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ASYMMETRIC INFORMATION AND REGULATION IN THE BRAZILIAN WATER DISTRIBUTION SECTOR

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Abstract

This dissertation aims to measure the impact of two different regulatory regimes (price-cap and cost-plus) in the Brazilian water distribution sector using municipal-level data of 20 state water utilities from 2007 to 2019. I estimated a cost function that incorporates adverse selection, moral hazard parameters, and a dummy that accounts for the regulatory regime faced by a given water utility. I used two specifications: Cobb-Douglas and translog with quality controls. The latter provided better estimates, and any price-cap regime is associated with a level of cost 11.83% lower than those utilities that operate under any cost-plus scheme. In addition, on average, the optimum level of effort under the price-cap regime is higher than under the cost-plus, and the distribution of types is statistically different between these regimes and over the years. Nevertheless, some water utilities that were regulated under the cost-plus regime and then regulated under a price-cap ended up reducing their optimum level of effort. Finally, quality outcomes, such as the incidence of fecal coliforms, turbidity samples out of the standard, maintenance, consumer complaints, and fluoridated water volume, are better under the price-cap regime. On the other hand, the tariff charged by firms under the price-cap regime is higher.

Key-words: Regulation, asymmetric information, water utilities, cost, quality, Brazil.

Resumo

O objetivo desta dissertação é medir o impacto de dois regimes regulatórios (*price-cap* e *cost-plus*) no setor de distribuição de água brasileiro, usando um painel de dados, por município, de mais de 20 concessionárias estaduais de água, entre os anos de 2007 a 2019. Estimei uma função de custo que incorpora seleção adversa, parâmetros de risco moral e uma *dummy* que representa o regime regulatório aplicado a uma concessionária de água. Duas especificações foram utilizadas: Cobb-Douglas e translog com controles de qualidade. Esta última forneceu melhores estimativas e, de fato, qualquer tipo de regime de *price-cap* está associado a um nível de custo 11.83% menor do que aquelas concessionárias que operam sob algum tipo de regime de *cost-plus*. Além disso, em média, o nível ótimo de esforço sob o regime *price-cap* é maior do que sob o regime *cost-plus*, e a distribuição dos tipos é estatisticamente diferente entre esses regimes e ao longo dos anos. No entanto, algumas concessionárias de água que eram reguladas pelo regime de *cost-plus*, e depois passaram a ser reguladas por algum regime *price-cap*, acabaram reduzindo seu nível ótimo de esforço. Finalmente, os resultados de qualidade, como a incidência de coliformes fecais e amostras de turbidez fora do padrão, manutenção, reclamações dos consumidores e o volume de água fluoretada, são melhores sob o regime de *price-cap*. Por outro lado, a tarifa cobrada pelas empresas sob o regime *price-cap* é mais alta.

Palavras-chave: regulação, assimetria de informação, distribuidoras de água, custo, qualidade, Brasil.

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ABAR	Associação Brasileira de Agências Reguladoras
Anatel	Agência Nacional de Telecomunicações
Aneel	Agência Nacional de Energia Elétrica
BNH	Banco Nacional de Habitação
CEDAE	Companhia Estadual de Águas e Esgotos
CESAN	Companhia Espírito Santense de Saneamento
COMPESA	Companhia Pernambucana de Saneamento
COPANOR	Copasa Serviços de Saneamento Integrado do Norte e Nordeste de Minas Gerais
COPASA	Companhia de Saneamento de Minas Gerais
CORSAN	Companhia Riograndense de Saneamento
COSANPA	Companhia de Saneamento do Pará
CPUC	California Public Utilities Commission
DESO	Companhia de Saneamento de Sergipe
EMBASA	Empresa Baiana de Águas e Saneamento
EMBRAPA	Empresa Brasileira de Pesquisa Agropecuária
IPCA	Índice de Preços ao Consumidor Amplo
PLANASA	Plano Nacional de Saneamento
SABESP	Companhia de Saneamento Básico do Estado de São Paulo
SANEAGO	Saneamento de Goiás
SANEATINS	Companhia de Saneamento do Tocantins
SANEPAR	Companhia de Saneamento do Paraná
SANESUL	Empresa de Saneamento Básico de Mato Grosso do Sul
SNIS	Sistema Nacional de Informações Sobre Saneamento
TSE	Tribunal Superior Eleitoral

SUMMARY

1. Introduction

Utility regulation has always been a classical problem for policymakers and has also been explored in the economic literature. The provision of electricity, gas, water, waste, sewage collection, etc., is vital to economic growth and development, but these services are not trivial. Funding is one of the main issues, as, for example, building water, electricity, and sewage networks are not cheap.

If the government wishes to provide one of these services, the policymaker will have to choose, among a pool of companies, the best one. Several criteria can be taken into account, such as productivity, tariff level, operational cost, etc. Nevertheless, this information is not completely available, and the manager of the company may not provide it to the policymaker so he can make the right decision. Moreover, even after choosing the best company, the policymaker needs to guarantee that the firm will provide the service, according to the needs of the population. For example, a water utility may be badly administrated, with the firm's manager investing in non-reliable sources of water but that is less costly to the firm.

In the economic literature, we say that these deadlocks are adverse selection and moral hazard problems. While the former happens, because the principal (policy-maker) does not have enough information to differentiate the agents (companies) in the pool of those who wish to provide the service and choose the best among them, the latter happens as the principal cannot observe the level of effort of the company's manager. Thus, it is not always possible to know if the company provides the best service to the population.

A way to mitigate these issues is to design a contract that 1) makes the best company provide the service and 2) makes the chosen firm provide the best service possible. Therefore, notice that this contract will reduce the asymmetry of information between the principal and the agent. When informational problems are not solved, service providers may be negatively impacted, and customers will be seriously affected, primarily because electricity, water, and gas, are vital to wellbeing.

When it comes to access to water, Brazil has indicators poor indicators. According to the Trata Brazil Institute, 83.7% of the Brazilian population has access to treated water, which means that 35 million people do not have this essential good. Analyzing this indicator by region, 57.5% of the population in the North has access to treated water, while this number jumps to 91.1% in the Southeast. Furthermore, in the Northeast, 73.9% have access to treated water, and 90.5% of the population in the South have access to this good. Therefore, notice that there is a substantial inequality of access to water in the country.

The quality of the service is also precarious, as 39.2% of the water supplied is lost in the transmission. According to the Trata Brazil Institute, in the North, for example, more than half of the water supplied is lost before it reaches the households. The primary source of water is rivers, and they receive most of the municipalities' untreated sewer. According to the Trata Brazil Institute, more than half of the tailor produced in Brazil reaches the rivers without any treatment. It has a relevant impact on the quality of water used by households.

A recent example is the "Crise da Geosmina" (Geosmin Crisis) faced in the past two summers by Rio de Janeiro. The primary water source in the city is the Guandu River; there are several municipalities along its length. Nevertheless, as said before, most of the sewer is thrown untreated in the rivers, and it is not different for Guandu. The concentration of pollutants in the water is so high that, during the summer, the level of cyanobacteria increases. Thus, the water that reaches the households has a terrible smell and taste. The Rio de Janeiro State Water and Sewage Company (CEDAE) is responsible for the water supply in the city, and investments to improve the Guandu's waters treatment should be done to solve this problem. However, the utility's effort seems timid, and the problem remained unsolved.

The literature about water distribution in Brazil focused on the dichotomy of public and private utilities. Most of the works show that private operators (marginally) more efficiently than public ones. Therefore, who owns the company does not seem to impact the quality of the service and its efficiency. However, Tupper and Resende (2004) and Motta and Moreira (2006) give some clues about the primary source of the problem: regulation.

Before 2007, municipalities were allowed to make concessions for public services for "local" interests, and state and federal governments were supposed to guarantee that contracts were fulfilled. In metropolitan areas, the states were allowed to legislate on issues related to sanitation. Thus, it created a judicial problem regarding who (municipality or the state) should legislate and offer sanitation services in a given country area.

According to Kresch (2020), after 2005, this problem was addressed as a bill was submitted to Congress to strengthen sanitation's regulatory framework. Bill 5.296/2005 entered Congress in 2005 and gave two critical contributions to resolving the dispute between municipalities and states. The first one was about who was responsible for water, sewage, and solid waste services, and it was decided that cities would be in charge of it.

Thus, it solved the concerns regarding the "local" interests from the 1988 Federal Constitution. The bill was approved in 2007 and provided a legal framework to municipalities contract services from the state public sanitation companies, private operators, or even create its utility. On the other hand, as pointed by Motta and Moreira (2006), the definition of tariff regimes and how regulatory agencies would deal with integrated management of local and multiple-use services as some utilities operate both water and sewage services in Brazilian municipalities.

The 2007 Regulatory Framework mitigated several problems related to sanitation, but the lack of rules and who would apply them reduced its power. Before the bill was approved, some regulatory agencies existed. According to the Brazilian Association of Regulatory Agencies (ABAR), there were 21 regulatory agencies in the sanitation sector. This number more than doubled, and, in 2015, 50 agencies were operating at the municipal and state level.

However, as Araújo and Bertussi (2018) showed, local and state regulatory agencies cannot do their jobs properly. The strong political influence in state companies reduces the agencies' regulatory power. The application of tariff rules is still far from what other national regulatory agencies, such as Brazilian Electricity Regulatory Agency (electricity) and National Telecommunications Agency (telecommunications), do. Even the (recent) 2020 Regulatory Framework could not address this issue, as the bill's main focus was to obligate municipalities to make biddings to create more competition in the process and provide more room to private companies.

Through regulation, the government can mitigate informational problems. Nevertheless, as said above, Brazil is far from solving this issue as municipalities and states do not have enough sources to regulate water utilities. Thus, this dissertation aims to investigate the relevance of moral hazard and adverse section problems in the utility's level of cost and the quality of the service provided by them. Notice that this approach is related to the regulatory system, which is being explored by the recent literature [see e.g., Barbosa and Brusca (2015), Estache et al. (2016), Araújo and Bertussi (2018), and Kresch (2020)].

There are two types of regulatory schemes considered canonical in the regulation literature: price-cap and cost-plus. The former gives the utility incentives to reduce its cost level, as it is the residual claimant of any cost reduction. Therefore, the firm receives the remainder of the sum after the accounting of its costs. On the other hand, the latter does not provide incentives for cost reduction, as the firm receives a specific amount of profit for its expenses.

As discussed later, variations of these regimes have were adopted to regulate Brazilian water utilities only after the 2007 Regulatory Framework was approved. This heterogeneity of rules adopted allowed me to compare different outcomes of 20 state water utilities that operate under the price-cap and the cost-plus. This information was obtained by analyzing technical notes from each state sanitation regulatory agency.

This dissertation is divided as follows: the next chapter summarizes both the theoretical and empirical literature and the link between them. The third chapter analyzes the history of water distribution and regulation in Brazil. In the fourth chapter, I discuss some theoretical and empirical works regarding regulatory regimes and summarizes the schemes adopt by 20 Brazilian regulatory agencies over the last years. Chapter five presents the empirical strategy, just like the dataset used, and the results obtained in the econometric estimations. Finally, chapter 6 concludes the dissertation.

2. Regulation and Asymmetric Information: Conceptual Aspects

2.1 – Theoretical literature: a brief overview

The advancement of Industrial Organization literature took place relatively rapidly during 1980 and 1990, with the appearance of increasingly sophisticated structural models of oligopoly that aimed to explain firms' market power when the marginal cost is not observable. Later, models aimed to develop more robust theoretical foundations for the stochastic terms used in econometric modeling were developed. Therefore, we can say that the birth of what came to be known as the "New Empirical Industrial Organization." Several authors contributed to this literature, but it is worth point out the contributions of some of them.

2.1.1 – Baron and Myerson (1982)

In this work, the authors wish to develop a model to regulate a natural monopolist when its cost structure is unknown to the regulator. The latter wants to maximize social welfare, which is a function of the firm’s profit and consumers’ surplus. Let us assume that the firms’ cost $C(q,\theta)$ is a function the quantity produced q, and a not observable parameter θ to the regulator.

$$C(q,\theta) = (c_0 + c_1\theta)q + (k_0 + k_1\theta) \text{ if } q > 0, \text{ and } C(0,\theta) = 0 \qquad (1)$$

Where c_0, c_1, k_0, and k_1 are unknown constants that satisfies condition $c_1 \geq 0$, and $k_1 \geq 0$. Moreover, let us assume that $\theta \in [\theta_0, \theta_1]$, and that $\theta_0 < \theta_1$. The value of θ is kwon by the firm, and given it, the regulator must determine the levels of the subsidy and the regulated price of the service provided by the company.

The regulator has a subjective prior probability distribution $f(.)$ for θ, prior receiving any cost report from the firm. Thus, $f(\theta)$ will be a continuous function, and $f(\theta) > 0$, over the interval $[\theta_0, \theta_1]$. $F(\theta)$ is the cumulative distribution function for θ. On the other hand, both the regulator and the company observe the demand given by the inverse demand function $P(.)$, and price at which consumers demand the output q is $P(q)$. The area under the demand curve yields the total value $V(q)$ to costumers of a unit of q.

$$V(q) = \int_0^q P(\tilde{q})\, d\tilde{q} \qquad (2)$$

$V(q) - qP(p)$ will give the consumer surplus. To maximize both the consumer and producer surplus, the regulator can decide whether the firm will be allowed to do business, control the price or quantity supplied by the firm, and to give a subsidy of charge a tax from it. Therefore, we can design a regulatory policy using four outcome functions (r, p, q, s).

For any $\hat{\theta}$, in $[\theta_0, \theta_1]$, if the firm reports that its cost parameter is $\hat{\theta}$, the $r(\hat{\theta})$ is the probability that the regulator will permit it to operate. Notice that $0 \leq r(\hat{\theta}) \leq 1$. In this case, its regulated price will be given by $p(\hat{\theta})$, and $q(\hat{\theta})$ is the correspondent quantity, such as $p(\hat{\theta}) = P(q(\hat{\theta}))$. Finally, $s(\hat{\theta})$ is the subsidy paid by the firm that reports the type $\hat{\theta}$.

In practice, the expected profit of a risk neutral type θ company, when the regulatory policy (r, p, q, s) is implemented, will be given by:

$$\pi(\theta) = [p(\theta)q(\theta) - (c_0 + c_1\theta)q(\theta) - (k_0 + k_1\theta)]r(\theta) + s(\theta) \qquad (3)$$

Nevertheless, the type θ firm can report being type $\hat{\theta}$. In this case, the expected profit will be given by:

$$\pi(\hat{\theta}, \theta) = [p(\hat{\theta})q(\hat{\theta}) - (c_0 + c_1\theta)q(\hat{\theta}) - (k_0 + k_1\theta)]r(\hat{\theta}) + s(\hat{\theta}) \qquad (4)$$

Therefore, the following mechanism guarantees that the firm will report its actual type:

$$\pi(\theta) = maximum\ \pi^*{}_{\hat{\theta}}(\hat{\theta}, \hat{\theta}), \forall\ \theta \in [\theta_0, \theta_1] \qquad (5)$$

The individual rationality condition has to be fulfilled, so the firm will not operate under negative expected profits. One can say that this regulatory policy is feasible if the restrictions provided by the functions (r, p, q, s) are respected. Thus, it makes the firm reports its proper type, and social welfare is maximized.

One of the main contributions of this framework is that the regulator can offer a contract to the firm, which mitigates only the adverse selection problem, and the empirical and theoretical literature widely explored it. Nevertheless, Baron and Myerson (1981) did not address the moral hazard problem.

The work in question is considered seminal and was used several times in empirical and theoretical literature. According to Resende (1997), it is possible to analyze the theoretical regulation literature in two groups: statical and dynamic models. In the first group, we have Baron and Myerson (1982), Besanko (1984), Laffont and Tirole (1986), and Baron

(1989). We have Baron and Besanko (1984, 1987) and Laffont and Tirole (1988) in the second.

Notice that only Laffont and Tirole (1986, 1988) addressed the moral hazard problem. They worked on a general model that appears in Laffont and Tirole (1993). In the following subsection, let us discuss this model in detail.

2.1.2 – Laffont and Tirole (1993)

In this work, the authors a general model aiming at the same problem described lately. Let us assume that there is an indivisible public project with S value for consumers, and only one firm can do it. The company has the following cost function:

$$C = \beta - e \tag{6}$$

β is the efficiency paramenter, and e is the firms' manager level of effort. Notice that $e > 0$, and as the level of effort increases, the monetary cost of the project decreases. Thus, the firm faces a disutility in the level of effort represented by the function $\psi(e)$. For $e > 0$, $\psi'(e) > 0$, which means that the disutility increases at a rate $\psi''(e) > 0$ and satisfies $\psi(0) = 0$, $\lim_{e \to \beta} \psi(e) = +\infty$.

Furthermore, let us assume that the regulator can observe the firm's cost, which will be reimbursed to the firm by the regulator. To accept to do the project, the firm must receive a net transfer t in addition to the reimbursement of its cost. Therefore, its utility level is:

$$U = t - \psi(e) \tag{7}$$

The firm has to get a utility level in this project as high as in another project. This outside option (reservation utility), will be normalized to 0. It implies that the firm's individual rationality (IR) constraint is:

$$t - \psi(e) \geq 0 \tag{8}$$

$\lambda > 0$ is the shadow cost of public funds, which means that a discretionary taxation will cause a disutility of $\$(1 + \lambda)$ on taxpayers/consumers to levy \$1 to the government. Thus, their net surplus is equal to:

$$S - (1 + \lambda)(t + \beta - e) \tag{9}$$

For a utilitarian regulator, the ex-post social welfare is:

$$S - (1 + \lambda)(t + \beta - e) + t - \psi(e) = S - (1 + \lambda)[\beta - e + \psi(e)] - \lambda U \qquad (10)$$

It means that the social welfare function is equal to the difference between the consumer surplus linked to the public project mentioned before and the total cost of this project as perceived by consumers plus the firm's rent (above its reservation utility) times the shadow price the public funds. Notice that the regulator would like to reduce the rent left by the utility.

Suppose the regulator offers the firm a take or leave proposal. Let us assume that the information is complete, which means that the regulator observes both β, and e. Through the revelation principle, ley us represent this game in terms of a feasible mechanism. Thus, the following problem has to be solved:

$$max_{U,e} = \{S - (1 - \lambda)[\beta - e + \psi(e)] - \lambda U\}, \text{ subjected to } U \geq 0 \qquad (11)$$

The solution is given by:

$$\psi'(e) = 1 \text{ or } e \equiv e^* \qquad (12)$$

$$U = 0 \text{ or } t = \psi(e^*) \qquad (13)$$

Therefore, the marginal disutility of effort must be equal to the marginal cost of savings, and, as $\lambda > 0$, the firm will receive no rent. Several contracts can be used in order to fulfill the solutions above but let us focus on the fixed-price contract:

$$t(C) = a - (C - C^*) \qquad (14)$$

Where $a \equiv \psi(e^*)$, and $C^* \equiv \beta - e^*$. In this case, the firm is the residual claimant for its costs savings, and will choose e that maximizes $a - (C - C^*)$. Therefore, its final utility is equal to 0. This type of contract is interesting because, under complete information, no rent is left to the firm, giving it an incentive to reduce costs.

Notice that, differently from Baron and Myerson (1981), this framework incorporates both adverse selection and moral hazard. The complete information assumption lets the regulator implement the first-best contract, which is not valid in reality. Nevertheless, Laffont and Tirole (1993) extended this model to incorporate cases when the regulator cannot observe the informational parameters. Therefore, e is not observed, and the regulator has a prior information about β.

2.1.3 – Schmalensee (1989)

Baron and Myerson (1982), Besanko (1984), Baron (1989), and Laffont and Tirole (1993) provided a theoretical framework so the regulator can implement optimal contracts in the presence of adverse selection and moral hazard. However, the implementation of such schemes is not trivial when it comes to actual regulatory policy. According to Schmalensee (1989), the economic regulation literature should provide theoretical models related to the regulatory regimes seen in the real world.

