rate to be monotonous.

Equations (3.1) and (3.2) state the familiar solutions of price equaling marginal costs and marginal value product of investment in R&D equaling the factor price.

Further condition (3.3) implies that once the regulatory policy is implemented the incentive for the firm is provided to set the social utility of quality (in terms of reduced damages) equal to the marginal costs of quality arising from an increase in abatement. In addition for the profits of the regulated firm not to be negative transfers have to cover at least fixed costs and costs of R&D:

$$\Pi^*(\theta) = T^*(\theta) - R^*(\theta) + K \geq 0 \tag{3.4}$$

If the regulator implemented such a first-best policy – given his naive believe in the report of the firm – the optimal response of the firm under asymmetric information would be to overstate true cost inducing a price above marginal costs and a transfer in excess of fixed costs and R&D investment.

Since the first-best solution is not feasible any more as the firm does not have the incentive to state its true value of θ, we have to use a revelation approach in order to induce the utility to report truthfully. Using optimal control theory the optimal schedule for investment in R&D, quality and price can be derived (see Appendix). The results are stated in:

Proposition 1: Asymmetric Information Optimum

$$p(\theta) = c(.) + (1 - \alpha) \frac{F(\theta)}{f(\theta)} c_{\theta}(.) \tag{3.5}$$

$$-q(p(\theta))\, c_R\,(.) = 1 + q(p(\theta))\,(1 - \alpha) \frac{F(\theta)}{f(\theta)} c_{\theta,R}(.) \tag{3.6}$$

$$D_s(s) = q(p(\theta)) \left(- c_s(.) - (1 - \alpha) \frac{F(\theta)}{f(\theta)} c_{\theta,s}(.) \right) \tag{3.7}$$

With respect to the interpretation of the results stated in proposition 1 we should consider the impact of social costs of public funds first.

As long as social costs of public funds don't have to be taken into account (α = 1) price, R&D and quality schedules are equivalent to those in the full information case. As before the transfer schedule

$$T(\theta) = \int_{\theta}^{\theta^+} c_{\theta^0}(.)\, q(p(\theta))\, d\theta^0 - (p(\theta) - c(.))\, q(p(\theta)) + R(\theta) + K \tag{3.8}$$

has to compensate for the firm's loss since revenues do not cover fixed costs and the costs of R&D. Furthermore an information rent given by the first term on the right hand side of (3.8) is transferred to the firm in order to induce the revelation of true type θ. As a result, firms are allowed to earn positive profits stemming from their private cost information with the most efficient firm getting the highest rent:

$$\Pi(\theta) = \int_{\theta}^{\theta^{+}} c_{\theta^0}(.)\, q(p(\theta))\, d\theta^0 \tag{3.9}$$

Since transfers do not induce social costs there is no need to distort the price, quality and R&D schedule to extract information rents from the firm so that any deadweight loss is avoided.

However, the picture changes considerably when we include positive social costs of public funds into the analysis. As transfers are socially costly then, the regulator finds it optimal to reduce information rents.

Hence, prices are distorted above marginal costs for all utilities except for the most efficient one and are furthermore rising in the social costs of public funds. Expected marginal information rents in (3.5) are given by:

$$\frac{F(\theta)}{f(\theta)}\, c_{\theta}\,(R(\theta),\, s(\theta),\, \theta).^{(5)} \tag{3.10}$$

Due to the increase in prices the quantity demanded is reduced which leads to a deadweight loss in consumer surplus. This loss is compensated for by the decrease in social costs of public funds, since transfers to the firms are lower due to the decrease in information rents. Additionally transfers are reduced by monopoly rents which firms are allowed to realize on the market. At the margin both effects – the deadweight loss induced and the reduction of social costs of public funds – balance. As the inefficiency with respect to R&D and quality is assumed to increase the more inefficient the firm is, the information rent is an increasing function of R and s.

Social costs of public funds also result in the distortion of investment in R&D – again except for the most efficient firm. The shadow price of R is found to be higher than the factor price assuming that the marginal cost reduction induced by an increased level of R&D is lower in inefficient types of firms:

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(5) Since we have assumed

$$F(\theta) \,/\, f(\theta)$$

to be non-decreasing, $p(\theta)$ will be monotonous, as required by the second order condition on the maximization of profits.

$$c_{\theta,\,R}(.) > 0.$$

This assumption is made as we take efficient types of firms to have a higher absorptive capacity as well as a higher accumulated stock of knowledge which leads to a more efficient and successful new investment in R&D. A higher shadow price induces an underinvestment in R&D compared to the cost-efficient solution. A decrease in information rents is enforced which is accompanied by a reduction of R&D subsidies. Expected marginal information rents stemming from the cost reducing effect of R&D are given by:

$$\frac{F(\theta)}{f(\theta)}\, c_{\theta,\,R}(.)\; q(p(\theta)). \qquad (3.11)$$

The inefficient use of R&D forces the marginal costs to rise leading to a rise in the price and consequently increasing the deadweight loss. At the margin the welfare gain by a decrease of social costs of public funds has to balance the loss in consumer surplus resulting from higher prices and lower quantities[(6)].

