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An Empirical Analysis of Water Supply Contracts[*]

Serge Garcia[†], *Alban Thomas*[‡]

Résumé / *Abstract*

Nous analysons les relations contractuelles entre une collectivité locale et un opérateur privé en charge du service d'eau potable. Une caractéristique importante de notre modèle de régulation repose sur l'existence de pertes d'eau en réseau qui peut réduire les coûts de l'exploitant. Nous dérivons les solutions du contrat optimal d'abord en information complète puis avec information privée cachée. Les solutions en information asymétrique sont simulées après calibration grâce aux paramètres estimés de la technologie et de la demande des usagers à partir de données de panel sur des services d'eau français. Nous montrons que le principal peut autoriser aux opérateurs privés des taux de perte plus élevés comme un outil pour réduire les rentes informationnelles.

We analyze the contract-based relationship between a local community and a private operator in charge of a water utility. An important feature of the regulation model is the existence of water network losses that may reduce the operator's cost. We derive solutions to the optimal contract both under complete information and with hidden private information. Asymmetric information solutions are simulated after calibration by estimated technology and demand parameters from a panel of French water utilities. We show that private operators can be allowed higher water loss rates as a way to reduce information rents.

Mots-clés : Services publics d'eau potable délégués, information privée, pertes d'eau, arbitrage entre extraction de rente et efficacité, simulation

Keywords: *Delegated water utilities, private information, water losses, rent extraction-efficiency trade-off, simulation*

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1 Introduction

In France, contrary to other industries such as electricity and telecommunications, public decision-makers have not yet included recent recommendations from contract theory in setting up regulation systems and authorities for water utilities. At the same time, representatives of local communities seem to be more and more concerned by the regulation of these utilities. Indeed, even if water utility operation is often delegated to private firms, local communities still remain by law responsible for the provision of residential water with adequate quantity to households, and with sufficient quality for human consumption.

When a local community decides to delegate the provision of water supply services to a private operator, it is within the framework of a long-run contract specifying, among other things, expected supply level and water rates charged to customers. In a majority of cases, capital expenditures are initiated by the local community, while the leaseholder has the obligation to operate the water utility following the BATNEEC ("best available technique not entailing excessive cost") rule, and to conduct maintenance works whenever appropriate.

An important feature of the water industry is the occurrence of network leaks. This loss is clearly a concern for water utility managers in terms of opportunity costs, as actual losses are 25% on average and can reach 50% of total distributed water volume in France. From a public viewpoint, water losses are undesirable in a context of resource conservation, especially in areas where shortage of water can be severe. In terms of environmental policy however, no particular guideline is directed toward local community managers as to how they should account for this issue in drafting contracts with private operators. This means that the main objective of these managers seems to be the definition of contract terms in such a way that local consumers are not faced with excessive water prices, and that water supply is adequate (no shortage, quality consistent with environmental standards). The fact that the network rate of return (defined as the ratio between water distributed to customers and extracted raw water) is not an ingredient of these contracts means that local communities set the priority on consumer welfare as far as water consumption is concerned.

For this reason, water network loss can be considered a non-desirable output that may be tuned by the private company when operating the water utility. We can reasonably assume that, in the absence of legal dispositions referring to it, water losses do not enter either the local community program, or the consumer welfare function. Moreover, the utility manager may find profitable not to minimize water network losses when producing and delivering water to final consumers (see Garcia and Thomas 2001). This could be the case if associated costs are significant compared to the opportunity cost of lost water, and because substitution patterns between inputs allow the operator to compensate for the decrease in water delivered to users by increasing water production. However we may think that cost arguments are not the only ones to justify observed levels of water losses. There may exist a less immediate reason in the way contracts between the local community and the operator are designed.

Since the beginning of the 1980's, the literature on incentives and regulation has studied intensively the contract-based relationship between a public regulator (the principal) and a private monopoly (the agent) under asymmetric information (see Laffont and Tirole 1993 for an exhaustive survey of these models). However, empirical applications of these models are still very few. In most econometric works dealing with water industry (Mann and Mikesell 1976; Crain and Zardkoohi 1978; Hayes 1987; Kim 1987; Renzetti 1992b; Bhattacharyya et al. 1995), the implications of asymmetric information are ignored, with the exception of the pioneer article of Wolak (1994).

