A Normative Analysis of Local Public Utilities: Investments in Water Networks

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Abstract

We analyze rehabilitation investments in a regulated water industry with perfectly inelastic demand. We compare alternative organizational solutions for local provision (*municipalization*, *corporatization* and *privatization*), though subject to a common regulatory mechanism. We can then assess the effects of incentive regulation in public firms and find that even benvolent politicians always stick to the price-cap, in order to save on distortionary taxation. However, incentives to invest result to be excessive only in private firms, as the cost of capital is accounted differently by public and private undertakings. We also provide a theory of mixed firms, based on strategic interaction between politicians and managers, which contributes to endogenously explain partial privatization and minority participation by private stockholders. In this last case incentives to invest appear to be driven just by governance and ownership reasons.

Key words: price-cap regulation, mixed firms, partial privatization, water networks, inelastic demand, natural monopoly

JEL Codes: H42, L32, Q95

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1 Introduction

One of the most important issues in the water industry concerns infrastructure investments, which are crucial both for service quality and water conservation policies. Developed countries are characterized by ancient investments and are frequently affected by an increasing amount of water leaks.[1] Water management can compensate leaks in the short run by increasing pressure or the amount of water input, but in that case, an increase of variable costs may ensue.[2] Leaks' social damages include a reduction of quality due to pollution, lower network pressure and, in the worst cases, service interruptions (Garcia and Thomas, 2003). Rehabilitation investments and adoption of new technologies for leaks detection imply significant long run costs, but can induce a decrease of both short run variable costs and social damages. However, the complete elimination of water leaks may not be efficient, when cosnidering the net benefits of new investments (Venkatesh, 2012).

With public funds becoming increasingly scarce, privatization has been invoked as a remedy. Both in the UK and in France privatization of water utilities occured when local authorities were lacking the technical and financial resources to make new investments required both by tighter European quality standards and delayed substitutions (Newbery, 2000; Dore et al., 2004). However, while in the UK privatization was complete and new investments were actually financed by private capital, in France most water undertakings became privately operated, but ownweship and responsibility of water supply remained within the public sector. The latter continued to subsidize network investments through public funds, with private companies financing just a third of capital expenditures (Dore et al., 2004). In the US most water utilities are owned and operated by private firms, though 80% of the population still receives water from publicly-owned systems (Wallsten and Kosec, 2006). In Germany and Italy water is mainly provided by the local public sector, but corporatization has been widespread (Grossi and Reichard, 2008), giving rise to mixed joint-stock companies with the participation of private investors as minority shareholders. In Spain water is provided by mixed firms, muncipalities or private undertakings (García-Valiñasa et al., 2013). Finally a new wave of re-municipalization occured recently in France (Hall et al., 2013).

Considering the persistence of municipal utilities in the water industries, and resort to mixed firms beyond pure privatization and delegation, we carry out a normative analisys of investment choices by considering alternative organizational solutions for water provision, with a centralized fix price regulation mechanism imposed by an independent national agency to any local water undertaking. We analyze how investments for the reduction of water leaks may be also affected by different ownership and governance structures at the local level. The effciency of capital is private information for the water undertaking. Therefore, asymmetric information affects the regulatory contract, but does not affect the agency relationship between politician and managers inside firms.

We assume that local governments act as welfare maximizers. We are aware of

[1] According to Garcia and Thomas (2003), in France actual losses amount to 25% on average and, in certain regions, reach a peak of 50% of distributed volumes. Egenhofer et al. (2012) provide some data concerning water leaks in Europe, showing a significant variability across and within countries.

[2] The increase of water injection in the network implies greater pumping efforts, giving rise to an increase of energy costs. Additonal chemicals for water treatment also contribute to increase variable costs.

the limits of this assumptions, as water provision by local governemnts has been traditionally affected by politicians pursuing their private agenda. However, we will remove the assumption of a benvolent local politician in a companion paper where we will keep the same assumptions concerning centralized regulation and organizational models for water provision, to carry out a positive analysis of investment decisions introducing political economy issues (Cavaliere et al., 2015). For the sake of simplicity we do not consider intertemporal issues and carry out the analysis of investment decisions in a one-period model.