The quality level is found to be lower than in the full information case assuming that the increase in marginal costs due to an increase in quality is higher in inefficient types of firms ($c_{\theta,\,s}(.) > 0$). The costs of an increase in quality are overestimated for all firms except the most efficient one as the shadow price in terms of generated costs of an increase in s is too high. Consequently the marginal damages to the consumers are higher than in the benchmark solution resulting from a suboptimal quality level. Again the rational behind the decrease in quality is to reduce information rents and thus to lower social costs of public funds. Expected marginal information rents resulting from the cost-increasing effect of providing quality are given by:

$$\frac{F(\theta)}{f(\theta)}\, c_{\theta,\,s}(.)\; q(p(\theta)) \qquad (3.12)$$

The regulator finds it optimal to decrease quality until the marginal increase in damages to consumers due to the quality reduction equals the marginal reduction of transfers and thus the marginal reduction of social costs of public funds.

[(6)] For $c_{\theta,\,R}(.) < 0$ – cost reductions of R&D being higher in inefficient types of firms – it can be argued that it is easier for less efficient firms to reduce costs by investing a relatively low amounts of money in R&D. In this case the level of R&D turns out to be higher than in the cost-efficient case: for higher cost reductions in inefficient firms an increase in R reduces information rents. As long as this reduction overcompensates the rise in R&D costs, investment in technical progress increases.

Summarizing, in the second-best optimum p will be higher than in the first-best solution, while R and s will be lower for the assumptions made above.

CONCLUSIONS

In the analysis presented our main focus has been on the regulation of water supply utilities. Since consumers are usually not able to infer the quality of water by taste or smell only, our model considers a quality-independent demand for water. We further assume the utilities to have private knowledge of their cost function, thereby providing them with a source for rent seeking activities. In this framework of asymmetric cost information we tried to characterize incentive compatible mechanisms while taking the relationship among price, quality and abatement technology into account.

When incorporating asymmetric information about abatement costs and process innovations, the search for an endogenous incentive compatible mechanism has to lead to a second-best solution. In contrast to the full information solution the regulator finds it optimal to allow firms to make profits. These profits solely consist of information rents that have to be transferred to the firm and thus induce social costs of public funds.

Due to the information rent prices are higher and quantities supplied lower allowing for higher producer surplus than in the full information case. With respect to the level of R&D the regulator finds it optimal to decrease investment in technical progress below the cost-efficient level at a given quantity in order to extract information rents that otherwise would have to be transferred, generating social costs of public funds. For the same reason the regulator decreases quality below the efficient level, thus increasing the damages to consumers but lowering social costs of public funds.

In our paper we took the average pollution level to be exogenous. Endogenous pollution could be integrated by including the level of the polluter in our analysis. This would again allow for a green tax or marketable permits to be introduced and might be an interesting extension for future work.

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APPENDIX

In order to solve the regulator's maximization problem methods of control theory can be applied. The corresponding Hamiltonian is given by:

$$H = \left\{ \int_{p(\theta)}^{\infty} \tilde{q}(p^0)\, dp^0 - D(s(\theta)) - T(\theta) + \alpha\Pi(\theta) \right\} f(\theta)$$

$$+ \lambda(\theta)\, q\left(p(\theta)\left[p(\theta) - c(R(\theta), s(\theta), \theta)\right] + T(\theta) - R(\theta) - K - \Pi(\theta)\right) \quad \text{(A1)}$$

$$+ \mu(\theta)\left(- c_\theta (R(\theta), s(\theta), \theta)\, q(p(\theta))\right)$$

$$+ \tau(\theta)\, \Pi(\theta)$$

with p, T, R and s being the control variables and Π as the corresponding state variable. Optimization thus yields the following first order necessary conditions:

$$\frac{\partial H}{\partial p(\theta)} = - q(p(\theta))\, f(\theta) + \lambda(\theta)$$

$$\left(q(p(\theta)) + \left(p(\theta) - c(R(\theta), s(\theta), \theta)\right) q_{p(\theta)} (p(\theta))\right) \quad \text{(A2)}$$

$$- \mu(\theta) c_\theta (R(\theta), s(\theta), \theta)\, q_{p(\theta)} (p(\theta)) = 0$$

$$\frac{\partial H}{\partial T(\theta)} = - f(\theta) + \lambda(\theta) = 0 \quad \text{(A3)}$$

$$\frac{\partial H}{\partial R(\theta)} = \lambda(\theta)\left(- c_R(R(\theta), s(\theta), \theta)\, q(p(\theta)) - 1\right) \quad \text{(A4)}$$

$$- \mu(\theta)\, c_{\theta, R} (R(\theta), s(\theta), \theta)\, q(p(\theta)) = 0$$

$$\frac{\partial H}{\partial s(\theta)} = - D_s (s(\theta))\, f(\theta) - \mu(\theta)\, c_{\theta,s} (R(\theta), s(\theta), \theta)\, q(p(\theta)) \quad \text{(A5)}$$

$$- \lambda(\theta) c_s (R(\theta), s(\theta), \theta)\, q(p(\theta)) = 0$$

$$\frac{\partial H}{\partial \Pi(\theta)} = - \mu_\theta = \alpha f(\theta) - \lambda(\theta) + \tau(\theta) \quad \text{(A6)}$$

$$\Pi(\theta) = q(p(\theta))\left[p(\theta) - c(R(\theta), s(\theta), \theta)\right] + T(\theta) - R(\theta) - K \quad \text{(A7)}$$

Equation (A3) obviously leads to:

$$f(\theta) = \lambda(\theta),$$

while from (A5) and the transversality condition

$$\mu(\theta) = (1 - \alpha)\, F(\theta)$$

can be derived. Using (A2), (A4) and (A5) as well as substituting for $\lambda(\theta)$ and $\mu(\theta)$ we obtain the optimal price, quality and R&D schedules (3.5) – (3.7). With respect to the second order conditions concavity of H in p, T, R and s is assured given the assumptions on $C(.)$ and $D(.)$.