One original feature of this paper is to propose an analysis of the relationship between a local community and a private operator of a water utility, in a multi-product framework. Two outputs are jointly produced: water for final consumers, and water lost in the distribution network. The main purpose of the paper is to show that, under certain circumstances, the presence of asymmetric information on the operator efficiency in the water production and delivery activities may lead to second-best contract solutions that entail higher water loss rates than in the perfect information case. Intuitively, this may occur when the information rent given to the operator for her truth-telling may be decreased by allowing the operator to increase her optimal level of water losses.

To address this point, it is essential to have a clear picture of the water production technology, particularly regarding the relationship between marginal production cost, water supply and water loss. Given this initial inference on technology, optimal contracts can then be inspected, both under complete and asymmetric information.

The first objective of this article is to analyze the impact of asymmetric information on production decisions of regulated water public utilities. Before delegating operation, the local community faces two problems: i) when it has to choose the private operator, it does not know the efficiency of firms engaged in competitive bidding, ii) the effort that the operator will exert to improve network quality by reducing water losses is not known, in particular because cost-reducing effort is obviously expensive. Regulation is based upon contracts in which produced, delivered water and network losses are observable. From a model *à la Baron-Myerson*, we first derive optimal solutions in the case of complete information. The second case in which the operator technology is private information is then examined.

The second objective is to study how data on French water supply utilities can validate the predictions of the standard contract theory under asymmetric information. The empirical analysis consists in, first estimating technology an demand parameters and second, using these estimates to simulate optimal contracts. The simulation exercise allows us to study water supply and water loss paths with respect to the operator efficiency for an average utility in our sample. This application also highlights the rent extraction-efficiency trade-off, a usual feature of these models.

The remainder of the paper proceeds as follows. Section 2 presents the structural model derived from water supply network technology and user demand. The regulation model and the contract design in the case of asymmetric information are presented in section 3. Section 4 deals with an empirical application to the French water industry, with a description of the data, cost and demand specification, and estimation issues. Section 5 presents the simulation experiment based upon consistent parameter estimates, and discusses the results. Section 6 is the conclusion.

2 The structural model

Water supply results from two successive production stages: raw water extraction and delivery to final users (customers). Raw water may be treated if unsuitable for human consumption, before it is pressurized for circulation in the delivery network. We consider first production of a single, representative water utility. Let V_e and V_c respectively denote extracted and delivered water. During the process, a part of distributed water is lost because of network leaks; we have $V_e = V_c + V_l$, with V_l the water loss in the distribution network.

Assuming that the water utility minimizes its operating expenses given the existing capital stock, under the usual conditions of regularity (see Lau 1976), there exists a cost function[1]

$$C = C(V_c, V_l, \theta), \tag{1}$$

where θ is an efficiency parameter, $\theta \in [\underline{\theta}, \bar{\theta}]$, such that higher values of θ correspond to less efficient operators.[1] We assume that $C_\theta \geq 0$, $C_{V_c} \geq 0$ and $C_{V_c\theta} \geq 0$, but we do not make assumptions on C_{V_l}. A high level of water loss is likely to reduce network maintenance costs, but may also require to extract more raw water for satisfying final demand.

The inverse demand function for water from consumers in the local community is denoted $P(V_c) = S'(V_c)$, where $S(.)$ is consumer gross surplus, with $S' > 0$, $S'' < 0$ and $S(0) = 0$, and P is water unit price. If we denote by T the fixed fee (multiplied by the number of users) of the two-part tariff of water that the user pays for the water supply service, consumer net surplus is:

$$W \equiv S(V_c) - P(V_c)V_c - T.$$

As consumers pay T directly through their water bill and not by way of local taxes, variations in the level of T do not create distortions, so that there is no social cost of public funds (Laffont and Tirole 1993).

As noted earlier, in the case of delegation contracts for water supply service, most investments are supported by the local community. Hence, T corresponds to a monetary transfer from the local community to the operator, whose purpose is to cover fixed costs engaged by the operator. Water utility profits are:

$$U \equiv T + P(V_c)V_c - C(V_c, V_l, \theta). \tag{2}$$

We assume that the local community preferences are represented by a weighted sum of the net surplus of users W and the operator profit U:

$$\pi W + (1 - \pi)U, \tag{3}$$

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[1] The expression for the cost function is simplified here, as only contractible variables appear. In the empirical part, other variables such as production factors, technical and capital variables will be introduced.