While there is a rich empirical literature concerning the water sector[3], theoretical analysis is less widespread. Despite the central role played by price regulation of water supply - given the scarce potential for market competition - until now regulatory economics has been more concerned with environmental issues, with some relevant exceptions dealing with regulation by contract inspired by the French case. As water quality is regulated and easily verifiable, Martimort and Sand-Zantman (2006) highlight that in the water sector investment decisions are not affected by the incentive to reduce quality as in Hart et al. (1997), suggesting an analytical framework with complete contracts. Still, there is a problem of regulation with asymmetric information, as the quality of the infrastructure is private information for the local governemnt who delegates asset mangement to a private contractor. Martimort and Sand-Zantman (2006) analize how signalling issues interact with the moral hazard problem faced by a risk averse informed local government and find that delegation to private firms is likely to occur when the infrastructure quality is worst. A paper closer to ours is Garcia and Thomas (2003), introducing water leaks into the analysis. Efforts to reduce water leaks can improve the quality of the network, however, cost-reducing efforts are expensive and the related technogy may be private information for managers, so that a problem of optimal contract design arises.

With respect to these contributions we consider long run investments to reduce water leaks and neglect the delegation contract. We firstly consider the case of perfect information, when investment and prices are chosen by a benevolent social planner who can implement a first best allocation. Then we introduce asymmetric information when considering water undertakings that are run by public or private managers. As the efficiency of investment varies across water undertakings, and it is only known at the local level, the uninformed regulator adopts a fix-price mechanism (a revenue-cap).[4] Such a mechanism allows for information rents left to water undertakings. These rents may increase the incentive to invest without effciency losses, due to price-inelastic demand. Since a revenue-cap allows for lower water charges to be chosen by local utilities, we can also account for the power of local politicians to change prices downwards, whenever they find it optimal. One contribution of our analysis is then to consider the effects of a fix-price mechanims imposed on welfare maximizers politicians. Actually, as highlighted by Bajari and Tadelis (2001) most part of the economic literature identifies cost-plus contracts with in-house production while fix-price mechanism are identified with outsourcing.

[3] A long list of empirical studies can be found in Abbot and Cohen (2009).

[4] As far as investment is concerned, traditional results in regulatory economics would call for the introduction of rate-of-return regulation, to the extent that it is likely to induce larger invetments. However, more recent empirical contributions (Cambini and Rondi, 2010; Égert, 2009) show that incentive regulation implemented jointly with an independent regulator has a positive impact on investment in network industries. Unfortunately, independent regulatory agencies are less widespread in the water sector than in energy and telecommunications (OECD, 2011).

On the contrary we consider the same high powered incentive contract (fix-price regulation) whatever the ownership and organization of the water undertaking.

In order to analyze investment behavior we actually compare three organizational models: municipalization, corporatization (with partial privatization) and full privatization. Beyond ownership[5] we consider differences related both to investment financing and to the governance of water undertakings. In case of municipalization the decision maker is a benevolent local politicians and there is no separation between ownership and control. Public subsidies are up-ward constrained and resort to debt may be also necessary. Optimal financing structures depends on the comparison between the cost of public funds and the cost of debt, once accounting for the regulated rate of return. The interplay between inelastic water demand and distortionary taxation makes it optimal to collect water revenues up to the allowed regulatory cap, in order to save on costly public funds.

With corporatization we find that the interesting case concerns resort partial privatization due to credit constraints. The economic literature about corporatization and mixed firm is scarce, with some exceptions focused on mixed oligopolies (Matsumura, 1998). On the contrary, public-private partnership has been widely studied, but corporatization with mixed ownership raises different questions about the objective functions of the firm and the compatibility of social goals with profit maximization.

Our contribution deals with the case of partial privatization through an increase of the capital stock that entitles private managers to choose the amount of investments, while local governments hold the majority of stakes and can set water charges according to welfare maximization. We can show that, despite the opportunity for a benevolent government to protect consumers by reducing prices, even with mixed firms it is optimal to maximize water revenues up to the regulatory cap, to save on costly public funds. Such a result is dependent on the strategy of private shareholders, finding it optimal to enter the firm with a share suffciently low to let to the local government an amount of dividends large enough to reduce the cost of public funds. We can then provide an endogenous expalnations for private participation with minority stocks, as we can observe in most cases. Previous results about partial privatization (Perotti, 2005) emphasized the decisions of governemnts to keep majority stakes in order to commit not to expropriate private shareholders ex-post. Our result drives the attention on the behavior of private shareholders that prefer to keep minority stakes in order to lead the welfare maximizing governemnt to increase fiscal gains, thereby excluding ex-ante any resort to investment expropriation ex-post.