Therefore, Schmalensee (1989) develops a model relating the quantitative properties of the "good" regulatory schemes to parameters the regulators may know. Notice that it is different from other models with general qualitative properties of fully optimal schemes or price caps in particular. Let us assume that the cost of a regulated, single-product, and risk-neutral monopoly that produces under constant returns to scale, with observable unit cost, is given by:

$$C = \alpha + \epsilon - \delta \tag{15}$$

Where α is the expected unit cost before the change in the regulatory regime. As regulators usually have information about the firm's cost structure, this parameter is observable by them. ϵ accounts for shocks that might impact the firm's level of cost, and its distribution is triangular symmetric over $[\epsilon_{min}, \epsilon_{max}]$. Furthermore, ϵ has the following properties: $E_\epsilon\{\epsilon\} = 0$, and: $E_\epsilon\{\epsilon^2\} = \delta^2 = (c\alpha)^2/6$, where $c \, \epsilon \, [0,1]$ is the maximum absolute value of exogenous cost change, as a fraction.

δ is the reduction in the unit cost produced by managerial effort beyond that expected before the regulatory regime change. In this case, regulators cannot observe this variable as there is no historical data. Thus, we have that:

$$\psi(\delta, \theta) = \theta\delta^2 \tag{16}$$

Where θ is observable by the firm but not by the regulator, the latter has an initial idea of the distribution of this parameter. Both parts also observe the demand, as the regulator usually has access to historical data about the quantity sold and the price charged. Therefore, the following linear demand equation is equal to:

$$Q = 1 - P \tag{17}$$

Q is the quantity demanded and P is the price charged by the firm. This model is solved numerically based on calibration. Gasmi et al. (1994) and Wunsch (1996) follow a similar approach.

2.2 – Structural econometric models in regulation: some basic aspects

Based on optimal regulatory regimes, numerous works using structural models emerged and focused on analyzing sectors whose technology is more straightforward, such as water distribution and public transport. Also, the focus was on firms that produce only one product, given that econometric modeling for a multi-product case would not be trivial.

2.2.1 – Models with optimal regulation

Wolak (1994) and Brocas et al. (2006) analyze the water distribution firms of the "Classe A" group (which serves more than 10,000 people) in California. These works take into account adverse selection but have the limitation of assuming that the regulator is sophisticated to the point of implementing optimal contracts. However, they have interesting results and help analyze the impact of asymmetric information in the design of contracts.

When estimating cost functions without considering the adverse selection, the distributor's returns to scale are overestimated. Also, there is a significant loss of welfare on the part of consumers since, in the presence of adverse selection, they end up paying higher tariffs and the firm's water production is lower (which reduces the consumption of the goods by customers). However, as Schmalensee (1989) demonstrated, structural models that provide optimal solutions may not be implemented in the real world.

According to Wolak (1994), the main costs faced by water distribution utilities are capital, labor, electricity, and the source (from where the firm withdrawals water). Thus, the utility i has the following production function:

$$Q_i = f(K_i, L_i^*, E_i, \varepsilon_q(i) | \beta) \tag{18}$$

K_i is the firm's capital stock, L_i^* is the labor, and E_i is the electricity. $\varepsilon_q(i)$ is a stochastic disturbance that the utility has to deal, after choosing the right capital stock that will be used to for production. This parameter, which is kwon by the firm, is independently and identically distributed over time and across utilities. β is not observable by econometrician but it is for both the regulator and the firm. It describes the technical coefficients of production.

L_i^* can be defined as $L_i^* = \frac{L_i}{d(\theta_i)}$. Notice that L_i^* is the actually used in the production process, while L_i is the observed physical quantity of labor input which is implied by the utility's total labor costs. Finally, $d(\theta_i)$ is an increasing function of θ, which is the firm's efficiency parameter, and as this parameter increases, the inefficiency also increases. Thus, the utility's observed cost is given by:

$$w_i L_i + r_i K_i + pe_i E_i \qquad (19)$$

Where w_i is the wage rate, r_i is the price of capital, and pe_i is the price of electricity. Remember that L_i, in this case, is no the same as $L_i^* = \frac{L_i}{d(\theta_i)}$. The source of asymmetric information among the firm and the regulator will be given by θ_i, and, just like Baron and Myerson (1982), and Laffont and Tirole (1993), the regulator will be capable of implementing a first-best contract by assuming that the regulator might observe θ_i. Furthermore, Wolak (1994) follows Besanko (1984), as he introduces a stochastic structure in your model. In fact, Wolak (1994) analyzes two cases: symmetric (model S), and asymmetric information (model A). In the former, the regulator observes θ_i but, in the latter, it only knows the distribution $F(\theta)$ of this parameter, that ranges from $[\theta_{high}, \theta_{low}]$, and is.

This distinction was made because the utility's choice of inputs is affected by the available information. Let us also assume that conditional on all observable characteristics of the utility and its customers, and the distribution of θ_i is independent of the other stochastic disturbances included in the model. This assumption implies that the utility's labor efficiency parameter is independent of any shocks to the regulatory environment.

To maximize their expected profits, each utility is going to solve the following minimization problem:

$$Min_{L,E}\ wL + peE, \text{ subject to } Q = f(K, L, E, \theta, \varepsilon_q | \beta) \qquad (20)$$

The solution yields the minimum variable cost factor demand functions for E, and L, conditional to K, and Q. By the time the utilities choose E, and L, they know ε_q which will enter into both input demand functions. Substituting both of the variable factor demand functions back into the expression for total operating costs yields the conditional variable cost function $CVC\left(pe, w, \theta, K, Q, \varepsilon_q, \eta_L, \eta_E \middle| \beta\right) + r_i K_i$. Both η_L, and η_E are mean one disturbances introduced to allow, obtaining L and E, through the first-order conditions. Finally, the utility's i total cost can be rewritten as:

$$TC = CVC\left(pe, w, \theta, K, Q, \varepsilon_q, \eta_L, \eta_E \middle| \beta\right) + r_i K_i \tag{21}$$

According to Reiss and Wolak (2007), the model presented in Wolak (1994) faced three main limitations concerning econometric estimation:

1. Shocks related to supply and demand.
2. Optimization errors are associated with the first-order conditions in the firm's maximization problem.
3. Unobservable heterogeneity in the form of the utility's private information θ_i.

In Appendix A, Wolak (1994) shows how to overcome these composite errors. In sum, he makes assumptions concerning distinct components. He obtains a composed error u for a log model, which has a log-normal distribution that is used to estimate the log-likelihood function. He uses it to assess the system of relevant equations.

2.2.2 – Models incorporating regulatory regimes

2.2.2.1 – The Dalen and Gomez-Lobo (1996, 1997) model

Both works aim to estimate a cost function that incorporates adverse selection and moral hazard. While the 1997 paper focuses on the theoretical development of the model, the 1996 working paper applies this model to 88 bus companies in Norway. Furthermore, the connection with the regulatory routine in the real world is more significant as they incorporate classic regulatory regimes in the cost function: price-cap and cost-plus. Therefore, Dalen and Gomez-Lobo (1996) simulate the distribution of types over time and which scheme yields the highest welfare level.

Let us divide the problem into two cases. First of all, it will present the regulator's situation and the firm's problem.

a) The regulator's problem

Let us assume that the regulated firm has the following cost function:

$$C = C(p, Q, \theta - e) \tag{22}$$

Where p the input prices, Q is the output, θ is the adverse selection parameter, and e is the unobservable level of effort parameter. θ is derivated from a cumulative distribution function $F(\theta)$, that ranges between $[\bar{\theta}, \underline{\theta}]$ with density $f(\theta)$. The manager of the firm, thus, has to maximize the following function:

$$U = t - \psi(e) \tag{23}$$

Where t is a net transfer that the regulator does to the regulated firm, $\psi(\mathrm{e})$ is the disutility effort function with following properties: $\psi'(e) > 0$, $\psi''(e) > 0$ and $\psi'''(e) \geq 0$. The regulator will maximize the society's expected welfare choosing output and efficiency. Net transfers are assumed to be costly to society, and the expected welfare function is the sum of consumer and producer surplus. Therefore, the function will be given by:

$$W = \big(S(Q) - R(Q)\big) + U - (1 - \lambda)(t + C - R(Q)) \tag{24}$$

$$W = S(Q) - \lambda R(Q) + U - (1 - \lambda)\big(C + \psi(e)\big) - \lambda U \tag{25}$$

Where $S(Q)$ is the total consumer surplus, $R(Q)$ is the revenue, and λ is the cost of public funds. The regulator's problem is to maximize expected welfare, subject to individual rationality constraint (IR) and individual compatibility constraint (IC):

$$max_{Q,e} = E[S(Q) - \lambda R(Q) + U - (1 - \lambda)\big(C + \psi(e)\big) - \lambda U] \tag{26}$$

Subject to

$$\frac{\partial U}{\partial \theta} = -\psi'(e) \tag{27}$$

$$U = t - \psi(e) \geq 0, \forall \theta \tag{28}$$

The (IC) is a crucial assumption to guarantee that a firm of type θ chooses the effort level and output corresponding to its type to implement an optimum contract. It will happen if the firm's utility from revealing its actual kind is not smaller than the utility it gains from pretending to be a different type. On the other hand, (IR) states that the contract offered by the regulator will guarantee a non-negative utility to the regulated firm. Therefore, the first-order conditions will be given by:

$$S'(Q) - \lambda R'(Q) = (1-\lambda)\frac{\partial C}{\partial e} \tag{29}$$

$$\psi'(e) = -\frac{\partial C}{\partial e} - \frac{\lambda}{1+\lambda}\psi''(e)\frac{F(\theta)}{f(\theta)} \tag{30}$$

This framework concludes that the regulator designs a contract to make efficient (inefficient) types pick high (low)-powered incentives contracts. However, the it faces a tradeoff between efficiency and rents. The first-best solution would be such that $\bar{C} = \bar{\beta} - e^*$ but it would live a high rent for the efficient type. The regulator reduces the effort level required for the inefficient type, and the rent transferred to the efficient type is reduced. Thus, the existence of asymmetric information forces the principal to give some rents to the efficient agents. The former can reduce the cost of these rents by distorting away from the first-best solution, as it is possible to reduce the required level of effort from the inefficient type.

The authors assume that a firm i can be regulated according to the following contract:

$$T_i = A_i - b_i(C_i - \bar{C}_i) \tag{31}$$

Where T is a monetary transfer, A is a constant, $b \in [1,0]$ measures the power of the contract (price-cap or cost-plus), C is are the ex-post costs and $\bar{C}$ are the ex-ante expected costs. According to them, this framework can accommodate several types of regulatory regimes. Therefore, when $b = 1$ the utility is under a price-cap regime, and when $b = 0$ the firm is under a cost-plus regime. In the former, the firm is a residual claimant of cost reduction and, thus, has more incentives to cost reduction. On the other hand, cost overruns do not reduce transfers, and utilities have no incentive to reduce costs when the latter applies.

Some models, such as the one proposed by Schmalensee (1989), do not assume the existence of transfers or subsidies. However, Laffont and Tirole (1993) adopt the convention that the government pays the firm's cost and then pays a net transfer t to the firm. These transfers can take several forms: direct subsidies, government loans, free government guaranties, and transfers of public goods, usually in procurement. For example, if the government is the only buyer (military weapons acquisition), the firm is not paid through consumers. Moreover, it also happens when the firm is public and it is able to borrow from the government with it consent[1].

b) The firm's problem

Let us assume a cost function with three inputs:

$$C_{it} = w_{it}L_{it} + r_{it}K_{it} + p_{it}M_{it} \tag{32}$$

Where C is the cost with labor L, capital K and materials M. The price of labor, capital and materials can be expressed respectively by w, r, and p. They also assume a well-behaved production function:

$$Q_{it} = g(L_{it}, M_{it}, K_{it}, Z_{it}, \theta_{it} - e_{it}) \tag{33}$$

Z is a vector firm's characteristics, θ is the adverse selection parameter, and e is the amount of cost-reducing effort by the manager. Notice that the econometrician does not observe them. It is possible to represent the cost reduction effort in monetary units, according to the function $\psi(e)$. This function has the following properties: $\psi'(e) > 0$, $\psi''(e) > 0$ and $\psi'''(e) \geq 0$.

If the firm's i manager is risk-neutral, she will maximize profit conditional on a level of effort and output. It can be represented in the following maximization program:

$$\pi(w_{it}, p_{it}, K_{it}, Z_{it}, \theta_{it} - e_{it}, Q_{it}) = max_{L_{it}, M_{it}}\, A_i - b_i(C_{it} - \bar{C}_i) - \psi(e_{it}) \tag{34}$$

$$s.t\; Q_{it} \leq g(L_{it}, M_{it}, K_{it}, Z_{it}, \theta_{it} - e_{it})$$

When $b_i > 0$, and conditional on Q_{it} and e_{it}, tthe program is equivalent to minimize costs subject to producing a given level of output. Thus, duality can be applied and a firm's profit can be expressed as:

$$\pi = A_i - b_i[C(w_{it}, p_{it}, K_{it}, Z_{it}, \theta_{it} - e_{it}, Q_{it}) - \bar{C}_i] - \psi(e_{it}) \tag{35}$$

The first-order condition will be given by:

$$-b_i \frac{\partial \mathrm{C}}{\partial e_{it}} = \psi'(e) \tag{36}$$

It yields the optimum level of effort $e^*(b_i, w_{it}, p_{it}, K_{it}, Z_{it}, \theta_{it}, Q_{it})$, that can be substituted in the cost function. Therefore, we obtain:

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[1] In this case, of the firm borrows \$1 from the government, the state's borrowing capacity would be \$1 lower, and then taxes should be raised by \$1 to recover the public budget. Welfare is not affected, thus.

$$C^*(w_{it}, p_{it}, K_{it}, Z_{it}, \theta_{it} - e^*{}_{it}, Q_{it}) \\ = C^*(b_i, w_{it}, p_{it}, K_{it}, Z_{it}, \theta_{it}, Q_{it}) \quad (37)$$

One of the assumptions to estimate the model is labor, as it can be considered a factor impacted by the level of effort. Thus, we can represent this input as:

$$\tilde{L}_{it} = \frac{L_{it}}{\exp{(\theta_{it} - e_{it})}} \quad (38)$$

Where L_{it} is the unadjusted number of man-hours used by the firm i. We can introduce this variable in the problem above, and do the minimization:

$$min_{\tilde{L}_{it}, M_{it}} = w_{it}\exp(\theta_{it} - e_{it})\,\tilde{L}_{it} + p_{it}M_{it} \\ s.t\ Q_{it} \leq g(\tilde{L}_{it}, M_{it}, K_{it}, Z_{it}) \quad (39)$$

We can obtain the following dual cost function from this program:

$$C_{it} = C(\widetilde{w}_{it}, p_{it}, K_{it}, Z_{it}, Q_{it}) \quad (40)$$

Where $\widetilde{w}_{it} = w_{it}\exp(\theta_{it} - e_{it})$. According to the authors, the above cost function is flexible and can be adapted for several cases of moral hazard and adverse selection. The main restriction that must be respected is the use of a wage rate in the form of $\widetilde{w}_{it}$. Therefore, they will use a Cobb-Douglas function as an example:

$$C_{it} = \beta(Z_{it})\widetilde{w}_{it}{}^{\beta}p_{it}{}^{\beta_p}K_{it}{}^{\beta_K}Q_{it}{}^{\beta_Q} \\ = \beta(Z_{it})w_{it}{}^{\beta_w}[\beta_w\exp{(\theta_{it} - e_{it})}]p_{it}{}^{\beta_p}K_{it}{}^{\beta_K}Q_{it}{}^{\beta_Q} \quad (41)$$

To know the impact of a marginal increase in the level of effort in the cost, we can do:

$$\frac{\partial C}{\partial e} = -\beta_w C \quad (42)$$

This result is significant and is related to the “Arrow effect”, as it implies that when cost levels are higher, the potential cost savings from the increasing effort are also higher. Thus, when a firm is significant, it will have a stronger incentive to be efficient than other smaller firms, as the former can benefit more from an eventual cost reduction. Furthermore, the homogeneity of degree one in the prices of factors ($\beta_w + \beta_p = 1$) is also a relevant assumption in the model’s identification.

Let us assume that the effort function can be expressed like:

$$\psi(e_{it}) = \exp(\tau e_{it}) - 1, \tau > 0 \quad (43)$$

The optimum level of effort is equal to:

$$\psi'(e_{it}) = \tau.\exp(\tau e_{it}{}^{*}) \tag{44}$$

From equation (36) and (42), we have that:

$$b_i \frac{\partial \mathrm{C}}{\partial e_{it}} = \psi'(e) = b_i \beta_w C = \tau.\exp(\tau e_{it}{}^{*}) \tag{45}$$

$$b_i \beta_w C = \tau.\exp(\tau e_{it}{}^{*}) \tag{46}$$

Linearizing this relation, we have:

$$lnb_i + ln\beta_w + ln\ C - ln\tau = \tau e_{it}{}^{*} \tag{47}$$

Thus, the optimum level of effort is[2]:

$$e_{it}{}^{*} = \frac{lnb_i + ln\beta_w + ln\ C - ln\tau}{\tau} \tag{48}$$

Linearizing (41), we have:

$$\ln C_{it} = \beta(Z_{it}, b_i) + \beta_w \ln w_{it} + \beta_p lnp_{it} + \beta_K lnK_{it} + \beta_Q lnQ_{it} + \beta_w \theta_{it} + \beta_w(\theta_{it} - e_{it}) \tag{49}$$

Substituting the optimum level of effort from (47) in (48), we have that:

$$\ln C_{it} = \beta(Z_{it}, b_i) + \beta_w \gamma \ln w_{it} + \beta_p \gamma lnp_{it} + \beta_K \gamma lnK_{it} + \beta_Q \gamma lnQ_{it} + \beta_w \gamma \theta_{it} \tag{50}$$

Where:

$$\gamma = \frac{\tau}{(\tau + \beta_w)} \tag{51}$$

The identification, however, is not completed yet as parameters γ and β are not identified. To do it, they impose homogeneity for input prices on the cost function ($\beta_w + \beta_p = 1$) and the result is:

$$\ln\left(\frac{C_{it}}{p_{it}}\right) = \beta(Z_{it}, b_i) + \beta_w \gamma \ln\left(\frac{w_{it}}{p_{it}}\right) + (\gamma - 1) lnp_{it} + \beta_K \gamma lnK_{it} + \beta_Q \gamma lnQ_{it} + \beta_w \gamma \theta_{it} \tag{52}$$

Notice that b_i is a dummy variable, that assumes the value of 1 if the regime practiced is the price-cap, and 0 if it is a cost-plus. Nevertheless, there are several combinations of regimes between the polar cases.

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[2] Notice that τ can be represented like $\tau = \frac{-\gamma\beta_w}{\gamma - 1}$.

Together, homogeneity and the Arrow effect assumptions identify gamma because, as the price of an input increases, total costs increase, which results in a higher level of effort. Thus, the rise in input price does not lead to a proportional increase in the firm's cost. Since $\gamma \leq 1$, the coefficient of p_{it} can only be negative or equal to 0. Finally, if the price of the input increases and does not imply a proportional increase in costs, then we can say that the difference will be attributed to a rise in the level of effort.

Furthermore, notice that as τ increases, the cost of effort becomes higher. In the limit, as τ increases infinitely, γ will approach to 1 and the cost functions collapses to a traditional Cobb-Douglas dual cost function. In this case, moral hazard will not be a relevant phenomenon since the cost effort is high. Parameters of a traditional cost function would be biased down. It happens because the rise will reduce the impact of higher input costs or output levels in the effort.

Therefore, firms that produce more will have an incentive to increase effort than those that make less. Regarding to scale economies (SCE), if the estimated function did not take into account asymmetric information, it would be overestimated as it is inversely related to the cost elasticity with respect to the output. One may represent it as $\frac{1}{\beta_Q}$. In fact, $\mathrm{SCE} \equiv 1 - \frac{\partial \mathrm{C}}{\partial \mathrm{Q}}$, where a positive value indicates scale economies and negative values indicate scale diseconomies. On the other hand, γ impacts the scale economies as the reciprocal of the cost elasticity with respect to the output becomes $\frac{1}{\gamma\beta_Q}$. If $\gamma < 1$, when estimating β_w, we would obtain a biased result and overestimated value.