[1] We could also interpret θ as a network quality index without changing the results. This would imply that all operators are identical but that they support different costs due to local variations of θ and other variables representing the particular service configuration.

with $\pi \in]\frac{1}{2}, 1]$. This is a way to compute the social surplus if a part of profits is redistributed locally.[2] From the definition of profit in (2), we have $W = S(V_c) - U - C$ and equation (3) reduces to $\pi[S(V_c) - U - C] + (1 - \pi)U$. Dividing by π, we get an equivalent criterion which will be used in the following:

$$S(V_c) - C(V_c, V_l, \theta) - \mu U, \qquad \text{with } \mu \equiv \frac{2\pi - 1}{\pi} \in]0, 1]. \tag{4}$$

Finally, a key assumption in the characterization of the optimal delegation contract is that the operator reservation profit, denoted u, is independent from θ[3].

3 The optimal contract

The principal wishes to maximize (4) under the participation constraint $U \geq u$, by means of a contract specifying water levels (V_c,V_l) and the lumpsum transfer, T.[4] If the local community knew parameter θ, information rent would be zero and the transfer can be selected such that $U = u$. The optimal solution (V_c, V_l, T) is therefore given by the system:

$$P(V_c) = C_{V_c}(V_c, V_l, \theta), \tag{5}$$

$$C_{V_l}(V_c, V_l, \theta) = 0, \tag{6}$$

$$T = u - P(V_c)V_c + C(V_c, V_l, \theta). \tag{7}$$

In the case of asymmetric information however, where the operator has private information about her costs, an indirect revelation mechanism should be implemented, to ensure truth-telling about the parameter θ. It is in practice difficult for the local community to infer θ from accounting and technical reports, as they may include aggregate expenses not related to current operation, or even this community. An operator may indeed choose to allocate several of its expenses between different water services whose it has the delegation.

The local community is assumed to have a prior information about θ, consisting of a density function f on the domain $[\underline{\theta}, \bar{\theta}]$ and the associated probability distribution $F(\theta)$.

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[2] See Baron 1989 for the characterization of welfare measures and Grossman and Helpman 1994 on elected representatives objective functions.

[3] In the case where θ represents network quality, this defines the minimum profit that the operators (supposed all identical except for local network characteristics) may gain by operating another service.

[4] Remember that the volume of extracted water can then be determined from these two quantities.

The revelation mechanism[5] takes the form of a menu of contracts indexed by θ, $[V_c(\theta), V_l(\theta), T(\theta)]$. The two constraints in the regulator problem are: (i) the Incentive Compatibility (IC) condition (the private operator ideally selects the menu item best suited to her efficiency type) and (ii) the Individual Rationality (IR) condition ($U \geq u$).

IC condition is:

$$v(\theta, \theta) \geq v(\theta, \theta'), \qquad \forall\, \theta, \theta' \in [\underline{\theta}, \bar{\theta}],$$

where

$$v(\theta, \theta') = T(\theta') + P[V_c(\theta')]V_c(\theta') - C[V_c(\theta'), V_l(\theta'), \theta],$$

and θ and θ' respectively denote the true value and the report of the efficiency parameter of the operator. Letting $U(\theta) = v(\theta, \theta)$, we have by the envelop theorem the following local condition:

$$U'(\theta) = -C_\theta[V_c(\theta), V_l(\theta), \theta] \leq 0. \tag{8}$$

The second-order condition is

$$C_{\theta V_c}[V_c(\theta), V_l(\theta), \theta]\frac{dV_c}{d\theta} + C_{\theta V_l}[V_c(\theta), V_l(\theta), \theta]\frac{dV_l}{d\theta} \leq 0. \tag{9}$$

As U is decreasing in θ, condition (IC) reduces to

$$U(\bar{\theta}) = u. \tag{10}$$

Ignoring this second-order condition for the moment, the regulator program is:

$$\max_{V_c(.), V_l(.)} \int_{\underline{\theta}}^{\bar{\theta}} \Big[S[V_c(\theta)] - C[V_c(\theta), V_l(\theta), \theta] - \mu U(\theta)\Big] f(\theta) d\theta \tag{11}$$

under constraints (8) and (10). The combination of these constraints gives the expression of the information rent received by the operator:

$$U(\theta) - u = \int_{\theta}^{\bar{\theta}} C_\theta[V_c(\tau), V_l(\tau), \tau] d\tau, \tag{12}$$