Finally we consider investment distortions by comparing optimal investmentsby the social planner with those arising in case of muncipalization, corporatization and privatization. By integrating theoretical anlysis with a calibration excercise we can then point out that, despite the existence of the same regulatory mechanisms, investments distortions are expected to be negligible in case of municipalization while result to be substantial in case of privatization. Differences in the objective function of the decision-maker are the most important driver of investment distortions, given that any water undertaking sticks to the revenue-cap.

[5]Empirical studies are not conclusive about the effect of ownership in the water sector. Concerning productivity and effciency, ownership appears to be less important than other factors (Abbot and Cohen, 2009; Pérard, 2009). As to compliance with water quality regulation, Wallsten and Kosec (2006) show there are no significan differences between private and public water systems.

The structure of the paper is the following. In Section 2 we consider a basic model for the demand and supply of clean water, introducing network leaks. In Section 3 we consider investments choices in the social optimum. In Section 4 we briefly specify the regulatory mechanism and characterize the alternative organizational strucutures for water provision. In Section 5 we consider the muncipalization case. In Section 6 corporatization and partial privatization are analyzed. In Section 7 full privatization is considered. In Section 8 we present a calibration of the model, also used for numerical simulations. In Secton 9 we carry out a comparison of the different organizational solutions to assess investment distortions with respect to the social optimum. In Section 10 we conclude.

2 Some Simple Economics of Water Provision with Network Leakages

There are specific features of water provision (Noll, 2002) which motivate a theoretical analysis of regulation restricted to this industry. Actually, the provision of clean water not only involves typical market failures due to externalities and natural monopoly, but is also characterized by local supply and vertical integration. With respect to electricity, natural gas or telecommunications, the water industry offers no liberalization opportunities as competition in the market is not feasible for strucutural reasons.[6]

One of the main feature of water provision is the very low price elasticity of demand, due both to the essentiality of water consumption and to metering problems. To the extent that we just consider the provision of water for drinking and sanitation utilization, we can assume that water demand is perfectly inelastic to price. Such an assumption appears to be more interesting from the analytical point of view and not far from reality, given the very low value of demand elasticity arising from empirical studies.[7] Therefore in this model market demand for water, denoted by Q^C, is perfectly inelastic up to a price $P^{\max}$,[8] and we normalize Q^C to one. Therefore $P^{\max}$ represents gross consumer surplus as well.

As we concentrate on water leaks L, we assume that the amount Q^S of supplied water is $Q^S \geq Q^C$, with $(Q^S - Q^C) = L$. Water leaks generate quality reduction and negative externalities which are accounted by the social damage function $D = dL$. Network investments can then reduce water leakages according to a technology

[6] A few liberalization opportunities may characterize water procurement at the upstream level, but they have been seldom exploited in practice (Armstrong et al., 1994). At the downstream level water retail provision continues to be vertically integrated with water distribution, which represents a typical example of a local natural monopoly.

[7] Empirical studies show estimates that consistently indicate a price-inelastic demand for water. A meta-analysis of almost 300 price elasticity studies, reports a mean price elasticity of -0.41 (Dalhuisen et al., 2003). Olmstead et al. (2007) consider the bias that could be due to estimations based on linear prices. They also consider non linear tariffs with separate estimates, finding an higher value for price elasticity, though equal to -0.59. Interestingly, they fail to identify a price elasticity significantly different from zero for the uniform-price households.

[8] Motivations for a perfectly inelastic demand, up to price $P^{\max}$ - implying a discontinuity at $P^{\max}$ such that for $P > P^{\max}$, water consumption becomes zero - may also include the opportunity of switching to substitutes like the resort to water distribution carried out by tank trucks (as it happens in areas not reached by the network).

characterized by decreasing returns to scale:[9]

$$L(K,i) = L_0 - 2iK + \frac{(iK)^2}{L_0}, \quad K \in \left[0, \frac{L_0}{i}\right], \tag{1}$$

being L_0 the exogenous amount of water leaks, K the amount of investments and i the efficiency of investments. The latter is a technological parameter, exogenously given and can be hydiosincratic to each water undertaking. Given exisiting technologies, we assume that $i \in \left[\underline{i}; \overline{i}\right]$. From (1), for $K < \frac{L_0}{i}$ we have

$$\frac{\partial L(K,i)}{\partial K} = -2i\left(1 - \frac{iK}{L_0}\right) < 0, \quad \frac{\partial^2 L(K,i)}{\partial^2 K} = -\frac{2i^2}{L_0} < 0.$$

Consequently, social damages $D = dL$ decrease when network investments K increase.