As previously mentioned, Dalen and Gomez-Lobo closed a gap left by Feinstein and Wolak (1991) and Wolak (1994). Their model assumes that the regulator can implement an optimum contract, and the price will increase monotonically according to the firm's type. An endogeneity is generated since the quantity produced will be correlated with the error term. Thus, the econometrician may overestimate eventual economies of scale.

The model's estimation was done using random effects and applied to a Norwegian public transport sector panel. It is possible to increase efficiency, as demonstrated further, if one uses share equations, as proposed by Spady and Friedlaender (1978) and Greene (2008). Considering the correlations across the error terms of the different equations may produce more efficient estimates within a seemingly unrelated regression (SUR) setup. Such possibility was not considered in the previous structural econometric models of regulation.

Dalen and Gomez-Lobo (1996, 1997) contribute to the structural estimation because, in addition to taking the adverse selection parameter into account, they use the effort level and a more flexible functional form. Another relevant point is that the regulator modeled by them, different from previous theoretical and empirical works, is not considered sophisticated and, therefore, capable of constantly implementing optimal contracts. Analyzing the Norwegian public transport sector, for the period 1987-1991, the authors conclude that asymmetric information reduces consumer well-being by 12 to 13% and increases transfers to firms by 8 and 9%.

2.2.2.2 – The Garcia and Thomas (2003) model

In Garcia and Thomas (2003), a cost function is estimated for the French water utilities and incorporates adverse selection. The moral hazard will be evaluated by the volume of water produced and water loss. Moreover, the estimation is done with a translog cost function.

Their framework is just like the one developed by Baron and Myerson (1982), as it takes only adverse selection into account. Furthermore, Garcia and Thomas (2003) adopt the strategy of comparing the volume of water produced and lost in two types of cases: complete and incomplete information. An exciting feature of this work is that, through simulation, they can also analyze how these outcomes change when in the range of the two polar informational cases.

They assume the following cost function:

$$C(\theta, V_c, I, w) = e^{\delta\theta} H[V_c(\theta, w), I(\theta, w), w] \tag{53}$$

Where θ is the firm's efficiency parameter, V_c is the volume of water delivered to the final consumers, I is the volume of water loss index, w is a vector of input prices, and H is the translog functional form of the cost function. It is possible to linearize this equation by the logarithmic form, by utility i, and year t:

$$logC_{it} = \delta\theta_i + logH[V_c(\theta, w), I(\theta, w), w] \tag{54}$$

The translog function with homogeneity restriction, thus, will be given by:

$$
\begin{aligned}
&\log\left(\frac{C_{it}}{w_{L,it}}\right) \\
&= \beta_{V_c} logV_{c,it} + \beta_I logI_{it} + \frac{1}{2}\beta_{V_cV_c}(logV_{c,it})^2 \\
&+ \frac{1}{2}\beta_{II}(logI_{it})^2 + \beta_{V_cI} logI_{it} logV_{c,it} \\
&+ \beta_{w_E}\log\left(\frac{w_{E,it}}{w_{L,it}}\right) \\
&+ \beta_{w_M}\log\left(\frac{w_{M,it}}{w_{L,it}}\right) \\
&+ \frac{1}{2}\beta_{w_{EE}}\log\left(\frac{w_{E,it}}{w_{L,it}}\right)^2 + \frac{1}{2}\beta_{w_{MM}}\log\left(\frac{w_{M,it}}{w_{L,it}}\right)^2 \\
&+ \beta_{w_{EM}} log\left(\frac{w_{E,it}}{w_{L,it}}\right) log\left(\frac{w_{M,it}}{w_{L,it}}\right) \\
&+ \beta_{w_EV_c}\log\left(\frac{w_{E,it}}{w_{L,it}}\right) logV_{c,it} \\
&+ \beta_{w_EI}\log\left(\frac{w_{E,it}}{w_{L,it}}\right) logI_{it} \\
&+ \beta_{w_MV_c}\log\left(\frac{w_{M,it}}{w_{L,it}}\right) logV_{c,it} \\
&+ \beta_{w_EI}\log\left(\frac{w_{M,it}}{w_{L,it}}\right) logI_{it} + \eta_{it} + \varepsilon_{it}
\end{aligned}
\tag{55}
$$

Where w_L, w_M, and w_E are the input prices of labor, materials, and energy, respectively. η_{it} is the individual effect, which corresponds to $\delta\theta_i$. δ can be normalized by 1, and then $\eta_t = \theta_i$. The authors argue that the endogeneity problem, because of the correlation between $V_{c,it}$ and I_{it} with η_{it} (as the three variables depend on θ_i.), can be solved using fixed-effects.

Garcia and Thomas (2003) also follow the line developed by Dalen and Gomez-Lobo (1996, 1997). However, the contribution of that work is to apply to model the water distribution system in the Bordeaux region in France. According to the authors, their model is flexible and assumes other functional forms; a translog function was used. The authors were able to estimate the impact of a series of regulatory regimes through the simulation method.

Therefore, as much as the empirical works have managed to overcome barriers imposed by the theoretical literature and substantially contribute to regulation, there is still work to do on this topic. The main problem of this kind of estimation is that, when incorporating regulatory regimes applied in the real world, these models tend to be less structural, especially regarding the specification of the stochastic part of the models. I will discuss these points in the following section. Moreover, just like Dalen and Gomez-Lobo (1996, 1997), they did not use share equations, which can reduce the robustness of the estimations they obtained.

2.2.2.3 – Gagnepain and Ivaldi (2002, 2017)

As discussed before, the main problem of the theoretical literature regarding regulation is that they can hardly be applied to real-world cases, as informational constraints reduce the capacity of the regulator to deal with adverse section and moral hazard issues. Furthermore, the need for a sophisticated regulator capable of implementing first-best contracts is also a rigid assumption.

On the other hand, even after considering regulatory regimes, such as the price-cap and the cost-plus in the estimation, the empirical literature ended up distancing from the canonical structural models. It could compromise the results obtained by them, primarily because of identification issues.

Nevertheless, it is worth mentioning two works that were able to deal with these problems. Gagnepain and Ivaldi (2002, 2017) follow the line developed by Dalen and Gomez-Lobo (1996,1997) since they consider both adverse selection and the moral hazard under consideration. The authors manage to analyze better the behavior of the adverse selection term in the 2002 work, using better data for the public transport system of some cities in France. Also, they could do more detailed counterfactual exercises. In the 2017 paper, the authors consider the possibility of the regulator being captured in addition to the parameters already discussed.

Moreover, Gagnepain and Ivaldi (2002, 2017) also use tools proposed by Laffont and Tirole (1993), and, especially, Wolak (1994), as their structural model is based on the latter. Thus, their work seems to be more robust than what was seen so far in the literature.

3. History and regulation of water distribution in Brazil

Problems related to water scarcity were usual throughout Brazil's history. According to Ritta (2009), the first register of sanitation in the country was in 1561 when Rio de Janeiro city's founder Estácio de Sá ordered a well to supply the town with water. Nevertheless, the town grew fast, and the water demand also increased. The construction of fountains and the capitation of water from nearby rivers were insufficient to indulge Rio de Janeiro's thirst.

After a hundred years, the Crown built a modern aqueduct to supply the city, but it was still hard to find water as fountains were sometimes far from where the inhabitants lived. On the other hand, some citizens could buy gallons that natives or slaves sold on the streets. Only in 1876, the Imperial government started to build networks that could supply households with water. The regulation began in 1882, according to decree 8775 that allowed the state company to charge for the water delivered. In 1898, water meters started to be installed the households and improved the service charge.

When it comes to sewage, the problem was even worst. Households did not have access to a network, and people threw the waste on the streets or in ditches. Moreover, slaves were used to transporting the waste to nearby ditches. The terrible smell and proliferation of mosquitos, rats, and diseases forced the Imperial government to invest in a sewage system that could supply all the empire's capital.

In 1863, the government signed a contract with a private company to operate the city's sewage system: the Rio de Janeiro City Improvements Company, also known as "City". Starting in the neighborhoods from the center, the company expanded its services through the city over the following decades. Only in 1947, its contract was finished, but the government nationalized the service. Notice that this is a brief resume of Rio de Janeiro's water distribution history. The city was relevant as it was Brazil's capital until 1960. However, there was no sanitation plan or regulatory framework for the entire country.

It changed in 1934 during Getúlio Vargas' dictatorship when the "Código de Águas" (Water Code) was created to define the game's rules in the water distribution sector. At that time, private and public utilities owned concessions related to water, sewage, and electricity. Nevertheless, implementing this new framework aimed to give the government more power to control these services. It caused a profound impact as it defined strict laws that firms were supposed to follow. For example, according to

Giamgiabi and Além (2011), the government could fix a tariff to guarantee a minimum rate of return for the utility. Until 1970, municipalities were in charge of the sanitation provision, and the National Health Foundation (Funasa) did the supervision. Still, it changed in 1971 when the military government created a regulatory framework through the National Sanitation Plan (PLANASA).

According to Motta and Moreira (2006), it aimed to guide investments, credit concession in the sector, and establish state sanitation companies. Thus, each Brazilian state would have a sanitation utility that would provide water and waste services to its municipalities. In exchange, cities could have access to the loans provided by the National Housing Bank (BNH) if they made long-term concessions with the state sanitation utility. The militaries encouraged this monopolization by the state as they thought that economies of scale were essential to supply the fast-growing cities' sanitation demands. The regulatory regime adopted was the cost-plus, and tariffs had to provide a maximum rate of return of 12%.

The PLANASA was successful in its objectives, as each state had its sanitation utility operating in most municipalities. The piped water coverage increased from 61% to 90% of the population. Still, the funding mechanism created by the military regime and the regulatory framework was unsustainable because of the hyperinflation that impacted Brazil’s economy during the 1980 decade. As inflation rose, the 12% rate of return was destroying state utility finances as the tariff’s level was not growing fast. Furthermore, defaults and corruption were also causing several damages to BNH’s finances. With the end of the dictatorship, the 1988 Federal Constitution was promulgated, and new rules for the sanitation sector were established.

Municipalities were allowed to make concessions for public services for “local” interests, and state and federal governments were supposed to guarantee that contracts were fulfilled. Moreover, in metropolitan areas, the states were allowed to legislate on issues related to sanitation. Thus, it created a judicial problem regarding who (municipality or the state) should legislate and offer sanitation services in a given country area. In 1995, during Fernando Henrique Carodos’s administration, the government tried to solve this problem, but the bill that would mitigate it did not reach the floor in Congress. Notice that this problem was worsened because the concessions from the PLANASA’s period were expiring, and municipalities did not have a proper framework to contract sanitation services.

According to Kresch (2020), this problem was addressed only during the Luiz Inácio Lula da Silva's administration as a bill was submitted to Congress to strengthen the sanitation regulatory framework. Bill 5.296/2005 entered Congress in 2005 and gave two critical contributions to resolving the dispute between municipalities and states. The first one was about who was responsible for water, sewage, and solid waste services, and it was decided that cities would be in charge of it. Thus, it solved the concerns regarding the "local" interests from the 1988 Federal Constitution.

The bill was approved in 2007 and provided a legal framework to municipalities contract services from the state public sanitation companies, private operators, or even create its utility. On the other hand, Motta and Moreira (2006) pointed out the definition of tariff regimes and how regulatory agencies would deal with integrated management of local and multiple-use services as some utilities operate both water and sewage services in Brazilian municipalities.

The 2007 Regulatory Framework mitigated several problems related to sanitation, but the lack of rules and who would apply them reduced its power. Before the bill was approved, some regulatory agencies existed. According to the Brazilian Association of Regulatory Agencies (ABAR), there were 21 regulatory agencies in the sanitation sector. This number more than doubled, and, in 2015, 50 agencies were operating at the municipal and state level. Therefore, if a state utility supplies the municipality, a state regulatory agency will inspect the company's operations in that area. However, some cities can come together and create their sanitation utility and, when it happens, they will create a regulatory agency that will inspect this regional company. Finally, a municipality can have its utility and regulate it.

Kresch and Schneider (2020) show that there is a political component that has to be taken into account when analyzing the Brazilian sanitation sector. According to them, as state companies wanted to take over the operations in municipalities with self-run utilities, mayors that belong to the same party as the state's governor decrease the local investment in sanitation. Therefore, it would reduce the service's quality, and a door to the takeover would be opened. Nevertheless, Estache et al. (2016) obtain different results. According to them, when the mayor belongs to the same party as the governor, sewage treatment provision is between 18 % and 46 % higher in municipalities in which the mayor is aligned with the governor of the state of São Paulo.

Araújo and Bertussi (2018) show that local and state regulatory agencies cannot do their jobs properly. The strong political influence in state companies reduces the agencies' regulatory power. Furthermore, the application of tariff rules is still far from other national regulatory agencies, such as Brazilian Electricity Regulatory Agency and National Telecommunications Agency do. State utilities coordinate to preserve the power they accumulated during the PLANASA's days, and regulators cannot face their influence.

Even the (recent) 2020 Regulatory Framework could not address this issue. The bill's main focus was to obligate municipalities to make biddings to create more competition in the process and provide more room to private companies. Barbosa and Brusca (2015) analyzed the lack of regulatory authority. They showed that the level of tariffs charged by local utilities does not differ from the one accused by state utilities. However, when a local private utility is not regulated, the mean tax charged is higher. Moreover, the regime chosen by the regulatory agency does not impact the tariff charged. Thus, these results are in line with Araújo and Bertussi's (2018) conclusions.

Table 1 summarizes the relevant historical events concerning regulatory changes, in the Brazilian water sector.

Table 1 – Main historical events concerning the regulation of water services in Brazil

Year	Event
1934	Implementation of the "Código de Águas"
1970	Implementation of the PLANASA
1988	Promulgation of the Federal Constitution
2007	Sanitation regulatory framework

4. Regulatory Regimes

Liston (1993), Resende (1997), and Sappington (2002) provide a detailed summary of the literature on regulatory regimes, as well as their costs and benefits. As we mentioned earlier, there are two regulatory regimes: price-cap and cost-plus. However, between these two extremes, there is a range of schemes that the regulator can use. It depends on your objective: expansion of the service or efficiency in providing the service. What these reviews show is that the price-cap ends up being higher than the cost-plus.

On the other hand, for this difference to occur, Resende (1997) shows that the homogeneity of the efficiency factor X, which must be prospective, is quite relevant for the first regime to be superior to the second. Besides, Façanha and Resende (2004) show that the quality-of-service provision can be compromised in price-cap schemes. Furthermore, quality can also be affected when the regulated firm has an incentive to reduce its costs, just like Currier (2007a, 2007b) and De Fraja and Iozzi (2008) demonstrated.

According to Laffont and Tirole (1993), regulators will use utility's demand and accounting data to monitor its performance. The government will reimburse part of the firm's expenses C, and $b \in [0,1]$ will define the fraction of the reimbursement. The authors assume that the government pays the utility's cost, and also pays a net transfer t to the firm. This transfer has the following form:

$$t = a - bC \tag{56}$$

A "fixed fee" will be represented by a, and the government pays a fraction of $(1 - b)$ of the utility's cost. Furthermore, b will define the power of the scheme mechanism that is going to be used by the regulator. Two canonical schemes that can be implemented by the regulator. The first one is the cost-plus or rate-of-return, and it applied when $b = 0$. They say that it is a low-powered incentive because the utility does not bear any of its cost. Moreover, the price-cap scheme is considered a high-powered regime as it is implemented when $b = 1$. When it is adopted, the government does not have to pay the utility's cost, only a fixed fee.

Notice that Laffont and Tirole (1993), Resende (1997), and Weisman (2019) show that there can be other schemes between the canonical ones presented before. Sometimes, regulators can mix regimes for several reasons. Resende and Façanha (2004) explored one of them is that service quality can be harmed by the price-cap regime, as the utility will focus on profit sacrificing service quality. Therefore, even if the price-cap is considered a high-powered regime, it is not a panacea and is far from a consensus in the literature.

In Brazil, the majority of the sanitation regulatory agencies started to apply these regimes after 2007, after the approval of the sanitation framework. The cost-plus scheme is used according to the following rule:

$$IRT = \frac{(VPA.IrA) + (VPB.IrB)}{RO} \tag{57}$$

Where IRT is the tariff readjustment index, VPA represents the non-administrative costs that are expanses with electricity, taxes, materials, and other exogenous expanses that cannot be affected by the utility. VPB represents the administrative costs, that include expanses with distribution, maintenance, workers, services, etc. IrA and IrB are indexes that will correct VPA, and VPB, respectively. The former is composed by the volume of produced water in t and $t-1$, and the latter is composed by an inflation index, such as the Consumer Price Index (IPCA)[3]. RO is the firm's operational revenue.

Another possible cost-plus regime can be applied according to the following rule:

$$IRT = T.(1 + \Delta IPCA) \tag{58}$$

Where the tariff T is adjusted by an inflation index of the last 12 months. Notice that these rules are simple and are similar to the one presented in Resende (1997).

The regulator can apply another type of cost-plus and follow the discounted cash flow (DSF) formula. This scheme aims to assure that the utility will have a return over its capital stock. Therefore, the tariff defined will make the operation profitable.

The regulators consider more sophisticated rules as a price-cap regime that is implemented according to the following rule:

$$P_t = (1 + \Delta IPCA - X).P_{t-1} - FAQ_t \tag{59}$$

Where P_t is the maximum tariff that can be charged, $\Delta IPCA$ is the inflation index of the last 12 months, X is the efficiency factor, and FAQ is the quality factor. Notice that a mix between the rules can also be applied. When it happens, scheme (58) is adopted by the regulator, but the factor X is subtracted be the IrB.

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[3] The IPCA is one of the main inflation indexes in Brazil.

$$IRT = \frac{(VPA.IrA) + [VPB.(IrB - X)]}{RO} \qquad (60)$$

Equation (59) is closer to the canonical price-cap regime presented in Laffont and Tirole (1993), but, as (57) can also incorporate the efficiency factor, another possible price-cap scheme is possible. Equation (60) represents this regime.

Therefore, regulatory agencies in Brazil can adopt at least five schemes closer to the cost-plus or price-cap. Rules (57), (58), and the DSF are closer to the cost-plus, as they do not have an efficiency factor. On the other hand, (59) and (60) are closer to the price-cap, because they incorporate the efficiency factor. Table 2 summarizes all the regimes adopted by the state regulatory agencies in 20 Brazilian states between 2007 and 2019.

5. Econometric Analysis and Results

5.1 – Institutional background

State water utilities operate in municipalities from a given state. Therefore, the São Paulo State Basic Sanitation Company (Sabesp) (that belongs to the state of São Paulo government), will operate in most of the municipalities from this state. If some cities decide to have their own sanitation company our come together to create a small regional utility that will run in more than one municipality.

Each state water utility regulation is made by a state agency that faces both adverse selection and moral hazard problems. The first one happens because the regulator cannot observe if the utility hired by a municipality is the best for the assignment. On the other hand, the second occurs because the regulator cannot monitor properly if the utility provides the best service with the highest level of effort.

Thus, the regulator will design a contract to mitigate these problems and choose one of the regulatory schemes between the price-cap and the cost-plus. Notice that the former is considered the best scheme to deal with informational issues, while the latter is not. In Brazil, regulatory agencies apply several regulatory schemes closer to price-cap, cost-plus, or even a mix between both regimes. Table 2 summarizes the rules adopted by each 20 state regulatory agencies.