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[5] We use the standard technique for problems with adverse selection used by Baron and Myerson 1982 and extended by Guesnerie and Laffont 1984.

and by introducing expression (12) in the criterion (11), the regulator program becomes:

$$\max_{V_c(\theta),V_l(\theta)} \int_{\underline{\theta}}^{\bar{\theta}} \left[S[V_c(\theta)] - C[V_c(\theta), V_l(\theta), \theta] - \mu \frac{F(\theta)}{f(\theta)} C_\theta [V_c(\theta), V_l(\theta), \theta] \right] f(\theta) d\theta. \tag{13}$$

Optimal levels of V_c and V_l are finally available as solutions to the system

$$P(V_c) = C_{V_c}[V_c(\theta), V_l(\theta), \theta] + \mu \frac{F(\theta)}{f(\theta)} C_{\theta V_c}[V_c(\theta), V_l(\theta), \theta], \tag{14}$$

$$0 = C_{V_l}[V_c(\theta), V_l(\theta), \theta] + \mu \frac{F(\theta)}{f(\theta)} C_{\theta V_l}[V_c(\theta), V_l(\theta), \theta]. \tag{15}$$

An important result concerning the model solutions is the following. As the expected value of $U(\theta)$ is equal to the expected value of $u + C_\theta F(\theta)/f(\theta)$, reducing the information rent is therefore equivalent to decreasing C_θ. The cross derivatives $C_{\theta V_c}$ and $C_{\theta V_l}$ are the two major components in the magnitude of the distortion with respect to the complete-information case. In particular, if $C_{\theta V_l} < 0$, that is, if it is more costly for more inefficient operators to reduce losses, then an increase in V_l reduces this rent. In other words, it would be in the interest of the local community to let the operator increase water losses above the (first-best) optimal level, so that a more efficient operator does not benefit in mimicking an inefficient one. Hence, asymmetric information would bring an additional justification to the existence of significant water losses in water supply networks.

4 Application to water supply utilities in the Bordeaux region

4.1 Data description

Our database consists of 188 observations for 47 municipal or district water utilities in the Bordeaux region, south-west of France, for the years 1995, 1996, 1997 and 1998. All utilities are delegated to private companies by way of leasing contracts.[6] The main source of data comes from annual accounting and technical reports to the Gironde Local Administration for Agriculture and Forestry (Gironde DDAF), containing information on total operating and maintenance costs, water volumes produced, electricity and labor inputs, as well as technical data on networks. The other source of data is a mail survey directed toward local communities and the ESG private

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[6] Lyonnaise des eaux (SLE), Générale des eaux (Vivendi-CGE), CISE, SAUR, Electricité Service Gironde (ESG) and SOGEDO.

company marketing services. From this additional source, data on input costs and network features were complemented.

Produced, consumed and lost water quantities V_e, V_c and V_l are expressed in cubic meter per year, and the network return rate (r) is computed as $r = V_c/V_e = 1 - V_l/V_e$. Water utility operating cost is defined as the sum of labor (L), electricity (E), materials and other expenses (M). Labor input price (w_L) is obtained by dividing wage expenses by total hours worked. Unit price of electricity (w_E) is defined as the ratio of total electric power expenditures divided by the total quantity of electricity used in production and distribution stages. For materials, we construct a price index for input materials (w_M) as the unit cost per cubic meter delivered.[7] Miscellaneous, technical variables are the number of customers ($Cust$), the number of communities supplied (Com), network length ($Leng$), production capacity ($Prod$), stocking capacity ($Stoc$), and pumping capacity ($Pump$). We denote by P the unit (marginal) price for water charged by the private operator and AP the total average price (including fixed charges in particular) paid by the customer. Fee is the fixed fee in the two-part tariff. Finally, we have data on customers at the community level: average water consumption per user, average taxable income (in French Francs per year) and the average number of household members ($Pers$). Descriptive statistics for variables used are available from the authors upon request.

4.2 Cost function estimation

The most important step in our empirical application concerns the estimation of the water utility cost function, from which inference can be made on production technology. Two critical aspects are the specification of the cost function, and the way we introduce the efficiency parameter θ into this function.