Considering that leaks could partially become endogenous to the public utility, because of the investment effects, then water supply becomes:

$$Q^S = Q^C + L(K,i). \tag{2}$$

The cost of water provision is then the sum of operational costs and capital costs arising from network investments K. To the extent that investment costs depend also on financial decisions, capital costs may be idyosincratic to organizational structures (cfr. next sections). At this stage, we simply consider as capital costs the fixed cost K. Let then be β the constant variable cost per unit of water provided, including both labor and energy costs. Given (2), and being Q^C normalized to one, the cost function can be expressed as follows:

$$C = \beta Q^P + K = \beta\left[1 + L_0 - 2iK + \frac{(iK)^2}{L_0}\right] + K.$$

Remark that network investments, by reducing water leaks, have two positive effects: on the one hand, they reduce variable costs; on the other they reduce social damages.

3 Social Optimum

In order to find a benchmark for the normative analysis carried out in next sections, we firstly consider welfare maximization by a benevolent social planner, which is perfectly informed about the effciency of investments $i \in \left[\underline{i}; \overline{i}\right]$. We assume that investments are financed by revenues net of variable costs (self-financing) and by public funds T, raised through non-distortionary taxation. Social welfare is given by the sum of gross consumer surplus $P^{\max}$, minus revenues P, minus the social damages dL due to water leaks, minus the social cost of taxation T; plus profits, given by

$$\Pi = P - \beta\left[1 + L_0 - 2iK + \frac{(iK)^2}{L_0}\right] - K + T. \tag{3}$$

[9]The assumption of decreasing return to scale appears to be rather intuitive in this case and has been already used in similar frameworks (e.g., see Chakravorty et al., 1995).

Therefore, social welfare can be expressed as

$$W = P^{\max} - P - d\left(L_0 - 2iK + \frac{(iK)^2}{L_0}\right) - T + \Pi =$$
$$= P^{\max} - \beta - (\beta + d)\left(L_0 - 2iK + \frac{(iK)^2}{L_0}\right) - K,$$

and the maximization problem of the social planner is

$$\max_K W = \max_K \left\{ P^{\max} - \beta - (\beta + d)\left(L_0 - 2iK + \frac{(iK)^2}{L_0}\right) - K \right\}$$
$$\text{s.t. } K \geq 0, K < \frac{L_0}{i}.$$

The level of optimal investment K^* shall satisfy the first order condition

$$2i(\beta + d)\left[1 - \frac{(iK^*)}{L_0}\right] = 1. \tag{4}$$

On the left side, the marginal benefits of investments are given by the reduction of variable costs and social damages due to the reduction of water leaks. On the right side, we find the marginal cost of investments, i.e. one Euro to be raised indiferrently either by market revenues or by non-distortionary taxation. The optimal level of K^* is

$$K^* = \frac{L_0}{i}\left(1 - \frac{1}{2i(\beta + d)}\right) < \frac{L_0}{i}.$$

Notice that, investments are independent both from T and P, since with non-distortionary taxation and perfectly inelastic demand, it is indifferent to finance investments by public subsidies or by increasing prices.

4 Price Regulation and Organizational Structures

The analysis of the social optimum can represent a useful benchmark, as optimal investments by a benevolent social planner can be compared with outcomes resulting from decisions carried out by regulators, politicians and firms involved in water provision. Actually, optimal investments cannot be decentralized through competitive markets, due to market failures affecting water provision. For the sake of simplicity, we shall not consider environmental regulation, then our analysis of investments in the water sector will derive from the interaction of price regulation with decisions by politicians and managers inside water utilities.

4.1 Price Regulation

Each water undertaking operates under the supervision of a national regulatory agency that adopts a fix-price mechanism which is independent from the organizational structure. The resort to a fix-price mechanism is due to the assumption of asymmetric information between the regulator and managers of water undertakings, as the efficiency of capital is private information. The regulator just knows the range $\left[\underline{i}; \overline{i}\right]$ of possible values for i. Considering that variable costs are decreasing

in i, to make water supply and investments feasible, even for undertakings characterized by the lowest effciency of capital $\underline{i}$, the fix-price mechanims should allow the recovery of operational costs up to the level $\beta\left[1+L_0-2\underline{i}K+\frac{(\underline{i}K)^2}{L_0}\right]$. Therefore any water undertaking with an efficiency parameter $i>\underline{i}$ is left an information rent:

$$\beta\left[\left(2iK-\frac{(iK)^2}{L_0}\right)-\left(2\underline{i}K-\frac{(\underline{i}K)^2}{L_0}\right)\right]=\beta(i-\underline{i})K\left[2-\frac{(i+\underline{i})K}{L_0}\right]>0.$$

As, by assumption, the demand for water is perfectly inelastic: *(i)* such a rent does not create any distortions in allocative effciency; *(ii)* a fix price-mechanism reduces to a revenue-cap.