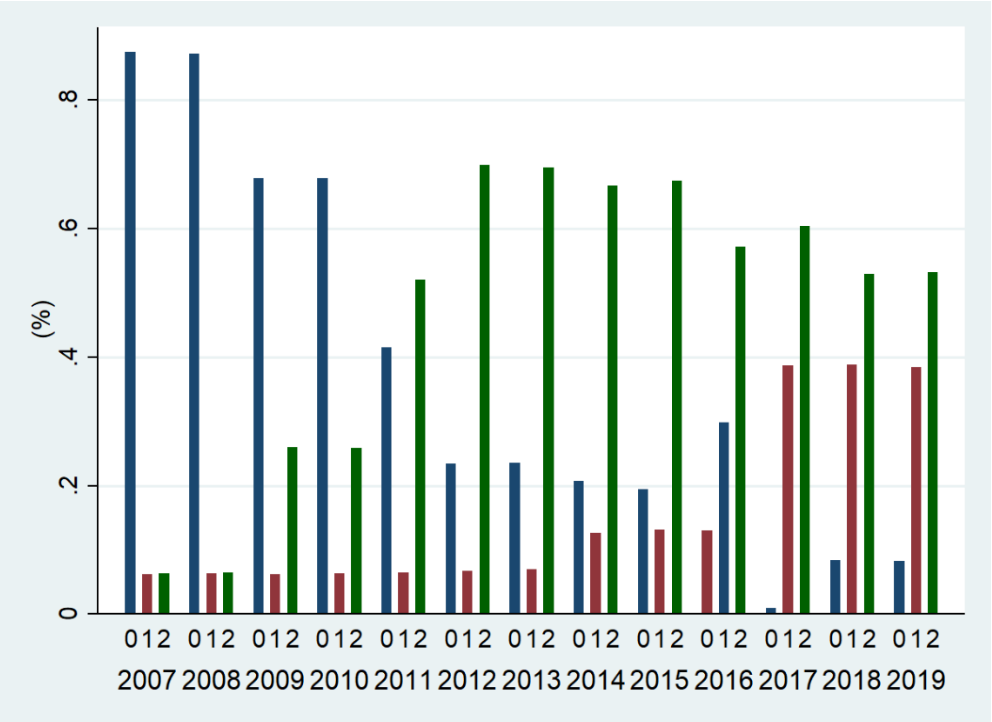
Notice that there is a variance in the regimes adopted. The regulatory agency from São Paulo, for example, started adopting a kind of cost-plus, but adopted a type of price-cap, that is similar to the canonical case in 2014. On the other hand, some agencies did not start to regulate state utilities yet, as is the point of Amapá and Roraima. Finally, most states use some cost-plus regime.

Figure 1 summarizes the evolution of water utilities' regimes over the years, and the unit analyzed is the municipality where a given water utility was operating. Three regulatory regimes were considered: no regulatory regime (0), price-cap (1), and cost-plus (2). Notice that the year when the 2007 Regulatory Framework was approved, most of the utilities were not regulated. It changed after 2009 when the states' regulatory agencies started to adopt the cost-plus. In fact, in 2012, most of the firms were held under this scheme.

Until today, the most popular regulatory regime is the cost-plus. Nevertheless, in 2017, the proportion of firms regulated under the price-cap increased. It represents almost 40 %

of the municipalities in our sample. In addition, the number of unregulated companies is less than 10 %.

Figure 1 – Evolution of the regulatory regimes



This table shows the proportion of municipalities where each water utility operates, according to the following regulatory regimes: no regulatory scheme (0), price-cap (1), and cost-plus (2), between 2007 and 2019. In Brazil, the state utilities operate in most municipalities, and the state regulatory agency defines the regulatory scheme. However, cities are not obligated to buy water from a state firm. They can have their utility or make a group of municipalities and make their water enterprise. In this case, I used only cities supplied by state firms.

5.2 – Data

The National Sanitation Information System (SNIS) is a public data set managed by the Ministry of Regional Development (MRD) and contains detailed information about the utilities' operation in a municipality, by year. As a water utility can operate in several municipalities, the SNIS provides information by the city, especially if the company belongs to a state. Therefore, I created a panel where one can observe operational pieces from the states' companies. In addition, the SNIS provides a list of codes to facilitate the identification of variables. Table 2 summarizes them.

Following Dalen and Gomez-Lobo (1996), I obtained data about labor expenditure and the total number of employees. Thus, I could calculate the cost of labor. Moreover, I estimated the cost of materials using the total expenses with chemical products and the number of samples used to measure quality. According to the SNIS, this information is relevant because utilities periodically measure the water quality by analyzing its turbidity, chlorine, and fecal coliforms concentration. I also used information about the volume of water produced and consumed.

It is also possible to know the incidence of non-standard samples and the total number of samples of turbidity, fecal coliforms, and chlorine analyzed by the utility and this information will be used as a quality variable. Tariff level, service outages, service interruption, complaints, maintenance performed, quality ordinance attendance[4], and the volume of treated, lost, and fluoridated water will also be used as service quality variables.

When one wishes to estimate a cost function for utilities, it is recommended to have a cost of the capital measure. However, it is not trivial to obtain such information (especially when dealing with developing countries' data). The same happens to Brazil because the SNIS does not have estimates on the capital stock or cost of capital. Let us summarize the discussion about this issue in the literature.

Wolak (1994) provides three measures of return to capital. The first measure consists of taking the district's balance sheet capital stock and subtracts the ending balance of the sum of all its accumulated depreciation to date. Then, multiply that period's rate of return on capital by this capital stock measure. After that, one has to add the utility's operational expenses to yield the utility's total cost for that period. The second measure is obtained by taking the difference of the ending accumulated depreciation and the beginning accumulated depreciation plus current investment expenditures.

Finally, the third measure is based on Pakes and Griliches (1984) that take the linear combination of the beginning and ending capital stocks—beginning and ending accumulated depreciation stocks, which best explains total revenues less total operating expenses. Presumably, the difference between total revenues and total operational costs is the return to capital. Notice that Wolak (1994) already has a measure of the capital stock and calculates its return according to the California Public Utilities Commission (CPUC) information.

Nevertheless, other authors could not have precise capital stock measures and, thus, the return on capital. It is the case of Estache and Rossi (2002), Garcia and Thomas (2003),

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[4] Regarding water quality, it allows knowing the type of service to Ordinance No. 2.914/2011 of the Ministry of Health, questioning whether the service provider serves it (fully, partially or not), what is the number of analyzed samples, minimum mandatory or with non-standard results for residual chlorine, turbidity and total coliforms.

and Nauges and Berg (2008). In the first work, to deal with the lack of information about capital stock, they estimated an arbitrary cost function for water utilities in Asia without including a variable for the price of capital. Furthermore, the last two used the extension of the water network length to estimate a cost function for the French water utilities and compare water and sewage utilities from Brazil, Moldova, Romania, and Vietnam.

Moreover, the user cost methodology was also not possible. It would be necessary to measure the municipality's capital stock of water plants, and the SNIS does not provide it. In addition, the inexistence of detailed information about all utilities' bonds makes this strategy unplayable to this case. On the other hand, Farsi and Filippini (2009) that, just like Friedlaender and Chiang (1983), used the residual method to obtain the cost of capital, the company's total cost net of labor expenditures and purchases of electricity and natural gas.

Therefore, the capital stock variable is the extension of the water network, and the cost of capital is the company's total costs net of labor, materials, and energy expenditures. I used the energy price as an input, so, using the data provided by SNIS, I calculated it by dividing the total energy expenses by the total energy consumption.

To know which regulatory regime was being applied in a given year and municipality, I analyzed several state regulatory agencies' technical notes. The scheme will be considered a cost-plus type when the regulatory agency applies a simple tariff rule that replaces the tariff level by the main inflation index used in Brazil: IPCA. On the other hand, some agencies started to adopt the price cap regime and, when it is explicitly introduced, the rule will be considered price-cap[5].

The Superior Electoral Court (TSE) provides data about elections since 1945. Nevertheless, information on mayoral election results is only available since 1998. Thus, it is possible to know the party, number of votes, if the candidate won or not, etc. The Center for Public Sector Policy and Economics from the Getúlio Vargas Foundation (CEPESP/FGV) organized this data set in a friendly way, and I extracted information about if the municipality’s mayor belongs to the same party as the governor from it, like Kresch and Schneider (2020) did. I also obtained data about GDP per capita and population from the SNIS, and I used them to calculate the GDP per capita.

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[5] For more information about the regulatory regimes, please check table 2.

Finally, I obtained data about the land gradient through Brazilian Agricultural Research Corporation (EMBRAPA), which provides raster files with relief data for the entire national territory. I combined these files with building a raster file containing the relief information for each Brazilian state. I combined this file with a shapefile of municipalities for each state to make a local measure of the mean gradient measured in degrees. Table 3 summarizes the variables and descriptive statistics.

Table 4 shows the mean value of the outcomes used in the following section by the regulatory regime. Notice that firms operating under the price-cap scheme have a lower level of cost when compared to those that serve under the cost-plus. The same happens to the incidence of fecal coliforms samples out of the standard, the volume of lost water, and the tariff charged. Maintenances, complaints, outages, and interruptions are also smaller when water utilities are under a price-cap regime.

On the other hand, it is possible to see that the incidence of turbidity and chlorine samples out of the standard are higher when firms are under the price-cap regime. In addition, the volume of treated and fluoridated water is also higher among water utilities that are under the cost-plus scheme. Therefore, we have some clues that the regulatory regimes impact the outcomes used in this dissertation.

Table 4 – Outcomes' means by regime

Variable	Price-cap	Cost-plus
Total cost (R$)	1524134.68	2312477.82
Incidence of fecal coliforms samples out of the standard	1.95	3.45
Incidence of chlorine samples out of the standard	12.62	8.19
Incidence of turbidity samples out of the standard	147.35	138.29
Tariff (R$)	5.10	5.30
Complaints	1561.26	2247.37
Outages	2.02	5.47
Interruptions	2.60	62.41
Maintenance	1221.82	1781.95
Volume of treated water (1,000 m^3)	383.71	490
Volume of fluoridated water (1,000 m^3)	151.70	376.01
Volume of lost water (1,000 m^3)	187.25	233.93

This table shows the mean value of the outcomes used in the econometric analysis by the regulatory regime. I did it to check if there is a difference in the mean value when water utilities are under two regulatory schemes.

5.3 – Estimation

5.3.1 – Cobb-Douglas

Dalen and Gomez-Lobo (1996) estimate a cost function using a Cobb-Douglas function as a random-effects model using maximum-likelihood. Just like them, thus, I am going to estimate the following equation with random effects:

$$\ln\left(\frac{C_{imt}}{p_{imt}}\right) = \beta_0 + \beta_1 Regime_{imt} + \beta_2 \ln\left(\frac{w_{imt}}{p_{imt}}\right) + (\gamma - 1) lnp_{imt} + \beta_4 e_{imt} + \beta_5 lnK_{imt} + \beta_6 lnQ_{imt} + \theta_{imt} + \varepsilon_{imt} \tag{61}$$

C_{imt} is the total cost[6] of firm i portion, that is operating in municipality m, on year t. $Regime_{imt}$ [7]is a dummy that indicates the regime that the portion of firm i is under, in a municipality m, and in year t (price-cap $= 1$, cost-plus $= 0$). p_{imt} is the cost of samples used by the portion of firm i to treat and/or analyze the water supply. e_{imt} is cost of energy faced by the portion of firm i. K_{imt} and Q_{imt} are, respectively, the extension of water network, and the volume of water demanded by the portion of firm i. Finally, ε_{imt} is the idiosyncratic error.

Notice that, just like Dalen and Gomez-Lobo (1996,1997), homogeneity of degree one on the inputs was applied, and $\beta_3 = (\gamma - 1)$. Therefore, all the estimates obtained will have to be scaled by γ to obtain the right value of each parameter, and the value of τ. Let us assume that the efficiency parameter γ is independent and identically distributed to all firms and years in our samples. It implies that there is no persistence in the adverse selection parameter, from a year to another. The persistence will be captured by the parameter δ_m, that will be also independent, identically distributed, and not correlated to θ_{imt}. Notice that the estimation of θ consists in one the main problems of the structural estimation.

Dalen and Gomez-Lobo (1996,), on the other hand, follow a strategy similar to the one adopted by Wunsch (1994) and estimate θ by the distribution of error. As their data set had few observations, they were not able to apply a non-parametric test. To obtain the distribution of θ, the recommendations pointed by Hu (2017) and Lewbel (2019) will be used.

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[6] Sum of labor, energy, materials, and capital expenses.

[7] In this case, $Regime$ is similar to the variable b from the theoretical model. However, Dalen and Gomez-Lobo (1996,1997) assume that there are several regimes in the range $b \in [0,1]$. For simplification, let us work assuming that there are only two regulatory regimes.

Thus, by analyzing the distribution of ε_{imt} it is possible to obtain the estimates of θ, as we can see how the types changed over the years, and by regime adopted by the regulator. Furthermore, it is also possible to apply a non-parametric test to check if the distributions are statistically different from each other. Finally, the value of $\beta_2 = \beta_w$ will be estimated, and also the optimum level of effort by regulatory regime.

It is essential to point out, once again, that only utilities that run water services in a given municipality were considered. It is usual to find sanitation utilities operating both water and sewage services. Nevertheless, to follow the strategy designed by Wolak (1994) and Brocas et al. (2006), only state utilities that run the service of water distribution were used in the sample.

5.3.2 – Translog with quality controls

The majority of the Brazilian states have their public-owned sanitation utility that operates in multiple municipalities. The state regulatory agency also belongs to the state, but the political intervention suffered by the formers ends up reducing the agencies' regulatory power. Furthermore, Kresch and Schneider (2020) pointed out that political alliances are also relevant in this framework. According to them, mayors and governors that belong to the same political party coordinate to reduce municipal sanitation investments.

Estache et al. (2016) demonstrated that mayors and governors that belong to the same party could work together. The authors show that in municipalities where the mayor belongs to the same party as the governor, the commitment to water environmental protection is higher than in cities with no political alignment. Notice that there is an informational problem among the governor, which has to keep the river's water clean, and the mayor has control over the city's water treatment.

Gagnepain and Ivaldi (2017) show that political capture must be considered when issues related to regulation are being analyzed. Araújo and Bertussi (2018) give some clues about the political economy of the relation between the regulators and sewage utilities in Brazil. According to them, state sanitation companies are more powerful than the regulators and are always trying to keep the status quo created during the 1970 and 1980, mainly because the formers suffer from political intervention. Therefore, I should consider the political economy in the specification.

The works that make comparative assessments between regulatory regimes indicate the superiority of the price-cap scheme concerning regulation by cost-plus in terms of the incentive for productive efficiency as indicated, for example, in conceptual discussions in Liston (1993) and Resende (1997). That said, empirical studies seek to highlight these differences between regimes, especially for the telephone sector, as in Resende (1999, 2000). However, a possible side effect can emerge in terms of quality degradation.

Resende and Façanha (2005) demonstrated evidence in this regard in the context of the telephone sector in the United States. The concern with the quality of service in regulated sectors in Brazil has increased, although without a specific link with specific regulatory regimes, as indicated by Resende and Cardoso (2019) and Marinho and Resende (2019) in the context of electricity distribution. Such considerations, which extrapolate productive efficiency aspects, motivate complementary analyses in terms of estimates with reduced forms.

Danelo et al. (2021) show that it is essential to take water attributes of water distributed when estimating water utilities' cost function. These authors found that in percentage point increase in the incidence of turbidity samples out of the standard increased the cost of utilities by 0.11%. Moreover, Spady and Friedlaender (1978) find that when the firm's output is heterogeneous, the estimation of cost functions that do not take quality measures into account may lead to biased results. Thus, he estimates a translog hedonic cost function for the American trucking industry, taking several output characteristics into account. Applying this methodology to the water sector can seem counterintuitive, but the quality of the water supplied in each state or municipality can vary.

Furthermore, they show that some problems emerge if the econometrician chooses the specification used by Dalen and Gomez-Lobo (1996, 1997). The first one is biased estimates when simple homothetic production functions are used, like a Cobb-Douglas or CES. Furthermore, Dalen and Gomez-Lobo's (1996, 1997) exercise does not consider quality aspects. Notice that, as we are dealing with water supply, the quality of the water received by each municipality is relevant, as the product may not be homogeneous.

For example, inhabitants from multiple cities from the State of Rio de Janeiro have to drink water with geosmin. It is an organic compound produced by cyanobacteria that is present in places where there is organic matter due to pollution from domestic waste (sewage), agricultural fertilizers, and industrial effluents, discharged directly into rivers and lakes. The main river from where the Rio de Janeiro State Water and Sewage Company (CEDAE) draws water for some cities is polluted. It directly impacts the flavor and smell of the water supplied.

Thus, quality aspects will have to be used to obtain accurate estimates of (61). The controls used were: the total number of chlorine, turbidity and fecal coliforms samples analyzed, the share of the fluoridated water in a given municipality, the land gradient, outsourced services expenses, demand per connection of water, the utility revenue in a given city, and the tariff charged there.

I will estimate (61) as a translog function, that is, the functional form used by Garcia and Thomas (2003). According to Greene (2008), the translog cost function is considered a flexible functional formal and has been widely used in the literature. As it was pointed out by Arrow et al. (1961), the Cobb-Douglas function has a restriction that all elasticities of factor substitution must be equal to one, which does not happen in the translog specification.

Take $Y = f(x)$ as a production function, with a set of factor demands given by $x_i = x_i(Y, p)$. Therefore, the total cost of production will be given by:

$$C = \sum_{i=1}^{M} p_i x_i(Y, p) = C(Y, p) \tag{62}$$

If one assumes constant returns to scale, we have that $C = Yc(p)$ or:

$$\frac{C}{Y} = c(p) \tag{63}$$

Where $c(p)$ is the average cost-function. The cost-minimizing factor demand will be obtained by applying the Shephard's (1970) lemma. If $C(Y, p)$ yields the minimum total cost of a production function, then the cost-minimizing factor demands will be:

$$x_i^* = \frac{\partial C(Y, p)}{\partial p_i} = \frac{Y \partial c(p)}{\partial p_i} \tag{64}$$

If one passes the logarithm, and differentiate, we obtain he cost-minimizing factor cost-shares:

$$s_i = \frac{\partial lnc(p)}{\partial lnp_i} = \frac{p_i x_i}{C} \tag{65}$$

Constant returns to scale imply that $lnC(Y, p) = logY + logc(p)$, and the shares will be:

$$s_i = \frac{\partial lnc(p)}{\partial lnp_i} \tag{66}$$

By expanding the cost function $\log c\,(p)$ in a second-order Taylor series about the point where $\log p = 0$:

$$\ln c\,(p) \approx \beta_0 + \sum_{i=1}^{M} \left(\frac{\partial \ln c}{\partial \ln p_i}\right) \log p_i + \frac{1}{2} \sum_{i=1}^{M} \sum_{j=1}^{M} \left(\frac{\partial^2 \ln c}{\partial \ln p_i\, \partial \ln p_j}\right) \ln p_i \ln p_j \tag{67}$$

All the derivatives are evaluated at the expansion point. If one interprets them as coefficients and impose the symmetry of the cross-price derivatives, we can rewrite the former cost function as:

$$\ln c = \beta_0 + \beta_1 \ln p_1 + \beta_2 \ln p_2 + \cdots + \ \beta_M \ln p_M + \delta_{11} \left(\tfrac{1}{2} \ln^2 p_1\right) + \\ \delta_{12} \ln p_1 \ln p_2 + \delta_{22} \left(\tfrac{1}{2} \ln^2 p_2\right) + \delta_{MM} \left(\tfrac{1}{2} \ln^2 p_M\right). \tag{68}$$

Notice that if $\delta_{if} = 0$, the function collapses to a Cobb-Douglas specification. The shares will be given by:

$$s_1 = \frac{\partial lnc}{\partial lnp_1} = \beta_1 + \delta_{11} \ln p_1 + \delta_{12} \ln p_2 + \cdots + \delta_{1M} \ln p_M \tag{69}$$

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$$s_M = \frac{\partial lnc}{\partial lnp_M} = \beta_M + \delta_{1M} \ln p_1 + \delta_{2M} \ln p_2 + \cdots + \delta_{MM} \ln p_M \tag{70}$$

In order to sum one, we need that $\beta_1 + \beta_2 + \cdots + \beta_M = 1$. The following restrictions are necessary to make the model operational: $\sum_{i=1}^{M} \delta_{ij} = 0$ (column sums equal zero), and $\sum_{j=1}^{M} \delta_{ij} = 0$ (row sums equal zero). It is important to point out that this function has to follow the form provided by Dalen and Gomez-Lobo (1996,1997) too.