We assume that efficiency is defined by the operator's ability to provide a sufficient water volume to users with minimum network losses. θ is a multiplicative coefficient affecting directly the consumption-loss ratio $V_c/V_l = V_e/V_l - 1$. The translog cost function (Christensen et al. 1973) is chosen as a convenient flexible functional form for computing substitution and returns

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[7] Price of materials is simply defined as total expenses of different miscellaneous inputs such as subcontracting, stocking and maintenance work, divided by total distributed water volume.

to scale measures. The variable cost function to be estimated is[8]:

$$C(V_{c,it}, V_{l,it}, X_{it}, \theta_i) = H(V_{c,it}, V_{l,it}, X_{it}) \exp\left(\theta_i \frac{V_{c,it}}{V_{l,it}}\right) \exp\left(\varepsilon_{it}\right),$$

where i and t are the utility and the time period index respectively, X_{it} is the vector of input prices, technical and capital variables, $H(V_{c,it}, V_{l,it}, X_{it})$ is the exponential of the translog functional form, and ε_{it} is an independently and identically distributed error term. We present in the appendix the expression for the second-order conditions that must be satisfied for an optimal contract, depending on our cost function specification. Dividing left and right-hand sides by $V_{c,it}/V_{l,it}$ and taking logs, we end up with a translog cost function for panel data (pooled cross-sections and time-series), complemented by an additive individual effect, θ_i.

The system of equations consisting of the above cost function and cost share equations is estimated under the usual cost homogeneity restriction.[9] As the translog cost function is a second-order Taylor expansion around the mean of observations (in logs), all right-hand side variables are to be normalized by their sample (geometric) means (mean-scaling transformation). To deal with a possible endogeneity bias in the cost equation, we use the Fixed-Effects method for panel data (Within transformation, see Baltagi 1995). The advantage of this method is that we deal with the possible endogeneity bias by removing individual effects θ_i. The parameter variance-covariance matrix is estimated consistently by an Iterated SURE technique, jointly with the Within procedure.

Because the translog specification entails cross-products of output, input prices and technical variables, we do not report all parameter estimates, to save space,[10] but present only estimates for the marginal effects of water volumes and input price variables:

$$\begin{array}{lccccccccc} \log C = & 8.8580 & + & 0.7995 & V_c & -0.2909 & V_l + & 0.0971 & w_E + & 0.2927 \quad w_M, \\ & (0.1332) & & (0.1469) & & (0.1312) & & (0.0100) & & (0.0183) \end{array}$$

(standard errors in parentheses). As all variables are divided by their sample means, reported parameters are interpreted as marginal effects on variable cost, at the sample mean for all

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[8] It would seem more immediate to introduce θ as: $V(V_c, V_l, X, \theta) = H(V_c, V_l, X) exp(\theta)$. This specification does not allow to explain the observed distortion on lost water however, since it is impossible to distinguish the incomplete-information case from the complete-information one.

[9] Imposed by dividing variable cost and input prices w_E and w_M by labor unit price w_L.

[10] Full estimation results are available from the authors upon request.

variables. $\bar{R}^2$ are 0.99 for log C, 0.83 and 0.95 respectively for energy and material cost shares.

It can be seen that water losses decrease production cost, all other things being equal. From these parameter estimates, predicted fixed effects θ_i are computed as the difference between actual and predicted individual means (across time periods) of $\log C_i$ (divided by $V_{c,it}/V_{l,it}$). These estimates are distributed between -0.275 and 0.110 on the sample, with a mean of -0.127 and a standard deviation of 0.076. Graphical inspection of fitted θ's reveals that a normal distribution is a reasonable approximation for the true distribution of θ. The Bera-Jarque test statistic for normality (Jarque and Bera 1980) is equal to $\chi^2(2)$ =2.7281, thus the normality hypothesis is not rejected at the 5 percent level.

Marginal costs of water supply are also estimated from the fitted translog cost function. The average marginal cost for V_c and V_l is 1.92 and 1.97 FF (French Francs) per cubic meter respectively. Interestingly, with these estimates obtained outside the structural regulation model, the predicted value of marginal cost with respect to V_l in the first-order condition (6) for the complete-information case is far from 0, indicating that this model is not supported by our data.