Each water undertaking can recover the cost of water provision according to a revenue-cap $\overline{P}$ including operational costs and the cost of capital. The revenue-cap accounts only for the share of investment financed by debt and/or equity. [10] Moreover, we assume that the regulator - in order to induce efficiency concerning the structure and cost of financing - allows any water undertakings to recover a rate of return ρ on the share cK of non-subsidized investments, being ρ the risk-adjusted cost of capital for the water industry, and c the share of investments not financed by local taxation. Accordingly, the revenue-cap depends on investments K

$$\overline{P}=\beta\left[1+L_0-2\underline{i}K+\frac{(\underline{i}K)^2}{L_0}\right]+(1+\rho)cK. \tag{5}$$

Assuming a one-period model, the entire amount cK of non subsidized investment is recovered in the price cap.

The function $\overline{P}$ then specifies the lowest level of price that assures the supply of water with a rate of return ρ on capital, even in the worst technological case $i=\underline{i}$. As local governments control water charges, local politicians can set a price $P\leq\overline{P}$.

4.2 Organizational Structures

In our stylized representation we consider a single municipality which either manages directly the provision of water services or delegates it to a corporation with mixed ownership or to a private firm.[11] We shall not discuss the delegation mechanism, and in next sections we will distinguish three main organizational structures: 1) *Municipalization*: water services are provided by a branch of the local public administration. Such a branch may also be organized as a separate municipal firm, with its own balance sheet, though totally controlled by the local politician, which is responsible for investment and pricing decisions. In case of municipalization, investments can be financed by a mix of debt, local public subsidies - though constrained by municipal budgets - and self-financing through profits. Delegation of pricing and investment decisions to a manager does not affect analytical results, as there is no asymmetric information between politician and manager. 2) *Corporatization*: water services are provided by a joint-stock company, created by the local public government, that becomes a shareholder. Corporatization excludes the

[10] As the regulator excludes investments financed by public subsidies from the regulatory asset base.

[11] The case of multiple municipalities that are grouped either in a single local institution to delgate water provision or in a single local undertaking directly involved in water provision will not affect our analysis and conclusions.

resort to public subsidies.[12] Frequently, corporatization represents the first step towards partial privatization. In this last case, private shareholders jointly own the company together with the local govermenment, that traditionally continues to hold the majority of stakes. Being interested in investment decisions, we consider the case of partial privatization occuring through an increase of the capital stock completley financed by private investors and aimed to support new investments. Private shareholders then become entitled to choose the amount of investments (to be financed also by debt). In our framework, private owners are not distinguished from private managers. As governance constraints lead the local government to keep the majority of capital stock, local politician sets prices, once accounting for the revenue-cap. 3) *Privatization*: water provision is completly delegated to a private joint-stock company, the politician is supposed to be excluded from control, which is delegated to a manager selected by private shareholders.

5 Municipalization

In this case, the decision-maker is a benevolent local politician, that chooses the amount of investments K. Delegation to a public manager will not have any effect, as the latter shares both the objective function and the information with the local politician. With respect to the social optimum, public subsidies are financed by distortionary taxation, therefore we introduce a marginal cost of public funds λ. Moreover, public funds are supposed to be constrained by an upper bound, due to tight fiscal policies limiting the expansion of local taxation: $T \leq \overline{T}$.