Departing from a cost function similar to (41), where ${e'}_{it}$ is the price of energy faced by the portion of utility i, operating at the municipality m, in the year t, we have that:

$$\begin{aligned} C_{imt} &= \beta(Z_{imt})\widetilde{w}_{imt}{}^{\beta} p_{imt}{}^{\beta_p} {e'}_{imt}{}^{\beta_{e'}} K_{imt}{}^{\beta_K} Q_{imt}{}^{\beta_Q} \\ &= \beta(Z_{imt}) w_{imt}{}^{\beta_w}[\beta_w \exp\,(\theta_{imt} \\ &\quad - e_{imt})] p_{imt}{}^{\beta_p} {e'}_{imt}{}^{\beta_{e'}} K_{imt}{}^{\beta_K} Q_{imt}{}^{\beta_Q} \end{aligned} \tag{71}$$

This equation can be linearized, and we get:

$$\begin{aligned} \ln C_{imt} &= \beta(Z_{imt}, b_{imt}) + \beta_w \ln w_{imt} + \beta_p lnp_{imt} + \beta_{e'} ln{e'}_{imt} \\ &\quad + \beta_K lnK_{imt} + \beta_Q lnQ_{imt} + \beta_w \theta_{imt} + \beta_w(\theta_{imt} - e_{imt}) \end{aligned} \tag{72}$$

Moreover, it is possible to write it as a translog cost function:

$$\begin{aligned} &\ln C_{imt} \\ &= \beta(Z_{imt}, b_{imt}) + \beta_w \ln w_{imt} + \beta_p lnp_{imt} + \beta_{e'} ln{e'}_{imt} \\ &+ \beta_K lnK_{imt} + \beta_Q lnQ_{imt} \\ &+ \frac{1}{2}\beta_{ww} \ln(w_{imt})^2 \\ &+ \frac{1}{2}\beta_{pp} \ln(p_{imt})^2 + \frac{1}{2}\beta_{e'e'} \ln\,({e'}_{imt})^2 + \frac{1}{2}\beta_{KK} \ln(K_{imt})^2 \\ &+ \frac{1}{2}\beta_{QQ} \ln(Q_{imt})^2 + \beta_{wp} \ln w_{imt} lnp_{imt} + \beta_{wK} \ln w_{imt} lnK_{imt} \\ &+ \beta_{wQ} \ln w_{imt} lnQ_{imt} + \beta_{we'} \ln w_{imt} ln{e'}_{imt} + \\ &+ \beta_{pK} \ln p_{imt} lnK_{imt} \\ &+ \beta_{pQ} \ln p_{imt} lnQ_{imt} + \beta_{pe'} \ln p_{imt} ln{e'}_{imt} \\ &+ \beta_{e'K}\, ln{e'}_{imt} lnK_{imt} + \beta_{e'Q}\, ln{e'}_{it} lnQ_{imt} + \beta_{KQ} \ln K_{imt} lnQ_{imt} \\ &+ \theta_{imt} + \beta_w(\theta_{imt} - e_{imt}) \end{aligned} \tag{73}$$

Substituting the optimum level of effort, just like we did in (50), we have that:

$$
\begin{aligned}
&\ln C_{imt} \qquad (74)\\
&= \beta(Z_{imt}, b_{imt}) + \beta_w \, \gamma \ln w_{imt} + \beta_p \gamma lnp_{imt}\\
&+ \beta_{e'} \gamma lne'_{imt} + \beta_K \gamma lnK_{imt} + \beta_Q \gamma lnQ_{imt}\\
&+ \frac{1}{2} \beta_{ww} \gamma \ln(w_{imt})^2\\
&+ \frac{1}{2} \beta_{pp} \, \gamma \ln(p_{imt})^2 + \frac{1}{2} \beta_{e'} \ln \, (e'_{imt})^2\\
&+ \frac{1}{2} \beta_{KK} \gamma \ln(K_{imt})^2 + \frac{1}{2} \beta_{QQ} \gamma \ln(Q_{imt})^2\\
&+ \beta_{wp} \gamma \ln w_{it} lnp_{imt} + \beta_{wK} \gamma \ln w_{imt} lnK_{imt}\\
&+ \beta_{wQ} \gamma \ln w_{imt} lnQ_{imt} + \beta_{we'} \, \gamma \ln w_{imt} lne'_{imt} +\\
&+ \beta_{pK} \, \gamma \ln p_{imt} lnK_{imt}\\
&+ \beta_{pQ} \gamma \ln p_{imt} lnQ_{imt} + \beta_{pe'} \, \gamma \ln p_{imt} lne'_{imt}\\
&+ \beta_{KQ} \gamma \ln K_{imt} lnQ_{imt}\\
&+ \beta_{e'K} \gamma \, lne'_{imt} lnK_{imt} + \beta_{e'Q} \, \gamma lne'_{imt} lnQ_{imt} + \gamma \theta_{imt}
\end{aligned}
$$

Imposing homogeneity for input prices on the cost function ($\beta_w + \beta_p + \beta_{e'} = 1$), we obtain:

$$
\begin{aligned}
&\ln\left(\frac{C_{imt}}{p_{imt}}\right) \\
&= \beta(Z_{it}, b_i) + \beta_w\,\gamma\ln\left(\frac{w_{imt}}{p_{imt}}\right) + \beta_p(\gamma-1)lnp_{imt} \\
&+ \beta_{e'}\ln\left(\frac{e'_{it}}{p_{imt}}\right) + \beta_K\gamma lnK_{imt} + \beta_Q\gamma lnQ_{imt} \\
&+ \frac{1}{2}\beta_{ww}\gamma\ln\left(\frac{w_{imt}}{p_{imt}}\right)^2 \\
&+ \frac{1}{2}\beta_{pp}\,(\gamma-1)\ln(p_{imt})^2 + \frac{1}{2}\beta_{e'e'}\ln\left(\frac{e'_{imt}}{p_{imt}}\right)^2 \\
&+ \frac{1}{2}\beta_{KK}\gamma\ln(K_{imt})^2 + \frac{1}{2}\beta_{QQ}\gamma\ln(Q_{imt})^2 \\
&+ \beta_{wp}(\gamma-1)\ln w_{imt}lnp_{imt} + \beta_{wK}\gamma\ln\left(\frac{w_{imt}}{p_{imt}}\right)lnK_{imt} \\
&+ \beta_{wQ}\gamma\ln\left(\frac{w_{imt}}{p_{imt}}\right)lnQ_{imt} + \beta_{we'}\,\gamma\ln\left(\frac{w_{imt}}{p_{imt}}\right)ln\left(\frac{e'_{it}}{p_{imt}}\right) + \\
&+ \beta_{pK}\,(\gamma-1)\ln p_{imt}lnK_{imt} + \beta_{pQ}(\gamma \\
&- 1)\ln p_{imt}lnQ_{imt} + \beta_{pe'}\,(\gamma-1)\ln p_{it}lne'_{imt} \\
&+ \beta_{KQ}\gamma\ln K_{imt}lnQ_{imt} \\
&+ \beta_{e'K}\gamma\,ln\left(\frac{e'_{it}}{p_{imt}}\right)lnK_{imt} + \beta_{e'Q}\,\gamma ln\left(\frac{e'_{it}}{p_{imt}}\right)lnQ_{imt} + \gamma\theta_{imt} \\
&+ \varepsilon_{imt}
\end{aligned}
\tag{75}
$$

According to Greene (2008), it is possible to increase efficiency in estimation using a seemingly unrelated regression equations (SUR) model. Considering possible correlations across the errors of the different equations allows improving the precision of the estimates using the corresponding generalized least squares strategy. Thus, to do it, through Shephard’s (1970) lemma, one has to estimate the share equations:

$$
\begin{aligned}
s_{e'} = \frac{\partial lnC}{\partial lne'} = \beta_{e'} + \beta_{e'e'}\gamma\ln\left(\frac{e'_{it}}{p_{imt}}\right) + \beta_{e'w}\gamma ln\left(\frac{w_{imt}}{p_{imt}}\right) + \beta_{e'Q}\gamma lnQ_{imt} \\
+ \beta_{e'K}\gamma lnK_{imt}
\end{aligned}
\tag{76}
$$

$$s_w = \frac{\partial lnC}{\partial lnw} = \beta_w + \beta_{we'}\gamma ln\left(\frac{e'_{it}}{p_{imt}}\right) + \beta_{ww}\gamma \ln\left(\frac{w_{imt}}{p_{imt}}\right) + \beta_{wQ}\gamma lnQ_{imt} + \beta_{wK}\gamma lnK_{imt} \tag{77}$$

$$s_K = \frac{\partial lnC}{\partial lnK} = \beta_K + \beta_{Ke'}\gamma ln\left(\frac{e'_{it}}{p_{imt}}\right) + \beta_{Kw}\gamma ln\left(\frac{w_{imt}}{p_{imt}}\right) + \beta_{KQ}\gamma lnQ_{imt} + \beta_{KK}\gamma \ln K_{imt} \tag{78}$$

I can use this system of equations to estimate (75). Nevertheless, to do it, the shares must sum to one. It is necessary to solve the singularity issue of the disturbance of the covariance matrix on the share equations. Therefore, we have to eliminate one of the share equations, and, in this case, the equation chosen was the share of the inputs (that is not represented in the system of equations).

This system of equations will be estimated using the Stata module XTSUR. It was designed to compute a Seemingly Unrelated Regression (SUR) with random effects, based on Biørn (2004). For an unbalanced panel, the approach consists of constructing a stepwise algorithm using Generalized Least Squares (GLS) and the Maximum Likelihood (ML) procedures. An exciting feature of this procedure is that it does not require a balanced panel, which is a restrictive assumption when working with panel data. Several observations may be lost to balance the panel. Thus, this STATA command integrates, for random effects situations, the regression system ML approach to balanced panel data with the single equation approach to unbalanced panel data, when the attrition or accretion is random.

5.3.3 – Quality and welfare

The considered estimation framework, analogous to Dalen and Gomez-Lobo (1996, 1997), allows flexible, functional forms like the translog. However, in terms of a Cobb-Douglas function, a simpler functional form will also be considered in the later estimations. The water distribution is characterized by non-negligible heterogeneity of the output across different utilities, and therefore additional controls for attributes about quality indicators may be pertinent.

In that sense, a complimentary analysis that relies in reduced forms may be relevant. Specifically, the impact of regulatory regimes on service quality and welfare variables can also be tested with the data I collected. Thus, the following equation will be estimated:

$$lnY_{imt} = \beta_0 + \beta_1 Regime_{imt} + X'_{imt}\beta + \eta_m + \mu_t + \varepsilon_{imt} \tag{79}$$

Where Y_{imt} can be the incidence of fecal coliforms, chlorine, turbidity samples out of the standard, tariff charged, complaints, outages, service interruptions, maintenance, volume of treated, fluoridated, and lost water of firm i portion, that is operating in municipality m, on year t. $Regime_{imt}$ is a dummy that indicates the regime that the portion of firm i is under, in a municipality m, and in year t (price-cap $= 1$, cost-plus $= 0$).

As controls, we have the population, Gini index, and the Gross Domestic Product (GDP) per capita in the municipality m, and year i, where the portion o firm i is operating. Furthermore, we have got the extension of the water network, price of samples, and the water utility investment in the municipality m, and year i, where the portion o firm i is operating.

Following Angrist and Pischke (2008), to control for unobservable characteristics in the municipality where the portion of firm i is operating, municipality and time fixed effects were used. Thus, η_m is the municipality fixed effect, and μ_t is the time fixed-effect. Finally, ε_{imt} is the idiosyncratic error.

5.4 – Results

5.4.1 – Cobb-Douglas

Table 5 shows the results of regression (61), and we can see those utilities operating under any price-cap regime have a cost lower than those operating under the cost-plus scheme. Firms operating under the price-cap rule have a level of cost 1.72% smaller than those working under the cost-plus regime.

Table 5 – Cobb Douglas specification

	Log(Cost)
Price-cap	-0.0174^{***}
	(0.00452)
Log(price of labor)	0.178^{***}
	(0.00292)
$(\gamma - 1)$	-0.763^{***}
	(0.00384)

Log(price of energy)	0.0393^{***} (0.00229)
Log(network extension)	0.378^{***} (0.00294)
Log(water consumed)	0.113^{***} (0.0207)
Log(water consumed)^2	0.0218^{***} (0.00187)
Constant	5.750^{***} (0.0705)
Random-effects	X
N	15898

This table shows the results of regression (61), which is similar to the one estimated by Dalen and Gomez-Lobo (1996). In this specification, it is possible to see that the price-cap regime is associated with a higher level of cost when compared to the cost-plus. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Wages, energy price, capital expenses, and the volume of water consumed positively impact cost, and the results obtained are statistically significant. In addition, like Dalen and Gomez-Lobo (1996,1997) demonstrated, the value of $(\gamma - 1)$ cannot be bigger than zero, because $\gamma \leq 1$. The results for this parameter followed their conclusion, as the point estimation obtained for $(\gamma - 1)$ was -0.763. It is also possible to check if the utilities from our samples face economies of diseconomies to scale. I calculated it, according to Mckay (1988) by $\mathrm{SCE} \equiv 1 - \frac{\partial \mathrm{C}}{\partial \mathrm{Q}} = 0.88$, and we can conclude that they face economies to scale.

It is necessary, however, to follow the conclusions from equation (61) to analyze their real impact on utilities' costs, nevertheless, and we need the value of γ to get the right estimates for $\beta_w\gamma$, $\beta_e\gamma$, $\beta_K\gamma$, $\beta_Q\gamma$, and τ. Table 6 summarizes these results.

Table 6 – Scaled parameters

$(\gamma - 1)$	γ	$\beta_w\gamma$	$\beta_e\gamma$	$\beta_K\gamma$	$\beta_Q\gamma$	τ
-0.76	0.24	0.74	1.63	1.57	0.47	0,97

This table shows the scaled values of the parameters estimated in equation (61). It follows the procedure developed by Dalen and Gomez-Lobo (1996, 1997). It is possible to see that if one considers a model without asymmetric information, the value of the parameters will be underestimated. After the corrections, the coefficients of the parameters were increased. Moreover, results show that utilities face economies of scale, as the value of the parameter of the water produced is positively related to cost level.

After the corrections, it is possible to notice an increase in the value of the coefficients. We correct the bias pointed out by Wolak (1994) and Dalen and Gomez-Lobo (1996,1997) by scaling the parameters. The correction of the SCE shows that economies to scale are lower (0.53), which means that, without the corrections, one is overestimating it.

According to Wolak (1994), economies of scale would be overestimated in regulated industries as the regulator, in his model, offers an optimal contract to the companies. Thus, the price schedule of this optimal contract will be monotonically increasing in the utility type θ, and the quantity produced will be correlated with the error term producing the upward bias.

On the other hand, Dalen and Gomez-Lobo (1996,1997) explain that this upward bias happens because the impact on costs of a rise in input prices or output level will be mitigated by an increase in the effort. Therefore, firms with a higher output will have more incentives to increase effort than firms with a smaller production, which is an implication of the “Arrow effect”.

From (45) it is possible to obtain the optimal level of effort by regime and firm. Thus, we will multiply the value of the coefficient β_w by the mean cost of the utility operating in a given regime, and check what is the participation of the level of effort in the companies’ revenue. Table 7 summarizes the optimum level of effort by firm and regime.

Notice that some companies did not transition between regimes, or our dataset did not have information about its costs and revenues, so we cannot compare all the utilities. On average, the optimum level of effort in the companies’ revenue is higher under the price-cap regime. The participation of the level of effort in the utilities’ revenue that operates under the price-cap is 4 p.p higher than those operating under the cost-plus.

On the other hand, when analyzing the transitions to the price-cap, only CAERD, and CONAPOR demonstrated a higher level of effort. The change from the cost-plus increased the optimum level of effort of the former by 52 p.p and by 1 p.p the latter's level. CASAN, COMPESA, COPASA, and SABESP's respectively level of effort decreased 11, 8, 9, and 27 p.p. Even if the price-cap yields a higher level of effort on average and is associated with a lower level of cost, the transition to this regime did not increase water utilities' effort.

One would expect that a change from a cost-plus to a price cap led to an increase in the optimal level of effort as a percentage of the utility’s revenue. A possible explanation for it is that the regulatory routine of the agencies could not go along with the regulatory change, and, thus, regulated firms did not increase their optimum level of effort. Another possible reason is that; sometimes, the regulator can be captured as the agencies, according to Araújo and Bertussi (2018), still do not have proper tools (financial and human resources) to regulate the utilities. Nevertheless, on average, the price-cap is still associated with a higher level of effort.

To analyze the distribution of θ, an analysis of the residuals has to be done. This strategy is pointed out by Wunsch (1994), Dalen and Gomez-Lobo (1996), and Hu (2017), and it can be useful for us in this kind of model. In figure 2, I plotted the distribution of the thetas and it is possible to see that it fitted a normal distribution curve. Using the procedure developed by Kaplan (2019) with the Stata module distcomp, it is possible to compare the distributions according to the regime adopted and years. Therefore, one can check if these distributions, controlling for the characteristics motioned before, are statistically different from each other.

According to Kaplan (2019), this command is based on Goldman and Kaplan (2018) and its usage is similar to a two-sample t test or a two-sample Kolmogorov–Smirnov (KS) test. Respectively, they compare the distribution means and a single hypothesis of distributional equality. Nevertheless, the distcomp tests the equality of the distributions point by point. Thus, it goes beyond a refection or nonrejection of a hypothesis and displays ranges of values in which the distribution's difference is statistically significant. Like the KS test, it shows the goodness-of-fit (GOF) and controls for false positives. Furthermore, this new method is sensitive to deviations as it is more evenly spread across the distribution.

The command takes one variable, such as a utility's total cost. It separates it into two groups (for example, utilities that operate under the price-cap regime and the cost-plus) with a value of 0 and 1. Sampling is assumed independent and identically distributed from these two respective group population distributions, and it is assumed that they are sampled independently. Moreover, the value of interest is considered to have a continuous distribution.

Its first result is the GOF, that is the same type of test as the KS test. Therefore, the null hypothesis is that the two CDFs are identical, and they are reported at the 1, 5, and 10% level. Furthermore, a p-value is also reported. The second result focus on the multiple test procedure, and it displays ranges of value for which the difference between CDFs is statistically significant, accounting for the multiple testing nature of the procedure.

Remember that this procedure evaluates the distributions by point. Thus, if we have two CDFs' distributions $F(.)$ and $G(.)$, then each individual null hypothesis is $H_{0x}: F(x) =$

$G(x)$, and the set of such hypothesis for all the values of x are taken into account. Following Goldman and Kaplan (2018), as a result, we obtain the ranges of x, where $H_{0x}: F(x) = G(x)$ is rejected along with a plot with the empirical CDFs of the two groups and with the rejection ranges (if they exist).

It is also possible to check if there was a change in the θ by the years. Thus, with Kaplan's (2019) procedure, we compared if the distribution of θ in 2007 is equal to the distribution of θ in 2008, 2009, etc. Table 8 summarizes the results. Notice that it is not possible to reject the hypothesis that the distribution of θ in 2007 is statistically different from its distribution in 2008 and 2009, in almost all levels of significance. After that, the distribution of θ is always different from the one observed in 2007. Furthermore, the test was done to check if the distribution of θ is the same between regimes, and I could reject this hypothesis at all significance levels.

Thus, we can conclude two things in the analysis of the residuals. The first one is a difference between firms operating under any cost-plus and price-cap regime. The second one is that the types changed over the years. As said before, after 2007, the Regulatory Framework for sanitation altered, and most of the states' regulatory agencies started to adopt some incentive scheme. However, notice that these results face some limitations. I was able to show that the companies are changing over time and according to different regimes. Nevertheless, one cannot assume that the best company took the contract designed by it or that the asymmetric information was reduced.

Figure 1 shows that the majority of the water utilities were operating under some cost-plus regime. Still, the evidence obtained here indicates that the minority, serving under any price-cap, is doing better regarding the level of cost. Furthermore, on average, the optimum level of effort seems to be yielded by the price-cap regime. Nevertheless, companies that changed from the cost-plus to the price-cap ended up reducing their optimum level of effort, even if this regime is associated with a lower level of cost.

5.4.2 – Translog with quality controls

According to Dalen and Gomez-Lobo (1997), their model is flexible and can be applied to other functional forms. Results obtained in structural estimations can vary according to the functional form used by the econometrician, so that I will estimate the translog cost function from (75) using Nguyen's (2008) procedure.