4.3 Demand function estimation

Estimated cost function parameters are not sufficient to derive solutions for V_c and V_l from the optimal contract equations. To evaluate consumer surplus $S(V_c)$, we also have to estimate the inverse demand function, which depends on the average price for water.[11] In our model however, we only consider marginal price charged by the private operator, P. For this reason, we assume a linear form for the inverse demand function, which allows marginal price to be separated from the component of the average price corresponding to fixed fees and taxes. We estimate the inverse demand function with the Fixed-Effects procedure, by regressing marginal price on unit water consumption and demand shifters:

$$\begin{array}{lllllll} P_{it} = & -0.0410 & \left(\frac{V_c}{Abon}\right)_{it} + & 0.0289 & Rev_{it} + & 0.1791 & Pers_{it}, \\ & (0.0103) & & (0.0151) & & (0.0837) & \end{array}$$

(standard errors are in parentheses). The inverse regression of $V_c/Abon$ on average price yields a price elasticity of -0.33 at the sample mean, a figure higher than what is usually reported in the

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[11] Average price for water depends on marginal price, fixed fee and various taxes.

empirical literature on residential water demand[12] since consumers in our case include industrials, which are generally characterized by higher price elasticities than domestic consumers (Renzetti 1992a).

5 Simulation of optimal contracts

5.1 The simulation experiment

The purpose of the simulation experiment is twofold. First, we wish to construct the water supply function as the solution to the contract scheme with asymmetric information. This information is useful in determining the sensitivity of the control variables V_c and V_l to the efficiency index θ, and to provide an estimate of the expected range of variation of water volumes for heterogeneous operators.

Second, the role of the regulator (the local community) preferences in the determination of optimal solutions is easy to assess, by computing contract solutions for different values of parameter π. The weight put on consumers as opposed to private operators is an essential component of these adverse-selection models, as the information rent crucially depends on this parameter.

Given cost and demand estimates described above, the only piece of information lacking to evaluate solutions for V_c and V_l is the weight π in the local community objective function. Because this parameter is not identifiable from either cost or demand equation, we define a grid of possible values for π, ranging from 0.5 to 1. As for π, we select values of θ in the range corresponding to the empirical distribution of θ (from the estimation stage of the cost function). For very small values of θ however, the ratio $F(\theta)/f(\theta)$ computed from a normal distribution with mean -0.127 and standard deviation 0.076, tends to zero, as does the asymmetric information term. First-order conditions are thus little different from those under complete information. And in this case, we have seen that the estimate of the marginal cost with respect to V_l is far from 0, this being an indication that the complete information assumption is not valid. Therefore, we restrict θ on the interval $[-0.139, -0.09]$, for which we observe the majority of water utilities in our sample, and draw 10 equidistant values of θ from the fitted normal distribution.

For the same reason, when π is less than 0.58, we are not able to distinguish contract

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[12] See Point 1993 for results on the Bordeaux region and Nauges and Thomas 2000.

solutions under asymmetric information from the complete-information case. We therefore base our simulation experiment on the domain $[0.6, 0.95]$ for parameter π, with 8 equidistant values and a step of 0.05.

Contract equations are neither linear in V_c and V_l because of the translog specification, nor linear in θ because of the expression $F(\theta)/f(\theta)$ under the normality assumption. Consequently, we make use of a numerical root-finding algorithm to solve for the optimal contract solutions in V_c and V_l.

Our cost model includes many variables such as input prices, capital and technical variables, whose heterogeneity is not crucial to consider in this simulation experiment. Consequently, we set all such auxiliary variables to their sample mean. Finally, we check that the numerical hessian matrix of the criterion maximized by the local community is semi-negative for all considered values of θ and π.

5.2 Results and comments

Simulation results are organized as follows. In table 1, we report numerical solutions for water output V_c, water loss V_l, lumpsum transfer T (all these values divided by the average number of households per local community, 1,897), network rate of return r and marginal water price $P(V_c)$, for the whole range of θ and a mid-interval value $\pi = 0.65$. With the latter value and the selected range for θ used in the simulation, second-order conditions that must be satisfied for the optimal contract under asymmetric information are verified (see the appendix).