It is worthwhile to notice that we do not assume any lower bound on public susbsidies. Negative subsides mean that a part of the revenues arising from the management of water provision is devoted to the reduction of local taxes (or expansion of public expenditures) by the muncipality. With respect to the social optimum, we also introduce the opportunity to finance investments through debt, for a share cK ($c \in [0,1]$), at a cost rcK, where r is the interest rate charged to the municipality. The profit then becomes

$$\Pi = P - \beta\left[1 + L_0 - 2iK + \frac{(iK)^2}{L_0}\right] - crK - K + T,$$

and the price-cap is

$$\overline{P} = \beta\left[1 + L_0 - 2\underline{i}K + \frac{(iK)^2}{L_0}\right] + (1+\rho)cK, \tag{6}$$

so that we can define profits when $P = \overline{P}$ as

$$\Pi = \underbrace{\beta(i-\underline{i})K\left[2 - \frac{(i+\underline{i})K}{L_0}\right]}_{\text{I}} + \underbrace{(\rho - r)cK}_{\text{II}} - \underbrace{(1-c)K}_{\text{III}} + T. \tag{7}$$

The term I represents the information rent. The term II depends on the difference between the rate of return on investment allowed by the regulator and the interest

[12] The transformation of municipal firms into joint stock companies has been frequently invoked to reach the aim of budget balacing through market revenues.

rate actually charged to the the municipality, considering its amount of debt cK.[13] The term III is the share of investment which is not financed by debt. It is not included in the regulatory asset base of the revenue-cap, to the extent that it is already financed by public subsidies raised through taxation.

From the previous assumptions, we obtain the following welfare function:

$$W^M = P^{\max} - P - d\left[L_0 - 2iK + \frac{(iK)^2}{L_0}\right] - (1+\lambda)T + \Pi =$$
$$= P^{\max} - \beta - (\beta + d)\left[L_0 - 2iK + \frac{(iK)^2}{L_0}\right] - \lambda T - K - crK.$$

Furthermore, we have to consider a list of constraints to welfare maximization to get the following constrained optimization program, where the variables are public subsidies T, the price level P, the amount of investments K and the share of the latter to be financed by debt, c:

$$\max_{T,P,c,K} W^M = \max_{T,P,c,K}\left\{P^{\max} - \beta - (\beta+d)\left[L_0 - 2iK + \frac{(iK)^2}{L_0}\right] - \lambda T - K - crK\right\}$$
$$\text{s.t. } \Pi = P - \beta - \beta L_0 + \beta\left[2iK - \frac{(iK)^2}{L_0}\right] - (1+rc)K + T \geq 0 \qquad (8)$$
$$T \leq \overline{T}$$
$$P \leq \overline{P} = \beta + \beta L_0 - \beta\left[2\underline{i}K - \frac{(\underline{i}K)^2}{L_0}\right] + (1+\rho)cK \leq P^{\max}$$
$$P \geq 0,\ K \geq 0,\ c \geq 0,\ c \leq 1,\ K < \frac{L_0}{i}.$$

Total welfare W^M is decreasing in T (while profits are strictly increasing in T), so the optimal value T^* is the lowest value satisfying the profit costraint (8), meaning that in the optimum, $\Pi = 0$ and therefore

$$T^* = -P + \beta + \beta L_0 - \beta\left[2iK - \frac{(iK)^2}{L_0}\right] + (1+cr)K.$$

By substitution in the objective function and in the constraints of the maximization

[13] For some water undertakings we cannot exclude that $r > \rho$, due for example to bad credit rankings for the municipality. In that case profits are reduced and may also become negative. For the sake of simplicity, we shall exclude this case from our analysis. However, it is important to notice that local governemnts with bad credit rankings may also be characterized by public deficits, implying also a greater cost of raising public funds. Local governments characterized by a restricted tax base, may find it difficult to raise public funds and in the meantime are also likely to experience budget deficits. The latter put them at a greater risk when borrowing funds in the financial markets. Therefore, some water undertakings may experience a joint increase of both λ and r.

problem we get

$$\begin{aligned}\max_{P,c,K} W^M = \max_{P,c,K} \Bigg\{ & P^{\max} + \lambda P - (1+\lambda)\beta \\ & - (\beta(1+\lambda)+d)\left[L_0 - 2iK + \frac{(iK)^2}{L_0}\right] - (1+\lambda)(1+cr)K \Bigg\} \\ \text{s.t. } & -P + \beta + \beta L_0 - \beta\left[2iK - \frac{(iK)^2}{L_0}\right] + (1+cr)K \leq \overline{T} \\ & P \leq \overline{P} = \beta + \beta L_0 - \beta\left[2\underline{i}K - \frac{(\underline{i}K)^2}{L_0}\right] + (1+\rho)cK \leq P^{\max} \qquad (9) \\ & P \geq 0,\ K \geq 0,\ K < \frac{L_0}{i},\ c \geq 0, c \leq 1.\end{aligned}$$

The first result concernig the price choice is then the following:

Proposition 1 *A benevolent politician sets* $P = \min\left\{P^{\max}, \overline{P}\right\}$.