Table 9 – Translog specification

	(1) Total cost	(2) Total cost	(3) Total cost
Price-cap	-	-0.0898*** (0.00189)	-0.126*** (0.00135)
Political ally	-	0.0164*** (0.00047)	0.0190*** (0.00085)
β_Q	0.112*** (0.0145)	0.0663*** (0.0142)	2.425*** (0.0356)
$\beta_{e'}$	0.386*** (0.00955)	0.163*** (0.00281)	0.373*** (0.0232)
β_w	1.694*** (0.00504)	1.688*** (0.00463)	0.627*** (0.0102)
β_K	0.253*** (0.0133)	0.228*** (0.0132)	0.817*** (0.0275)
$(\gamma-1)\beta_p$	1.020*** (0.0119)	0.871*** (0.00469)	-0.498*** (0.0284)
β_{QQ}	-0.143*** (0.00113)	-0.0960*** (0.00114)	-0.0653*** (0.00286)
$\beta_{e'e'}$	-0.0239*** (0.000158)	-0.0201*** (0.000139)	-0.00847*** (0.000404)
β_{ww}	-0.148*** (0.000816)	-0.147*** (0.000752)	-0.0366*** (0.00158)
β_{KK}	-0.0986*** (0.000937)	-0.113*** (0.000977)	-0.116*** (0.00215)
$(\gamma-1)^2\beta_{pp}$	0.175*** (0.000823)	0.169*** (0.000762)	0.0465*** (0.00166)
$(\gamma-1)\beta_{pQ}$	0.0253*** (0.00128)	0.0387*** (0.00130)	0.0228*** (0.00292)
$\beta_{e'Q}$	-0.0325*** (0.000471)	0.000455 (0.000454)	-0.0144*** (0.00119)
β_{wQ}	0.0624*** (0.00118)	0.0526*** (0.00117)	0.0329*** (0.00248)
β_{KQ}	0.166*** (0.000891)	0.148*** (0.000920)	0.138*** (0.00215)
$(\gamma-1)\beta_{pe'}$	-0.0369*** (0.000764)	-0.0258*** (0.000265)	-0.0354*** (0.00195)
$(\gamma-1)\beta_{wp}$	-0.140*** (0.000889)	-0.145*** (0.000851)	0.00862*** (0.00196)

$(\gamma - 1)\beta_{pK}$	-0.0118***	-0.00720***	-0.0712***
	(0.00115)	(0.00117)	(0.00261)
$\beta_{we'}$	-0.0300***	-0.0203***	-0.0308***
	(0.000767)	(0.000242)	(0.00183)
$\beta_{e'K}$	0.0338***	0.0160***	0.0178***
	(0.000405)	(0.000400)	(0.000976)
β_{wK}	-0.0544***	-0.0433***	-0.0881***
	(0.00109)	(0.00110)	(0.00230)
Chlorine samples	-	-	0.0200***
			(0.000525)
Turbidity samples	-	-	0.0360***
			(0.000343)
Fecal coliforms samples	-	-	0.0186***
			(0.000925)
Share of fluoridated water	-	-	0.0140***
			(0.000264)
Quality ordinance	-	-	-0.134***
			(0.000769)
Land gradient	-	-	0.0269***
			(0.000624)
Outsource expanses	-	-	0.115***
			(0.000670)
Demand per connection	-	-	-2.802***
			(0.0229)
Revenue	-	-	0.103***
			(0.00173)
Tariff	-	-	0.0169***
			(0.00181)
Energy share			
$\beta_{e'}$	-0.0674***	-0.0547***	-0.115***
	(0.000222)	(0.00131)	(0.000411)
β_Q	-0.0387***	-0.0361***	-0.0121***
	(0.000487)	(0.00380)	(0.000992)
β_w	0.0640***	0.0463***	0.114***
	(0.000225)	(0.00116)	(0.000306)
β_K	-0.0243***	-0.0301***	-0.0341***
	(0.000421)	(0.00368)	(0.00102)
Labor share			
$\beta_{e'}$	-0.0164***	-0.00809***	-0.0506***
	(0.00130)	(0.000388)	(0.00209)

β_Q	0.0291^{***}	0.00571^{***}	0.0496^{***}
	(0.00369)	(0.00111)	(0.00509)
β_w	0.0214^{***}	0.00916^{***}	0.0722^{***}
	(0.00116)	(0.000352)	(0.00155)
β_K	-0.0124^{***}	-0.00213^{*}	-0.0178^{***}
	(0.00345)	(0.00107)	(0.00521)
Capital share			
$\beta_{e'}$	-0.0274^{***}	-0.00859^{***}	-0.0532^{***}
	(0.000365)	(0.000137)	(0.000636)
β_Q	-0.00297^{**}	0.00428^{***}	0.0507^{***}
	(0.000964)	(0.000350)	(0.00155)
β_w	0.0348^{***}	0.0106^{***}	0.0732^{***}
	(0.000345)	(0.000138)	(0.000451)
β_K	-0.000165	-0.00857^{***}	-0.0300^{***}
	(0.000887)	(0.000302)	(0.00160)
Random-effects	X	X	X
Quality controls			X
N	15897	13997	8882

This table shows the results for the translog cost function. It was estimated using a SUR model with random effects following the procedure developed by Nguyen (2010) based on Biorn (2004). The incorporation of quality characteristics of the water supply based on Spady and Friedlaender (1978) and the political variable came from Kresch and Schneider (2020). Notice that the price-cap regime is associated with a lower level of cost when compared to the cost-plus. Moreover, political alliances are also relevant to explain the water utilities' level of cost. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Specification (1) shows the results for the translog cost function without any quality control, regulatory regime, or political alliance among the municipalities' mayor and the governor. The price of inputs and the measure of capital stock are positively associated to the total level of cost but, as the value of $(\gamma - 1)\beta_p$ is positive this result does not follow the hypothesis provided by Dalen and Gomez-Lobo (1996,1997). In the specification (2), I incorporated the regulatory and political dummies.

Results show that water utilities operating under any price-cap have a cost 8.58 % lower level than those working under any sort of cost-plus regime. Furthermore, when the mayor from a given municipality belongs to the same party as the governor, the portion of the utility operating in that local presents a level of cost 1.65% higher when compared to municipalities where there is no political alliance. Nevertheless, as the value of $(\gamma - 1)\beta_p$ is positive, this specification does not respect the theoretical assumptions.

Specification (3) is the preferred one. Controls concerning the quality of the service, water supplied to the municipalities, and other variables that may impact the utilities' cost were included. Notice that both the regulatory regime and political alliance coefficient increased by, respectively, 11.83% and -1.91%. The volume of water consumed, stock of capital, price of energy, and wage rate are associated with a higher level of cost. As the value of $(\gamma - 1)\beta_p$ is negative, which is line with the model's assumptions.

When it comes to economies of scale, some changes happened from the Cobb-Douglas specification. Notice that, in the specification (1) and (2), economies of scale have a value of 0.88 and 0.93, respectively. These values are close to what was found in the Cobb-Douglas specification. However, when one computes the economies of scale in specification (3), the value of the SCE is equal to -1.42, which means that this industry faces diseconomies of scale. This change is because specification (3) takes quality variables into account, and it does not happen in the other specifications.

Nevertheless, we need the value of γ to obtain the right estimates of $\beta_w\gamma$, $\beta_e\gamma$, $\beta_K\gamma$, $\beta_Q\gamma$, and τ, for specification (3). Table 10 summarizes these results.

Table 10 – Scaled parameters: Translog specification

$(\gamma - 1)$	γ	$\beta_w\gamma$	$\beta_{e'}\gamma$	$\beta_K\gamma$	$\beta_Q\gamma$	τ
-0.5	0.5	2.25	0.75	1.63	4.85	1.12

This table shows the results for the translog cost function. It follows the procedure developed by Dalen and Gomez-Lobo (1996, 1997), and it is possible to see that if one does consider a model without asymmetric information, the value of the parameters will be overestimated. Notice that, after the corrections, the values of the parameters were reduced.

This time, the value of $\gamma = 0.5$ was higher than in the Cobb-Douglas specification, which means that the reductions in the coefficients were higher. Another relevant result that was impacted by the corrections concerns the SCE. As its value changed for -3.85, it seems that water utilities face diseconomies of scale, which is different from the result without the parameters' corrections. Thus, economies of scale were overestimated without taking asymmetric information and quality controls into account.

Again, by scaling the parameters, we correct the bias pointed out by Wolak (1994) and Dalen and Gomez-Lobo (1996,1997). Furthermore, as Spady and Friedlaender (1978) demonstrated, homothetic specifications, such as the CES and the Cobb-Douglas functions, can lead to biased estimates, especially when one does not take product differentiation into account. Therefore, by correcting all these biases, we could better estimate how regulatory regimes impact utilities' level of cost.

It is essential to point out that this result is different from what has been obtained in other works. Nauges and Berg (2008) could not reject the null hypothesis of constant returns of scale for Brazilian sanitation utilities. Lucinda and Anuatti (2017) show that diseconomies of scale are extremely rare in the cities served by SABESP. However, these findings differ from ours as, in this dissertation, I only deal with water distribution, not water and sewer.

Let us calculate the optimal level of effort by the regime and utility using the same procedure from table 7. The results are summarized in table 11. The optimum level of effort's share of the revenue increased 99 p.p when the CAERD changed from a cost-plus to a price-cap regime. Another company that increased its optimal level of effort is the CONAPOR, and the change was 1 p.p. However, CASAN, COMPESA, COPASA, and SABESP reduce their optimum level of effort as a share of their revenue by 20, 15, 17, and 52 p.p respectively, after being regulated under the price-cap regime.

Let us analyze the residuals to check if θ changes between regimes, and over the years. Figure 2 shows the distribution of types for the translog specification, which follow a normal distribution. Comparing the distributions by regimes with the Kaplan's (2019) procedure, on can check that the distribution θ of firms operating under any kind of price-cap regime is statically different from that observed in firms operating under any cost-plus regime at 1, 5, and 10% of significance. Table 12 provides the results of the tests using 2007 as the base year. The results show that the distribution of types changed in 2008 but not in 2009. After that, the distribution of types was never the same again.

Therefore, compared to the results obtained in the Cobb-Douglas specification, the translog results seem more robust. However, some conclusions did not change when one reaches both models. The price-cap regime is associated with a smaller cost level, and the distribution of types over the years is not the same, just like the distribution between different regulatory schemes. Moreover, the price-cap regime, on average, yields a higher level of effort but most of the firms that were regulated under the cost-plus and then started to be regulated by a price-cap scheme ended up reducing their respectively optimum level of effort as share of the revenue. Finally, utilities seem to face diseconomies of scale.

Once again, notice that when it comes to the changes in the regulatory regimes from a type of cost-plus to a price-cap, and the distribution of the kinds over rule and year, our results face some limitations that were discussed in section 5.4.1.

5.4.3 – Quality and welfare

The following analysis focus on the impact of the regulatory regimes on the quality of the services provided by each utility welfare-related variables. Results from (79) are summarized in tables 13 and 14.

Analyzing table 13, we can conclude that firms operating under any price-cap have an incidence of non-standard fecal coliforms and turbidity, respectively, 63.94 and 18.86% smaller than those working under any cost-plus regime. Thus, we have evidence that the water quality supplied by firms operating under the price-cap is higher. Maintenances are also lower under the price-cap regime. Water utilities operating under this scheme have 24.87% fewer maintenances than those working under any cost-plus regime.

Costumers' complaints are 18.86% lower where firms operate under any price-cap regime, but this result is only significant at 5%. Furthermore, an exciting finding concerns the tariff charged because firms that operate under any type of price-cap set a tax 5.12% higher than those that work under any kind of cost-plus. This result, however, is only significant at 5%.

The evidence shows that firms operating under any type price-cap scheme treat 6.76 % less water than those that work under any kind of cost-plus when it comes to the volume of treated and fluoridated water. On the other hand, the volume of fluoridated water is 5.12 % higher when the water utility is under any type of price-cap regime. Notice, however, that these results are only significant at 10%.

Let us look now at table 14. Incidence of chlorine samples out of the standard, outages, interruptions, and the volume of water lost are not impacted by the regulatory regime, as the coefficients obtained were not statistically significant. Nevertheless, according to the results from table 13, we have evidence that the price-cap rule is associated with better quality indicators and a higher tariff level. All these results are in line with the theory.

It is worth mentioning that the result regarding the tariff level is different from what was found by Barbosa and Brusca (2015). They demonstrated that people's proximity to the utility dictates the tariff charged in Brazil, and local utilities charge a lower tariff than the regional ones. Notice that it does not invalidate any of the results provided here, and by Barbosa and Brusca (2015), as this dissertation only deals with state regulatory agencies and compares local and state utilities. Therefore, regulatory regimes may impact the tariff charged by the states' utility but, when compared one makes the comparison to the local firms, distance is a more prominent channel

6. Conclusion

The advances in regulatory literature during the 1980 and 1990s provided tools to economists to explain how natural monopolies can be regulated. Works like the ones produced by Baron and Myerson (1982) and Laffont and Tirole (1993) are seminal and contributed to theoretical and empirical works that were recently produced. Nevertheless, Schmalensee (1989) makes a relevant observation regarding these works. The strong assumptions, such as assuming a sophisticated regulator with the capacity to observe hidden information, and implement first-best contracts, make the optimal solutions proposed by them impartible in the actual regulatory routine.

In the empirical work, Wolak (1994), Garcia and Thomas (2003), and Brocas et al. (2006) applied the framework proposed by Baron and Myerson (1982) but notice that, even with exciting conclusions, the critic of Schmalensee (1989) can be applied to them. When it comes to empirical works that incorporated regulatory regimes, such as Dalen and Gomez-Lobo (1996, 1997), the main weakness is that their strategy is not as structural as the one proposed by Laffont and Tirole (1993), which can harm their results and conclusions.

Using a new dataset about regulatory regimes adopted by 20 Brazilian sanitation regulatory agencies and a structural model, a la Dalen and Gomez Lobo (1996, 1997), I estimated a cost function for water utilities that incorporates asymmetric information parameters. To improve the estimates obtained with a Cobb-Douglas specification, I followed Spady and Friedlaender (1978), Greene (2008), and Kresch (2020). Thus, a translog cost function was estimated incorporating moral hazard, adverse selection, political alliances, and quality indicators of the water supplied.

It is essential to point out that this strategy is different from what has been done so far. Most of the literature related to water provision in Brazil relies on comparisons between private and public utilities, using methods such as Stochastic Frontier (SF) and Data Envelopment Analysis (DEA) to measure efficiency and cost. Moreover, the impact of regulatory regimes was only explored by Barbosa and Brusca (2015), focusing on the tariff level, and Kresch (2020) and Kresch and Schneider (2020) focused on the impact of national regulatory reform and political alliances to study the behavior of investment level, and infant mortality rate. Those methods, however, do not account for asymmetric information problems, which are relevant to make a more accurate analysis as it was pointed out by Feinstein and Wolak (1991), Wolak (1994), Garcia and Thomas (2003), and Brocas et al. (2006).

The Cobb-Douglas specification showed that the price-cap regimes are related to a lower level of cost and that firms operating under any type of this regulatory scheme present a cost level 1.72% lower than those operating under any kind of cost-plus. Furthermore, the value of $\gamma = 0.24$ showed that a model that does not incorporate asymmetric information parameters underestimated the impact of the components on the level of cost, and utilities seem to face economies to scale. Moreover, economies of scale would be overestimated.

After incorporating the asymmetric information parameter, the value of the economies of scale fell from 0.88 to 0.53. This result is in line with the predictions of Dalen and Gomez-Lobo (1996, 1997), as economies of scale were overestimated. Moreover, the calculation of a firm's optimal level of effort as a share of its revenue showed that, on average, the price-cap regime yields a higher level of effort than the cost-plus regime. On the other hand, some firms that were operating under the latter and changed to the former reduced their level of effort.

The translog specification was much more interesting than the first one. I could show that firms operating under the price-cap regime have a level of cost 11.83 % lower than the utilities operating under the cost-plus regime. Notice that the magnitude of the impact of the regulatory regime changed dramatically from this specification to the latter. Furthermore, the value of $\gamma = 0.5$ showed that a model that does not account for moral hazard and adverse selection also overestimates the impact of the components on the level of cost, and utilities seem to face economies to scale. After incorporating the asymmetric information parameter, the value of SCE falls from -1.42 to -3.85. Thus, water utilities face diseconomies of scale. As one can see, without taking asymmetric information into account, economies of scale were overestimated.

The results from the translog specification are more accurate, because I followed the corrections provided by Spady and Friedlaender (1978). They demonstrated that homothetic specifications, such as the CES and the Cobb-Douglas functions, can lead to biased estimates, especially when one does not take product differentiation into account. I used several controls in the specification to account for differences in the water supplied and firms' characteristics (3).

As political alliances seem to be a relevant phenomenon to explain Brazil's water distribution, as demonstrated by Estache et al. (2016), and Kresch and Schneider (2020), I also controlled for political alliances among the municipality's mayors and states' governors. The evidence shows that, in cities where the mayor belongs to the same party as the governor, according to specification (3), the level of cost is 1.92% higher than in municipalities where there is no political alliance.

As our sample only contains state water utilities, the takeover hypothesis provided by Kresch (2020) and Kresch and Schneider (2020), cannot be applied to the results obtained in the specification (3). What is possible to know is that, somehow, the portion of state water utilities operating in municipalities where there is a political alliance are less cost-effective than those working in places where this alliance does not exist. Nevertheless, as demonstrated by Estache et al. (2016), coordination among different levels of government is usual when it comes to sanitation.

Both specifications provided pieces of evidence that the distribution of types under any type of price-cap or cost-plus regime is statistically different from each other. Moreover, the distribution of types changes from a year to another. This result is in line with the economic theory, as it was expected that the types change when different regulatory regimes are adopted. Furthermore, as the types changed over the years, it is possible to see that the regulatory effort done by the states' regulatory agencies is impacting the distribution of types and, thus, the adverse selection problem. On average, the price-cap regime yields a higher level of effort as a share of the utility's revenue. When a transition from the cost-plus to a price-cap happens, some companies reduce their optimal level of effort.

A limitation of these results concerns the regularity conditions. Resende (1997) demonstrated that cost functions should respect the following conditions: monotonicity, quasi-concavity in input prices, and non-negative marginal costs. Therefore, future research could focus on testing these properties to increase the robustness of the results obtained in the estimations. Furthermore, there can be an endogeneity problem regarding the regime chosen by the regulatory agency. Sometimes, it can be applied with the regulated utility participation, and changes in the schemes may not be decided willingly to mitigate informational problems. Another source of endogeneity is the quality control variables used in the translog specification, as the utility chooses, for example, the number of samples used to measure the quality of the water in a given municipality. Therefore, one could explore an exogenous shock to mitigate this problem.

When it comes to the impact of the regulatory regimes on quality indicators, compared to the cost-plus, the price-cap scheme reduces the incidence of non-standard fecal coliforms and turbidity, 63.94 and 18.86%, respectively. Moreover, maintenances are 24.87% lower under the price-cap regime. Costumers’ complaints are 18.86% lower where firms operate under any kind of price-cap regime, and they charge a tariff 5.12% higher than those that work under any type of cost-plus. On the other hand, the incidence of chlorine samples out of the standard, outages, interruptions, and the regulatory regime does not impact the volume of water lost.

Therefore, this dissertation contributes to the water utilities' regulation literature as it goes beyond the efficiency discussion and comparing private and public enterprises. Moreover, I demonstrated that the state's regulatory agencies adopt several regulatory regimes, and some of them rely on the canonical cases described by Laffont and Tirole (1993). It also explored several outcomes that can be impacted by the regulatory regimes and incorporated some advances provided in the literature that provided better estimations in the econometric exercises conducted.

The effort of mapping and differentiating the regulatory regimes adopted by each regulatory agency is one of the main contributions of this work. As far as I know, only Barbosa and Brusca (2015) did something closer to what was done here. Nevertheless, the level of detail in this dissertation is much more than what has been produced in the literature. A structural model, with share equations, was never applied to estimate cost functions in the works related to water distribution in Brazil, and not even in Wolak (1994) and Dalen and Gomez-Lobo (1996, 1997). Regularity conditions are also hardly tested in this literature.