[Table 1 here]

Efficiency in our model is defined as the ability to keep network water losses to a low level. An operator with a poor network rate of return has to extract more raw water to satisfy final users, for the same level of demand. In our case, higher values of θ (less efficient operators) are associated with larger consumed water volumes per household. Given that the inverse demand function is decreasing in V_c, these operators are proposed lower water unit prices, compensated by higher fixed parts of the tariff (T). But, as our model predicts, the solution to the optimal contract requires that the local community associates less efficient operators with lower network return rates. As noted above, the information rent is greater for more efficient agents (it is decreasing in θ), and an obvious way to diminish this rent is to allow for a higher level of water loss V_l, compared to the first-best solution.

Average water expenditure by household is about 747 FF. Average price is 6.26 FF per m^3 when θ=-0.139, compared to 4.18 FF when θ=-0.09. Comparing these simulated figures with actual prices in our sample, it can be seen that our contract scheme experiment is generally less favorable to consumers than what is actually observed in terms of water expenditures (the average expenditure per household being 430 FF for our sample), but average price is lower (observed average price of 5.36 FF per m^3). This is because consumer water demand is higher in our experiment, compared to actual figures (average observed consumption is 131 m^3 per household).

[Table 2 here]

Table 2 presents simulated values for V_c et V_l (divided by the average number of households), for different values of π and for an operator with an efficiency parameter $\theta = -0.127$). The same trend as in the previous table appears, when the local community weight put on consumers increases. When parameter π moves away from 0.5, this corresponds also to greater deviations from the perfect-information solution. Therefore, the impact of asymmetric information is clearly toward higher volumes of lost water, and lower marginal price for water. Between the two polar cases, when $\pi = 0.60$ and $\pi = 0.95$, water delivered to final users increases by 27.49 percent, water lost by 85.25 percent, and marginal price is cut by almost a factor of 4. The last column of table 2 presents the average price-marginal cost ratio (marginal cost with respect to consumed volume), which is decreasing in π. When consumers are more favored by the regulator compared to the operator, even if the lumpsum transfer increases and water losses are allowed for, operation of water service yields a lower marginal benefit to the operator. Average water expenditures are 623.59 FF per household when $\pi = 0.60$ (with an average price of 4.72 FF per m^3), and 704.88 FF when $\pi = 0.95$ (average price of 4.19 FF per m^3). Consequently, by promoting higher water demand levels, the incentive-based contract scheme under asymmetric information yields lower average prices for water as local community preferences for consumers are higher.

6 Conclusion

This paper has proposed a simulation experiment based on estimated production technology and water demand, to assess the impact of asymmetric information between a local community and a private operator, on the optimal contract outcome. From the assumption that productive inefficiency arises from the difficulty for the operator to improve network quality, the optimal contract specifies a consumed water volume V_c, a given network loss volume V_l, and a lumpsum transfer T. Optimal solutions under both complete and asymmetric information are computed, and the rent extraction-efficiency trade-off, a central result in the theory of incentives, is highlighted by our model. In our case, the local community finds it preferable to let the operator 'produce' water losses above the first-best (perfect information) level.

A major advantage of the paper is that, contrary to many simulation-based assessment studies, most technological and demand parameters are consistently estimated without any reference to optimal contract equations. Therefore, simulation results for an hypothetical incentive-driven contract scheme can be directly compared to actual output and price observations. In the simulation experiment, the sensitivity of our results is assessed with respect to a parameter measuring the weight put on consumers originating from the preferences of the local community. Simulation results show how water losses increase with the inefficiency of the operator. Hence, in order to give away a lower information rent to the private operator, the local community has to provide the operator with incentives to let water losses shift away from the optimal, first-best level. On the consumer side, this policy results in an increase in water consumption, implying a decrease in unit price, and at the same time, an increase in the fixed fee of the tariff. Consequently, the distortion originating from the need to reduce information rents causes consumer welfare to decrease, compared to the perfect-information case.