Because of the rigidity of the demand function, any price increase is non distortionary and leads to a welfare gain proportional to λ, due to the reduction of public funds necessary fo finance investments. As welfare increases with price, and considering the fix price mechanism, the optimal price is the price cap $\overline{P}$ provided that it is not larger than $P^{\max}$.[14]

Therefore, the constraint (9) is satisfied with the equality sign and, by substitution of $\overline{P}$ in the welfare function, we get

$$\begin{aligned}\max_{c,K} W^M = \max_{c,K} \Bigg\{ & P^{\max} - \beta - L_0(\beta+d) + ((1+\lambda)\beta + d)\left(2iK - \frac{(iK)^2}{L_0}\right) \\ & - \lambda\beta\left(2\underline{i}K - \frac{(\underline{i}K)^2}{L_0}\right) - (1+\lambda)K + \left[\lambda(1+\rho-r) - r\right]cK \Bigg\} \\ \text{s.t. } & -\beta(i-\underline{i})K\left[2 - \frac{(i+\underline{i})K}{L_0}\right] - (\rho - r)cK + (1-c)K \leq \overline{T} \qquad (10) \\ & K \geq 0,\ K < \frac{L_0}{i},\ c \geq 0,\ c \leq 1.\end{aligned}$$

The solutions of this maximization problem depend on the relationship between λ, ρ and r (check Appendix I) as stated in the following proposition:

Proposition 2 *If* $\lambda > r/(1+\rho-r)$*, it is optimal to finance investments through debt* ($c^* = 1$)*. If* $\lambda < r/(1+\rho-r)$*, it is optimal to maximize the resort to public subsidies.*

The economic intuition behind the previous result is the following. On the one hand, an increase of debt implies an increase of interests charged to the water undertaking. This increase of costs can be recovered through a corresponding increase of the price-cap, which in turn reduces welfare. On the other hand, an increase of debt leads to a reduction of public subsidies with a decrease of the local tax burden. The latter is due both to the direct effect of the increase of the share of investment

[14] We restrict our attention to this last case assuming that the regulator and the regulated firm share the same information about the demand function, so that the case $\overline{P} > P^{\max}$ can be excluded by the regulatory mechanism.

financed by debt and to the profit increase due to the difference between the allowed rate of return and the rate of interest. Therefore, a welfare gain is obtained by increasing debt only if the social benefits due to a decrease of the tax burden, (proportional to $\lambda(1+\rho-r^M)$) are greater than the surplus reduction due to the increase of the financial costs, proportional to r. Instead, if $\lambda(1+\rho-r)<r$ then the welfare gain due to a reduction of local taxation is lower than the welfare loss due to an increase of the financial cost, and then it is optimal to minimize the resort to debt.

Two main cases can be distinguished as follows.

1) $\lambda > \frac{r}{1+\rho-r} \Leftrightarrow \frac{\partial W^M}{\partial c} > 0 \Rightarrow c^M = 1$

Social welfare is strictly increasing in c and it is optimal to expand debt as much as possible to finance investments. With $c^M = 1$, the constraint on public subsidies (10) is not binding and the profits arising from the management of water supply are completley devoted to the reduction of local taxes, according to

$$T = -\beta(i-\underline{i})K\left[2-\frac{(i+\underline{i})K}{L_0}\right]-(\rho-r)K. \tag{11}$$

If $c^M = 1$, the optimal investment K^M depends on the following first order condition (check Appendix I for a formal proof), where marginal social benefits equal the marginal cost of investment:

$$\underbrace{(\beta+d)2i\left(1-i\frac{K^M}{L_0}\right)}_{\text{I}}+\underbrace{\lambda 2\beta(i-\underline{i})\left(1-\frac{(i+\underline{i})K^M}{L_0}\right)}_{\text{II}}+\underbrace{\lambda(\rho-r)}_{\text{III}}=1+r. \tag{12}$$

According to (12), the marginal social benefits are given by the sum of three terms: I the welfare increase due to the reduction of variable costs and marginal social damages implied by the reduction of network leaks; II the welfare increase due to savings on the marginal cost of public funds, proportional to the marginal information rent, that is cashed through a non distortionary increase of the price-cap; III the savings on the marginal cost of public funds due to the financial effciency of the water undertaking, which can recover a rate of return ρ on investment larger than the cost of debt r, implying an additional profit obtained through a non distortionary price-cap increase. The marginal cost of investment on the right hand side includes one Euro of investment costs plus the marginal cost of debt for the municipal undertaking.