More research, however, has to be done to know the precise impact of the regulatory regimes on the outcomes explored in this dissertation. One of the main limitations of this study was to consider only two regulatory schemes, but I was able to map five. In addition, notice that I only used utilities operating the water service in a given municipality to keep consistent with the literature. The regulatory routine of the agencies is still a black box, furthermore. Possible captures, the lack of the financial and human resources to regulate sanitation utilities and apply proper regulatory regimes are only some points that dimmish the power of the regulatory agencies. Therefore, these issues still impose several limitations in some of our results.

Unlike developed countries, such as the United States and France, water utilities in Brazil also operate sewage services. Thus, as firms in the country are, sometimes, multiproduct firms, it could change the results obtained where the utility only provides one or both services. The reason why the optimal level of effort, when utilities change from a cost-plus to a price-cap regime is not also clear. Furthermore, the impact of political alliances on the level of cost is also not clear.

This dissertation leaves some doors open to future research. One of them is to check the utilities' level of cost, quality, and welfare outcomes when more than two regulatory regimes are taken into account, which is possible according to the theoretical literature. As state regulatory agencies adopt different types of cost-plus and price-cap rules, one could measure the impact of each one of these regimes instead of assuming that there are only two schemes. Moreover, it is possible to explore deeply the regimes adopted by other state and local regulatory agencies, as the costumers' distance from the utility impacts the tariff charged.

Another possible extension is to evaluate the impact of different functional forms, just like Gagnepain and Ivaldi (2017) did, and how the mayor's political orientation impacts the outcomes analyzed here. An exciting way to improve the robustness of the results concerning quality indicators would be using more sophisticated econometric tools that go beyond simply panel techniques. Differences-in-differences, and regression discontinuity design, just like Estache et al. (2016), Kresch (2020), and Kresch and Schneider (2020), can be considered in addition to exogenous variations.

7. References

Agência de Regulação de Pernambuco (Arpe). Technical note 01, 2014. Available in: < http://www.arpe.pe.gov.br/images/NT/Nota_Tcnica_DEF_CT_01_2014_Metod_Tarif_28jan2014.pdf >.

Agência de Regulação de Pernambuco. Resolution (Arpe), 2009. Available in: < https://legis.alepe.pe.gov.br/texto.aspx?tiponorma=6&numero=33354&complemento=0&ano=2009&tipo=&url=>.

Agência de Serviços Públicos do Estado de Alagoas (Arsal). Resolution 151, 2015. Available in: <http://www.arsal.al.gov.br/editais_licitacoes/resolucoes/2015/DIARIO%20OFICIAL-09.06.2015-86-RESOLUCaO%20ARSAL%20No%20151-%20DE%2008.06.2015-REAJUSTE%20EXTRAORDINARIO%20TARIFAS%20DA%20CASAL.pdf>.

Agência Reguladora de Serviços de Saneamento Básico de Santa Catarina (Aresc). Resolution 03, 2011. Availablein:<https://www.aresc.sc.gov.br/index.php/documentos/resolucoes/resolucoes-agua/41-resolucao-003-2011/file>.

Agência de Regulação de Serviços Púbicos de Santa Catarina (Aresc). Resolution 061, 2017. Available in: <https://www.aresc.sc.gov.br/index.php/documentos/resolucoes/resolucoes-agua/1240-resolucao-aresc-n-061/file>.

Agência Estadual de Regulação de Serviços Públicos (Agepan). Resolution 087, 2012. Available in: <https://www.agepan.ms.gov.br/saneamentolegislacao/portaria-n-087-de-28-de-maio-de-2012/>.

Agência Estadual de Regulação dos Serviços Públicos Delegados do Rio Grande do Sul (Agergs). Technical note 01, 2010. Available in: < https://agergs.rs.gov.br/upload/arquivos/201910/22145404-arquivo2138.pdf >.

Agência Goiana de Regulação, Controle e Fiscalização de Serviços Públicos (AGR). Techinical note 3, 2020. Available in:< https://www.agr.go.gov.br/files/docs/ConsultasPublicas/2020/0001/Nota_Tecnica_n_3.2020.pdf >.

Agência Reguladora de Saneamento Básico do Estado da Bahia (AGERSA). Technical note 001, 2014. Available in: < http://www.agersa.ba.gov.br/wp-content/uploads/2014/04/Nota-tecnica-versao-final-Embasa-Rejuste-Tarifario-2014.pdf>

Agência Reguladora dos Serviços Públicos Delegados do Estado do Ceará (Arce). Resolution 164, 2013. Available in :< https://www.legisweb.com.br/legislacao/?id=251185 >.

Agência Reguladora de Saneamento Básico e infraestrutura Viária do Espirito Santo (Arsp). Technical note, 01, 2011. Available in: < https://arsp.es.gov.br/Media/arsi/Saneamento/Tarifas%20Saneamento/NOTA%20T%C3%89CNICA%20GET%20N%C2%BA%2001_2011.pdf>.

Agência Reguladora de Serviços Públicos do Estado do Maranhão (Arsema). Resolution 001, 2012. Available in: < http://www.arsema.ma.gov.br/files/2014/02/DOE_Resolu%C3%A7%C3%A3o-Arsema-n%C2%BA001.2012_EX20120530-inserir-no-site.pdf >.

Agência Reguladora de Serviços Públicos Delegados de Infraestrutura do Paraná (Agepar). Technical note 01, 2017. Available in: < https://www.documentador.pr.gov.br/documentador/pub.do?action=d&uuid=@gtf-escriba-agepar@750a506e-f6dd-42e4-872c-8e9fcdc369df&emPg=true >.

Agência Reguladora de Serviços Públicos Delegados ao Estado de Rondônia (Agero). Resolution 02, 2016. Available in:< http://www.diof.ro.gov.br/data/uploads/2016/08/Doe-29_07_2016.pdf >.

Agência Reguladora dos Serviços Públicos do estado de São Paulo (Arsesp). Technical note, 2009. Available in:< http://www.arsesp.sp.gov.br/ArquivosRegulamentacao/ConsultasPublicas/NT_Sabesp-Reajuste2009.pdf >.

Agência Reguladora dos Serviços Públicos do estado de São Paulo (Arsesp). Technical note 007, 2013. Available in:< http://www.sabesp.com.br/sabesp/filesmng.nsf/D57B154743BA7F4983257C16007CE59E/$File/nota_tecnica_reajuste_sabesp2013.pdf>.

Agência Reguladora de Serviços Públicos de Sergipe (Agrese). Technical note 03, 2019. Available in:< https://www.agrese.se.gov.br/doucumentos/267.pdf>.

Agência Reguladora de Energia e Saneamento Básico do Estado do Rio de Janeiro (Agenersa). Estudo de Metodologias para Reajustes Anuais e Revisão Tarifária Quinquenal, 2016. Available on:< http://www.agenersa.rj.gov.br/documentos/consultapublica/CEDAE-ReajusteAnualTarifa/EstudosReajuste.pdf>.

Antonioli B., Filippini M. (2001). The use of a variable cost function in the regulation of the Italian water industry. *Utilities Policy* 10, 181 – 187.

Araújo, F., Bertussi, G. (2018). Saneamento básico no Brasil: estrutura tarifária e regulação. *Planejamento e Políticas Públicas* 51, 165 – 202.

Barbosa, A., Brusca, I. (2015). Governance structures and their impact on tariff levels of Brazilian water and sanitation corporations. *Utilities Policy* 34, 94 – 105.

Baron, D., Myerson, B. (1982), Regulating a monopolist with unknown costs, *Econometrica*, 5, 911-930.

Baron, D. (1989), Design of regulatory mechanisms and institutions, In R. Schmalensee & R. Willig (eds.), *Handbook of Industrial Organization*, Amsterdam: North-Holland, 1347-1447.

Baron, D., Besanko, D. (1984), Regulation, asymmetric information and auditing, *RAND Journal of Economics*, 15, 447-470.

Baron, D., Besanko, D. (1984), Regulation and information in a continuing relationship, *Information Economics and Policy*, 1, 267-302.

Baron, D., Besanko, D. (1987), Commitment and fairness in a dynamic regulatory relationship, *Review of Economic Studies*, 54, 413-436.

Besanko, D. (1984), On the use of revenue requirements regulation under imperfect information, In M.A. Crew (ed.), *Analysing the Impact of Regulatory Change in Public Utilities*, Lexington, Lexington Books, 39-58.

Bhalotra, S., Cayeros, A., Miller, G., Miranda, A., Venkataramani, A. Urban Water Disinfection and Mortality Decline in Lower-Income Countries, *American Economic Journal: Economic Policy*, forthcoming.

Biorn, E. (2004). Regression systems for unbalanced panel data: a stepwise maximum likelihood procedure, *Journal of Econometrics*, 122, 281-291.

Brocas, I., Chan, K., Perrigne, I. (2006). Regulation under Asymmetric Information in Water Utilities. *American Economic Review*. 96, 62 – 66.

Currier, M. (2007a), Quality-corrected price cap, *Bulletin of Economic Research*, 59, 255-268

Currier, M. (2007b), A practical approach to quality-adjusted price cap regulation, *Telecommunications Policy*, 31, 493-501

Cruz, F., Motta, R., Marinho, A. Eficiência Técnica dos Serviços de água e esgoto no Brasil por tipo de atuação e gestão, *Revista Econômica*, 21.

Cruz, F., Motta, R., Marinho, A. Análise da eficiência técnica e da produtividade dos serviços de água e esgotos no Brasil, de 2006 a 2013, *Pesquisa e Planejamento Econômico*, 49.

Cutler, D., Miller, G. (2005). `The role of public health improvements in health advances: The twentieth-century United States. *Demography*, 42, 1 - 22.

Dalen, D., Gomez, L. (1997). Estimating cost functions in regulated industries characterized by asymmetric information. *European Economic Review* 41, 935 – 942.

Dalen, D., Gomez, L. (1996). Regulation and incentive contracts: An empirical investigation of the Norwegian bus transport industry. *IFS Working Papers* W96/08.

Danelon, A., Augusto, F., Spolador, H. (2021). Water resource quality effects on water treatment costs: An analysis for the Brazilian case, *Ecological Economics*, 188, 107 - 134

De Fraja, G., Iozzi, A. (2008), The quest for quality: a quality adjusted dynamics regulatory mechanism, *Journal of Economics & Management Strategy*, 17, 1011-1040

Estache, A., Garsous, G., Seroa da Motta, R. (2016). Shared Mandates, Moral Hazard, and Political (Mis)alignment in a Decentralized Economy, *World Development*, 83, pages 98 –110.

Estache, A.,Rossi, M., 2002. How Different Is the Efficiency of Public and Private Water Companies in Asia?, *World Bank Economic Review,* World Bank Group, 16, 139-148.

Façanha, L.O., Resende, M. (2004), Price cap regulation, incentives and quality: the case of Brazilian telecommunications, *International Journal of Production Economics* 92, 133-44.

Farsi, M., Filippini, M. (2009). An Analysis of Cost-Efficiency in Swiss Multi-utilities, *Energy Economics*, 31, 306 – 315.

Feinstein, J.S., Wolak. F. (1991), The econometric implications of incentive compatible regulation, In G.F. Rhodes (ed.), *Advances in Econometrics: Econometric Methods and Models for Industrial Organizations*, Greenwich-CT: JAI Press, 159-204.

Fundação Norte-Rio-Grandense de Pesquisa e Cultura (FUNPEC). *Estudo de Revisão Tarifária da CAER*, 2013.

Gagnepain, P., Ivaldi, M. (2002), Incentive regulatory policies: the case of public transit systems in France, *RAND Journal of Economics* 33, 605 – 629.

Galiani, S., Gertler, P., Schargrodsky, E. (2005), Water for Life: The Impact of the Privatization of Water Services on Child Mortality, *Journal of Political Economy*, 113, 83 – 120.

García-Valiñas, M., González-Gómez, F., Picazo-Tadeo, A. (2013), Is the price of water for residential use related to provider ownership? Empirical evidence from Spain, *Utilities Policy*, 24, 59 – 69.

Garcia, S., Thomas, A. (2003). Regulation of Public Utilities under Asymmetric Information. *Environmental and Resource Economics* 26, 145 – 162.

Gasmi, F., Ivaldi, M., Laffont, J.J. (1994), Rent extraction and incentive for efficiency in recent regulatory proposals, *Journal of Regulatory Economics*, 6, 151-176.

Giambiagi, F., Além, A. *Finanças Públicas: Teoria e Prática no Brasil*. Edition 5, Atlas.

Greene, W. (2008) *Econometric Analysis*. Edition 6, Pearson Prentice Hall, Upper Saddle River.

Hu, Y. (2017), The Econometrics of Unobservables: Applications of Measurement Error Models in Empirical Industrial Organization and Labor Economics, *Journal of Econometrics*, 154-168.

Instituto Trata Brasil. Principais estatística sobre água no Brasil. Available at: http://www.tratabrasil.org.br/saneamento/principais-estatisticas/no-brasil/agua

Kaplan, D. (2019). distcomp: Comparing distributions, *Stata Journal*, 19, 832-848.

Kresch, E., Schneider, R. (2020), Political determinants of investment in water and sanitation: Evidence from Brazilian elections, *Economics Letters*, 189.

Kresch, E. (2020). The Buck Stops Where? Federalism, Uncertainty, and Investment in the Brazilian Water and Sanitation Sector. *American Economic Journal: Economic Policy*, 12, 374-401.

Laffont, J. (1994), The new economics of regulation ten years after, *Econometrica*, 62, 507-537.

Laffont, J. (1997), Game theory and empirical economics, *European Economic Review*, 41, 1-35.

Laffont, J., Ossard, H., Vuong, Q. (1995), Econometrics of first-price auctions, *Econometrica*, 63, 953-980.

Laffont. J., Rochet, J. (1998), Regulation of a risk averse firm, *Games and Economic Behavior*, 25, 149–173

Laffont, J.,Tirole, J. (1986), Using cost observation to regulate firms, *Journal of Political Economy*, 94, 614-641.

Laffont, J., Tirole, J. (1988), The dynamics of incentive contracts, *Econometrica*, 56, 1153-1175.

Laffont, J., Tirole, J. (1993), *A Theory of Incentives in Procurement and Regulation*, Cambridge-MA: MIT Press.

Lavergne, P., Thomas, A. (2005). Semiparametric estimation and testing in a model of environmental regulation with adverse selection. *Empirical Economics* 30, 171 – 192.

Liston, C. (1993), Price-cap versus rate-of-return regulation, *Journal of Regulatory Economics*, 5, 25-48.

Lucinda, C., Anuatti, F. (2017), Economies of Scale and Scope in the Sanitation Sector, *Brazilian Review of Econometrics*, 37, 47 – 62

Mckay, N. (1988). An Econometric Analysis of Costs and Scale Economies in the Nursing Home Industry, *Journal of Human Resources*, 23, 57 – 75.

Moreira, T., Faria, R. (2005). Public Versus Private Water Utilities: Empirical Evidence for Brazilian Companies. *Economics Bulletin* 8 (2), 1 – 7.

Motta, R., Moreira, A. (2006). Efficiency and regulation in the sanitation sector in Brazil. *Utilities Policy,* 14, 185 – 195.

Nguyen, M. (2008). XTSUR: Stata module to estimate seemingly unrelated regression model on unbalanced panel data, *Statistical Software Components* S456953, Boston College Department of Economics.

Perrigne, I., Vuong, Q. (2011), Nonparametric identification of a contract model with adverse selection and moral hazard, *Econometrica* 79, 1499-1539.

Reiss, P., Wolak, P. (2007). Structural Econometric Modeling: Rationales and Examples from Industrial Organization". Handbook of Econometrics, in: J.J. Heckman & E.E. Leamer (ed.), *Handbook of Econometrics*, edition 1, volume 6, chapter 64, Elsevier.

Resende, M. (1997), Regimes regulatórios: possibilidades e limites, P*esquisa e Planejamento Econômico*, 27, 641-64.

Resende, M. (1999), Productivity growth and regulation in U.S. local telephony, *Information Economics and Policy*, 11, 23-44.

Resende, M., Façanha, L.O. (2005), Price cap regulation and service-quality in telecommunications: an empirical study, *Information Economics and Policy*, 17, 1-12.

Ritta, J. (2009), *A Água do Rio: do Carioca ao Guandu,* edition 1, Synergia.

Sabbioni, G. (2008). Efficiency in the Brazilian sanitation sector. *Utilities Policy,* 16, 11 – 20.

Schmalensee, R.C. (1989), Good Regulatory Regimes, *RAND Journal of Economics*, 20, 417-36.

Spady, R., Friedlaender, A. (1978). Hedonic Cost Functions for the Regulated Trucking Industry, *Bell Journal of Economics,* 9, 159 – 179.

Thomas, A. (1995). Regulating Pollution under Asymmetric Information: The Case of Industrial Wastewater Treatment. *Journal of Environmental Economics and Management*, 28, 357 – 373.

Tupper, H., Resende, M. (2004). Efficiency and regulatory issues in the Brazilian water and sewage sector: an empirical study. *Utilities Policy,* 12, 29 – 40.

Weisman, D. (2019). The power of regulatory regimes reexamined. *Journal of Regulatory Economics*, 56, 125 – 148.

Willians, S., Pickard, C., Glass, K., Glass, A. (2020). Benchmarking Water Retail Cost Efficiency in England and Wales. *International Journal of the Economics of Business*, 1 - 37.

Wunsch, P. (1996), Estimating a menu of linear contracts for mass transit firms, *CORE Discussion Paper* no. 9640

Wolak, F. (1994). An Econometric Analysis of the Asymmetric Information, Regulator-Utility Interaction. *Annales d'Économie et de Statistique,* 34, 13 – 69.

8. Appendix

Appendix A -Tables

Table 2 – Regulatory regimes by state and year

State	Price-cap	Cost-plus	Price-cap 1	Price-cap 2	Cost-plus 1	Cost-plus 2	Cost-plus 3
Alagoas	-	2014				X	
Amapá	-	-					
Bahia	-	2012			X		
Ceará	-	2009				X	
Espírito Santo	-	2011			X		
Goiás	-	2006				X	X
Maranhão	-	2012				X	
Mato Grosso do Sul	-	2012				X	
Minas Gerais	2016	2011		X	X		
Pará	-	-					
Paraná	2017	-		X			
Pernambuco	2014	2009		X	X		
Rio de Janeiro	-	2015					X
Rio Grande do Norte	-	2009			X		
Rio Grande do Sul	-	2009			X		
Rondônia	-	2016				X	
Roraima	-	-					
Santa Catarina	-	2011			X	X	
São Paulo	2014	2008	X		X		
Sergipe	-	2017			X		

Information about the regulatory regimes applied be agencies were obtained through resolutions, technical notes, and questionaries that were sent to each agency, and it consisted of two questions: 1) what is the regime adopted to regulate the states' water company, and 2) when the regime was adopted. The answers of the regulators came based on laws and/or technical notes published by the agency.