Appendix : Checking for the second-order condition of constraints IC

The second-order condition of IC is defined as:

$$C_{\theta V_c}[V_c(\theta), V_l(\theta), \theta]\frac{dV_c}{d\theta} + C_{\theta V_l}[V_c(\theta), V_l(\theta), \theta]\frac{dV_l}{d\theta} \leq 0.$$

From Laffont and Tirole 1993, p.206, a sufficient condition for a global maximum is

$$C_{\theta V_c}[V_c(\tau), V_l(\tau), \theta]\frac{dV_c}{d\tau} + C_{\theta V_l}[V_c(\tau), V_l(\tau), \theta]\frac{dV_l}{d\tau} \leq 0, \qquad \forall\theta, \forall\tau. \tag{16}$$

Assume the network return rate r is decreasing with θ: $\partial(V_c/(V_l + V_c))/\partial\theta < 0$ and so V_l/V_c is increasing with θ. Hence, $(dV_l/d\tau)V_c \geq (dV_c/d\tau)V_l$. Furthermore, as we know that $C_{\theta V_c} > 0$, then (16) yields

$$C_{\theta V_c}[V_c(\tau), V_l(\tau), \theta]V_c(\tau) + C_{\theta V_l}[V_c(\tau), V_l(\tau), \theta]V_l(\tau) \leq 0, \qquad \forall\theta, \tau.$$

Note that this last condition is stronger than (16).

With our specification for the cost function, the second-order condition becomes remarkably easy to handle. The cost function has the following form:

$$C(V_c, V_l, \theta) = H(V_c, V_l)exp(\theta\frac{V_c}{V_l}),$$

where $H(V_c, V_l) = exp[TL(V_c, V_l)]$, with TL the translog form of cost function. From this specification, we have

$$C_{\theta V_c} = C_{V_c}\frac{V_c}{V_l} + \frac{C}{V_l} = \frac{C}{V_l} + \frac{V_c}{V_l}\left(\frac{\theta}{V_l}C + exp(\theta\frac{V_c}{V_l})H_{V_c}\right),$$

$$C_{\theta V_l} = C_{V_l}\frac{V_c}{V_l} - \frac{\theta V_c}{V_l^2}C = -\frac{V_c}{V_l^2}C + \frac{V_c}{V_l}\left(-\frac{\theta V_c}{V_l^2}C + exp(\theta\frac{V_c}{V_l})H_{V_l}\right).$$

Multiplying these two equalities by V_c and V_l respectively, the condition to verify becomes finally:

$$TL_{V_c}[V_c(\tau), V_l(\tau)] \times V_c(\tau) + TL_{V_l}[V_c(\tau), V_l(\tau)] \times V_l(\tau) \leq 0, \qquad \forall\tau.$$

This condition does not depend on θ, and can be easily checked.

Table 1: Optimal contract simulation results - Fixed π (0.65)

θ	V_c	V_l	r	T	$P(V_c)$
-0.139	119.25	27.47	81.3	446.09	2.52
-0.133	133.50	39.62	77.1	488.07	1.94
-0.128	141.03	46.45	75.2	516.94	1.63
-0.122	147.32	52.38	73.8	544.65	1.37
-0.117	153.02	57.91	72.5	572.56	1.14
-0.112	158.39	63.26	71.5	601.27	0.92
-0.106	163.56	68.53	70.5	631.15	0.71
-0.101	168.61	73.81	69.6	662.50	0.50
-0.095	173.62	79.15	68.7	695.59	0.30
-0.090	178.62	84.59	67.9	730.73	0.09

Notes. V_c and V_l (distributed and lost water respectively) in m^3 per household. Network return rate r defined as $100\,V_c/(V_c+V_l)$ (in percent). Lumpsum transfer T in FF (French Francs) per household and marginal price P in FF per m^3.

Table 2: Optimal contract simulation results - Fixed θ (-0.127)

π	V_c	V_l	r	T	$P(V_c)$	$P - C_{V_c}$
0.60	132.06	38.81	77.3	359.47	2.00	0.31
0.65	142.38	47.69	74.9	419.88	1.58	0.00
0.70	149.39	53.97	73.5	467.37	1.29	-0.21
0.75	154.76	58.90	72.4	506.93	1.07	-0.36
0.80	159.08	62.96	71.7	540.76	0.89	-0.48
0.85	162.68	66.38	71.0	570.17	0.74	-0.58
0.90	165.73	69.33	70.5	596.04	0.62	-0.66
0.95	168.37	71.90	70.1	619.01	0.51	-0.73

Notes. V_c and V_l (distributed and lost water respectively) in m^3 per household. Network return rate r defined as $100\,V_c/(V_c+V_l)$ (in percent). Lumpsum transfer T in FF (French Francs) per household and marginal price in FF per m^3. C_{V_c} denotes marginal production cost with respect to distributed water.

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