Table 3 – Summary statistics

Variable	Obs.	Mean	Std. Dev.	Min.	Max.	SNIS code
Revenue (R$)	32270	1380908.9	2913957.9	-27576.04	1.310×8^{10}	FN002
Price of energy (R$/kWh)	30337	1.43	26.89	0	2601.24	AG028/FN013
Price of materials (R$)	30483	184.67	3605.99	0	247263.41	FN011/(QD006+QD008+QD016)
Population	32286	15586.35	22603.87	966	872762	X185
Network extension (Km)	32235	38.04	50.67	.02	1240.83	AG005
Volume of produced water (1,000 m³)	32227	670.82	1890.54	0	113514	AG006
Volume of treated water (1,000 m³)	32178	476.23	1677.42	0	82265	AG015
Volume of water consumed (1,000 m³)	32216	416.89	1348.35	0	68311.74	AG010
Volume of water lost (1,000 m³)	20254	221.87	709.90	-36591.39	32389	AG006-AG010
Water connections	32059	3111.31	4160.85	0	106809	AG021
Volume of fluoridated water (1,000 m³)	31829	337.22	1531.81	0	83351	AG027
Demand per water connection (1,000 m³ per connection)	20118	3.35	.92	-4.64	8.955	AG010/AG021
Outages	23890	5.05	22.8	0	1129	QD002
Interruptions	22430	44.67	1881.83	0	243571	QD021
Complaints	25678	2046.76	4566.29	0	219802	QD023
Maintenance	25861	1606.32	3573.67	0	213564	QD024
Materials expenses (R$)	32056	42936.96	115756.05	0	3494058.1	FN011
Energy expenses (R$)	32179	278968.16	580830.98	0	14907569	AG028
Total cost (R$)	30843	2163914.4	4881632.5	0	2.688×8^{10}	FN017
Utility investment (R$)	30425	192367.95	1363879.7	0	87881752	FN023
Labor expenses (R$)	32180	788330.56	1517855.7	0	64553411	FN026
Tariff (R$)	31292	4.88	29.44	0	4958.23	IN004
Outsource services expenses (R$)	20276	170681.3	470229.84	0	35390002	FN014
Price of labor (R$)	30973	127158.34	72464.42	0	2595671.2	FN010/FN026
Incidence of fecal coliforms samples out of the standard*	27920	3.376	10.71	0	100	IN084
Incidence of turbidity samples out of the standard*	28805	138.679	196.94	0	7027.5	IN076
Incidence of chlorine samples out of the standard*	30665	16.037	38.92	0	1772.22	IN075
Quality ordinance	20278	.297	.457	0	1	QD001
GDP (R$)	29944	2.14×8^{10}	5.86×8^{10}	4198940	2.142.1	-
Land gradient	32276	5.623	3.52	.395	17.28	-
Regulatory regime	20278	.258	.438	0	1	-
Political ally	18044	.165	.371	0	1	-

$\frac{Total\ samples\ out\ of\ standard}{Total\ samples\ analized}$. This table shows the summary statistics of all the data used in this dissertation. Notice that the code used to identify each variable in the SNIS is also presented in the table.

Table 7 – Optimum level of effort’s share in the revenue: Cobb-Douglas specification

Company	Price-cap	Cost-plus
CAEMA	-	19%
CAER	-	-
CAERD	59%	7%
CAERN	-	21%
CAESA	-	-
CAGECE	-	33%
CAGEPA	36%	-
CASAL	-	22%
CASAN	16%	27%
CEDAE	-	18%
CESAN	-	21%
COMPESA	18%	26%
COPANOR	30%	29%
COPASA	18%	27%
CORSAN	-	23%
COSANPA	46%	-
DESO	-	17%
EMBASA	-	26%
SABESP	21%	48%
SANEAGO	-	29%
SANEATINS	22%	-
SANEPAR	18%	-
SANESUL	-	19%
Mean	28%	24%
SD	14%	9%

This table shows the optimal level of effort by the utility and regulatory regime. It was calculated following the result (45), as, according to Dalen and Gomez-Lobo (1996, 1997) the optimum level of effort is given by: $b_i \beta_w C$. Thus, multiplying the value of the wage parameter (obtained in the Cobb-Douglas specification) by the mean level of cost of each utility, and dividing it by the firm’s revenue one obtains the results from this table.

Table 8 – θ distributions comparison for the Cobb-Douglas specification by year

Year/Level of confidence	1%	5%	10%
2008	Not rejected	Not rejected	Not rejected
2009	Rejected	Rejected	Rejected
2010	Rejected	Rejected	Rejected
2011	Rejected	Rejected	Rejected
2012	Rejected	Rejected	Rejected
2013	Rejected	Rejected	Rejected
2014	Rejected	Rejected	Rejected
2015	Rejected	Rejected	Rejected
2016	Rejected	Rejected	Rejected
2017	Rejected	Rejected	Rejected
2018	Rejected	Rejected	Rejected
2019	Rejected	Rejected	Rejected

This table shows the if the types θ changed over the years. It is based on the residual analysis proposed by Hu (2017), and was obtained following the procedure developed by Kaplan (2019). Therefore, one can check if a distribution of the residuals from equation (61) by year is statistically different.

Table 11 – Optimum level of effort's share in the revenue: Translog specification

Company	Price-cap	Cost-plus
CAEMA	-	37%
CAER	-	-
CAERD	113%	14%
CAERN	-	41%
CAESA	-	-
CAGECE	-	63%
CAGEPA	69%	-
CASAL	-	42%
CASAN	31%	51%
CEDAE	-	34%
CESAN	-	41%
COMPESA	35%	50%
COPANOR	57%	56%
COPASA	35%	52%
CORSAN	-	45%
COSANPA	88%	-
DESO	-	33%
EMBASA	-	51%
SABESP	40%	92%
SANEAGO	-	56%
SANEATINS	43%	-
SANEPAR	35%	-
SANESUL	-	36%
Mean	55%	47%
SD	28%	16%

This table shows the optimal level of effort by the utility and regulatory regime. It was calculated following the result (45), as, according to Dalen and Gomez-Lobo (1996, 1997) the optimum level of effort is given by: $b_i \beta_w C$. Thus, multiplying the value of the wage parameter (obtained in the Translog specification) by the mean level of cost of each utility, and dividing it by the firm's revenue one obtains the results from this table.

Table 12 – θ distributions comparison for the Translog specification by year

Year/Level of confidence	1%	5%	10%
2008	Not rejected	Not rejected	Not rejected
2009	Rejected	Rejected	Rejected
2010	Rejected	Not rejected	Not rejected
2011	Rejected	Rejected	Rejected
2012	Rejected	Rejected	Rejected
2013	Rejected	Rejected	Rejected
2014	Rejected	Rejected	Rejected

2015	Rejected	Rejected	Rejected
2016	Rejected	Rejected	Rejected
2017	Rejected	Rejected	Rejected
2018	Rejected	Rejected	Rejected

This table shows the if the types θ changed over the years. It is based on the residual analysis proposed by Hu (2017), and was obtained following the procedure developed by Kaplan (2019). Therefore, one can check if a distribution of the residuals from equation (61) by year is statistically different. It is possible to see that the distribution of types is always different, when compared to the distribution in 2008.

Table 13 - Impact of regulatory regimes on quality outcomes

	Fecal coliforms	Turbidity	Maintenance	Tariff	Complaints	Treated water	Fluoridated water
Price-cap	-1.020***	-0.209***	-0.286***	0.0509**	-0.209**	-0.0762*	0.0530*
	(0.127)	(0.0309)	(0.0693)	(0.0190)	(0.0655)	(0.0330)	(0.0269)
GDP per capita	0.00221	0.480***	1.326***	0.118***	1.350***	0.0691**	0.0973***
	(0.0657)	(0.0424)	(0.106)	(0.00910)	(0.109)	(0.0228)	(0.0230)
Population	0.0154	0.439*	0.496	-0.0963	-0.991	0.350*	1.243***
	(0.343)	(0.180)	(0.637)	(0.0732)	(0.616)	(0.151)	(0.266)
Network extension	0.373***	-0.0342	0.318*	0.0403*	0.260	0.0647	-0.00426
	(0.0960)	(0.0377)	(0.153)	(0.0175)	(0.146)	(0.0496)	(0.0391)
Utility investment	-0.0136	-0.000728	-0.00231	-0.000311	0.0134	-0.00266	-0.00111
	(0.00912)	(0.00395)	(0.00917)	(0.00159)	(0.00931)	(0.00282)	(0.00351)
Gini index	0.463	-0.764***	-0.135	0.0187	0.129	-0.115	-0.265**
	(0.452)	(0.176)	(1.586)	(0.0420)	(1.449)	(0.0816)	(0.0908)
Price of samples	0.0141	-0.129***	0.0309	0.0138***	0.0545**	0.00395	0.00171
	(0.0147)	(0.0117)	(0.0180)	(0.00255)	(0.0182)	(0.00456)	(0.00759)
Fixed-effects	X	X	X	X	X	X	X
N	5320	9250	7757	3697	7907	6629	6816
adj. R^2	0.032	0.126	0.062	0.010	0.057	0.017	0.043
F	11.60	44.59	39.42	3.818	39.14	6.092	14.12

This table is a part the results from equation (79) and shows the impact of the price-cap regime, in comparison to the cost-plus scheme, on incidence of non-standard fecal coliforms, and turbidity, samples, maintenance, tariff charged, costumers' complaints, volume of treated, and fluoridated water. All the variables are in log base, and standard errors are clustered by municipality. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

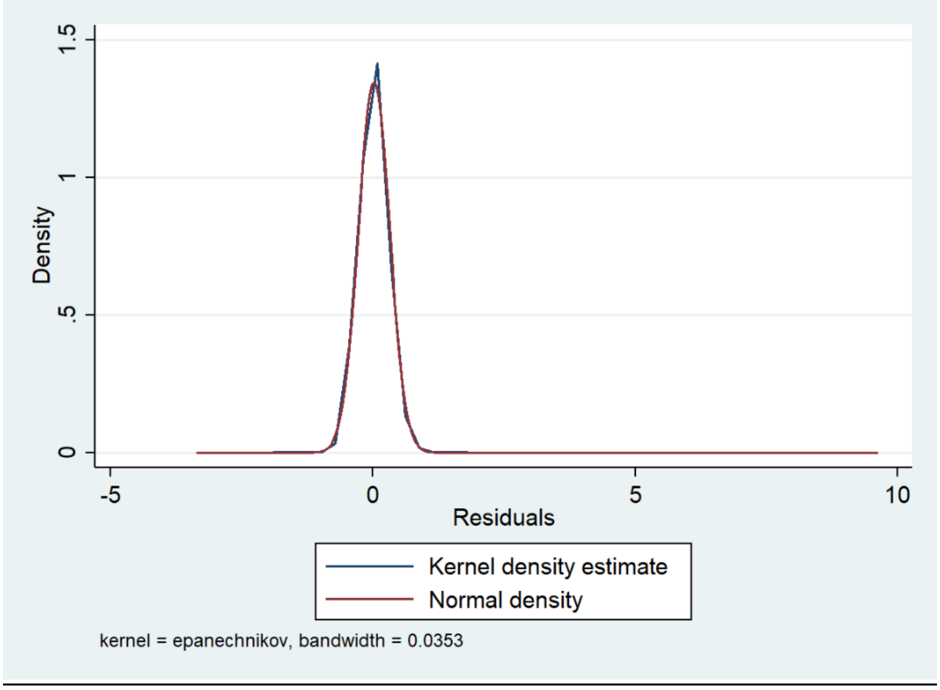
Table 14 – Impact of regulatory regimes on other quality outcomes

	Chlorine	Outages	Interruptions	Losses
Price-cap	0.208	-0.125	-0.465	-0.0842
	(0.133)	(0.195)	(0.284)	(0.0506)
GDP per capita	-1.180***	-0.0157	1.912***	0.0528
	(0.114)	(0.112)	(0.440)	(0.0379)
Population	-4.972***	1.706**	-0.754	0.452
	(0.743)	(0.632)	(2.284)	(0.235)
Network extension	0.552**	-0.0301	-0.247	0.155**
	(0.194)	(0.0884)	(0.242)	(0.0517)
Utility investment	-0.0561***	0.0486***	0.00392	-0.0106*
	(0.0145)	(0.0129)	(0.0321)	(0.00466)
Gini index	2.141***	-0.104	7.789	0.0883
	(0.438)	(0.495)	(4.167)	(0.159)
Price of samples	0.173***	-0.0334	0.0401	0.00339
	(0.0277)	(0.0191)	(0.0548)	(0.00856)
Fixed-effects	X	X	X	X
N	6381	3697	1588	9009
adj. R^2	0.088	0.010	0.047	0.009
F	42.58	3.818	3.046	4.351

This table is a part the results from equation (79) and shows the impact of the price-cap regime, in comparison to the cost-plus scheme, on the incidence of non-standard chlorine samples, outages, service interruptions, and volume of water lost. All the variables are in log base, and standard errors are clustered by municipality. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

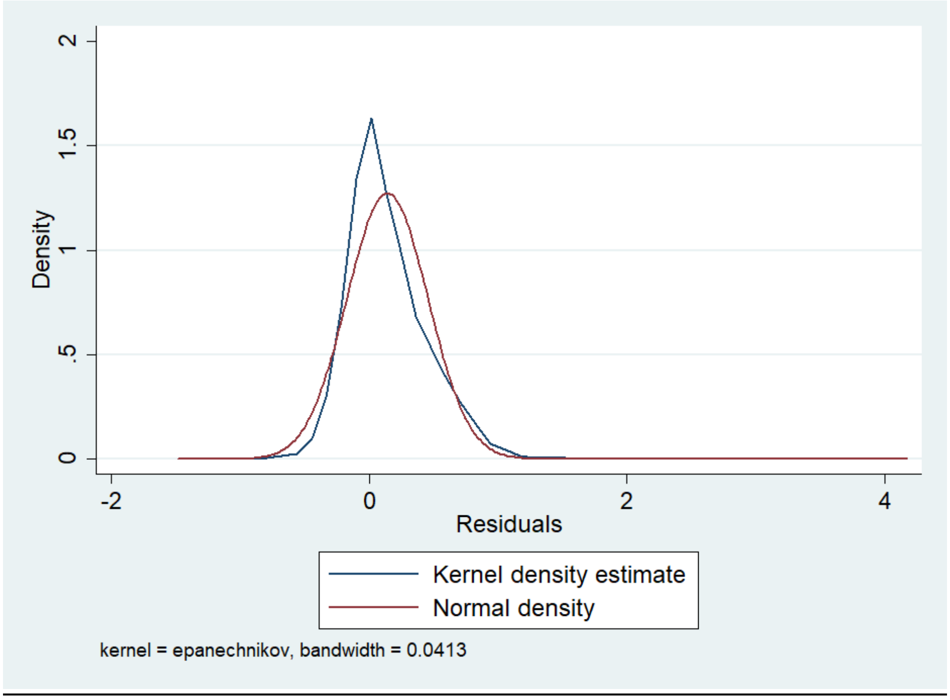
Appendix B - Figures

Figure 2 – Theta distribution of the Cobb-Douglas specification



This figure shows the distribution of types θ and it is based on the distribution the residuals from equation the Cobb-Douglas specification. It was obtained following the procedure discussed in Dalen and Gomez-Lobo (1996), and Hu (2017). Furthermore, a normal distribution was fitted to check if the residuals follow this kind of pattern.

Figure 3 – Theta distribution of the Translog specification



This figure shows the distribution of types θ and it is based on the distribution the residuals from equation the Cobb-Douglas specification. It was obtained following the procedure discussed in Dalen and Gomez-Lobo (1996), and Hu (2017). Furthermore, a normal distribution was fitted to check if the residuals follow this kind of pattern.

Appendix C - Regulatory regimes by state

Alagoas

The “Agência de Serviços Públicos do Estado de Alagoas” (Arsal) stablished to rule to regulate the state sanitation company “Companhia de Abastecimento de Água e Saneamento do Estado de Alagoas” (CASAL), in 2014. The rule adopted was similar to (58), as two inflation indexes were used to correct the tariff’s level: Índice de Preços ao Consumidor Amplo (IPCA), and the Índice Geral de Preços do Mercado (IGP-M). More information can be found in Arsal (2015).

Amapá

The “Agência Reguladora de Serviços Públicos do Amapá” does not regulate the “Companhia de Água e Esgoto do Amapá”, that is the local state sanitation utility.

Bahia

The “Agência Reguladora de Saneamento Básico do Estado da Bahia” (Agersa) started to regulate the “Empresa Baiana de Águas e Saneamento” (EMBASA), in 2012. The rule adopted by the regulator is similar to (57). For more information, check Agersa (2014).

Ceará

The “Agência Reguladora dos Serviços Públicos Delegados do Estado do Ceará” (Arce) started to regulate the “Companhia de Água e Esgoto do Ceará” (CAGECE) in 2009, and the regime adopted was similiar to (58). The inflation index used was the IGP-M. For more information, check Arce (2013).

Espírito Santo

The “Agência Reguladora de Saneamento Básico e infraestrutura Viária do Espirito Santo” (Arsp) started to regulate the “Companhia Espírito Santense de Saneamento” (CESAN) in 2011 and the regime adopted was similar to (57). The IPCA was chosen to correct the tariff’s level. For more information, check Arsp (2011).

Goiás

The “Agência Goiana de Regulação, Controle e Fiscalização de Serviços Públicos” started to regulate the “Saneamento de Goiás” (SANEAGO) in 2006, and created na index based on several inflation (IPCA, IGP-M, INPC, etc.) indexes to correct the tariff’s level.

It changed in 2015, when the regulator decided to adopt the discounted cash flow method to establish the new tariffs. By this methodology, even if the utility obtained a negative net present value it would be possible to obtain a return over capital. Thus, there was a transition from scheme (58) to the DSF. For more information, check AGR (2020).

Maranhão

The "Agência Reguladora de Serviços Públicos do Estado do Maranhão" (Arsema) started to regulate the "Companhia de Saneamento Ambiental do Maranhão" (CAEMA) in 2012, and adopted a regime similar to (58) as tariff should be corrected with the guarantee that the utility would have a 12% return over the investment done. For more information, check Arsema (2012).

Mato Grosso do Sul

The "Agência Estadual de Regulação de Serviços Públicos" (Agepan) started to regulate the "Empresa de Saneamento de Mato Grosso do Sul" (Sanesul) in 2012, and the scheme (58) was chosen by the regulator. The IPCA was the index used to correct the tariff' level. For more information, check Agepan (2012).

Pará

The "Companhia de Saneamento do Pará" was not regulated by the state regulatory agency. Therefore, any regime was adopted by the regulator.

Paraná

The "Agência Reguladora de Serviços Públicos Delegados de Infraestrutura do Paraná" started to regulate the "Companhia de Saneamento do Paraná" in 2017, and the regime adopted is a mix between (60) and the DCF as the authority uses an efficiency factor when fixing the tariff's level. For more information, check Agepar (2017).

Pernambuco

The "Agência de Regulação de Pernambuco" started to regulate the "Companhia Pernambucana de Saneamento" (COMPESA) in 2009. The regime adopted was similar to (58), but it changed in 2014 as the regulatory agency decided to implement a rule according to (60). More information can be found in Arpe (2009, 2014).

Rio de Janeiro

The “Agência Reguladora de Energia e Saneamento Básico do Estado do Rio de Janeiro” started to regulate the “Companhia Estadual de Águas e Esgotos” in 2015, and the regime adopted was developed by the Fundação Getúlio Vargas. It consists on the DCF, and, as it does not have an efficiency parameter, the scheme is a kind of a cost-plus (like the one adopted by in Goiás). Check for more information Agenersa (2016).

Rio Grande do Norte

The “Agência Reguladora de Serviços Públicos do Rio Grande do Norte” started to regulate the “Companhia de Águas e Esgotos do Rio Grande do Norte” in 2009, and the scheme used by the regulatory agency was similar to (57). Thus, it is similar to a cost-plus. Check FUNPEC (2013) for more information.

Rio Grande do Sul

The “Agência Estadual de Regulação dos Serviços Públicos Delegados do Rio Grande do Sul” (Agergs) started to regulate the “Companhia Riograndense de Saneamento” (CORSAN) in 2009, and the scheme used by the regulatory agency was similar to (57), but using more indexes. More information can be found in Agergs (2010).

Rondônia

The “Agência Reguladora de Serviços Públicos Delegados” ao Estado de Rondônia (Agero) started to regulate the “Companhia de Águas e Esgotos do Estado de Rondônia” (CAERD) in 2016, and the scheme used by the regulatory agency was similar to (57). Check Agero (2016) for more information.

Roraima

The “Companhia de Águas e Esgotos de Roraima” is not regulated by a state agency.

Santa Catarina

The “Agência Reguladora de Serviços de Saneamento Básico de Santa Catarina” started to regulate the “Companhia Catarinense de Águas e Saneamento” (CASAN) in 2011, and the scheme adopted was similar to (58). However, the regime changed in 2017 and the regulatory agency started to adopt rule (57). More information can be found in Aresc (2011, 2017).

São Paulo

The “Agência Reguladora dos Serviços Públicos do Estado de São Paulo” started to regulate the “Companhia de Saneamento Básico do Estado de São Paulo” (SABESP) in 2008, and the scheme adopted was similar to (57). However, the regime changed in 2014 and the regulatory agency started to adopt rule (59). Check Arsesp (2009, 2013) for more information.

Sergipe

The “Agência Reguladora de Serviços Públicos de Sergipe” (Agrese) started to regulate the “Companhia de Saneamento de Sergipe” (DESO) in 2017, and the scheme adopted was similar to (57). Check Agrese (2019) for mor information.