2) $\lambda < \frac{r}{1+\rho-r} \Rightarrow \frac{\partial W^M}{\partial c} < 0$

Social welfare is strictly decreasing in c, and then it is optimal to finance investment with public subsidies. However, due to the upper bound on available public funds, a share of investments may be still financed by debt. This share of investments should then be be as low as possible, once accounting for the constraint on (11):

$$\begin{aligned} &c^M = \min c \in [0,1]\,, \text{ such that} \\ &-\beta(i-\underline{i})K\left[2-\frac{(i+\underline{i})K}{L_0}\right]-(\rho-r)cK+(1-c)K \leq \overline{T} \end{aligned} \tag{13}$$

When turning to case 2, we are lead to consider two sub-cases. For any upper bound on public subsidies $\overline{T}$, we can notice that the greater the efficiency of capital i, the greater the contribution of the information rent to the increase of profits

available to finance investments. It is then more likely that investments could be financed without any resort to debt ($c^M = 0$). In the meantime, for any value of i, the greater is $\overline{T}$, the more likely that $c^M = 0$ (check Appendix I for formal proofs).
2a) $c^M = 0$
The optimal amount of investment K^M depends on the first order condition

$$\underbrace{(\beta + d)2i\left(1 - i\frac{K^M}{L_0}\right)}_{\text{I}} + \underbrace{\lambda 2\beta(i - \underline{i})\left(1 - \frac{(i + \underline{i})K^M}{L_0}\right)}_{\text{II}} = 1 + \lambda. \tag{14}$$

Marginal social benefits now accounts for: I the welfare increase due to the reduction of variable costs and marginal social damages obtained when reducing network leakages; II the welfare increase due to savings on the marginal cost of public funds proportional to the marginal information rent, to be cashed trough a non distortionary price-cap increase, which avoids further resort to costly public subsidies. Marginal costs still include one Euro related to the investment cost plus the marginal cost of public funds.[15]
2b) $c^M > 0$
The constraint on public subsidies (13) holds with the equality sign. This means that public subsides, together with variable profits, are not sufficient to finance investments. Therefore, some resort to debt is necessary: $0 < c^M < 1$. The optimal share of debt c^M is then derived through the constraint on public transfer (11), which is now binding

$$-\beta(i - \underline{i})K\left[2 - \frac{(i + \underline{i})K}{L_0}\right] - (\rho - r)c^M K + (1 - c^M)K - \overline{T} = 0. \tag{15}$$

The optimal amount of investments K^M depends on the condition

$$(\beta + d)2i\left(1 - i\frac{K^M}{L_0}\right) + \lambda 2\beta(i - \underline{i})\left(1 - \frac{(i + \underline{i})K^M}{L_0}\right) + \lambda(\rho - r)c^M = \\ = 1 + rc^M + \lambda(1 - c^M). \tag{16}$$

According to (16), marginal social benefits also include the marginal savings on the cost of public funds due to the financial efficiency of the water undertaking, implying additional profits to be cashed through a non distortionary increase of the price-cap and proportionally to the optimal share of debt c^M. Marginal costs in turn reflect the optimal finance mix as they include the marginal cost of debt r (for the share c^M) and the marginal cost of public funds λ (for the share $(1 - c^M)$).

6 Corporatization

As far as local governments face increasing constraints on the expansion of taxation and public expenditures, they can revert to off-budget government (Joulfaian and Marlow, 1991) by transforming municipal undertakings into local government sponsored enterprises. Such a trend was analyzed by Bennet and Dilorenzo (1982)

[15] The cost is due to the increase of local taxation which is necessary to raise public funds or eventually to the lower reduction of the tax burden in case variable profits are used to finance investments instead of accruing to municipal fiscal revenues.

for the US, showing that local governments have responded to tax and expenditure limitations by financing expenditures through "off-budget enterprises." A similar phenomenon occurred afterwards in Europe, where local governemnts had to cope with tight fiscal policies imposed by the EU[16]. Empirical evidence shows that many government sponsored enterprises are involved in water supply.[17] Furthermore corporatization may be the first step towards partial privatization. The local governemnt decides to involve private investors as shareholders of the corporation, in order to get both financial and entrepreneurship resources to implement new investments.[18]

Given our interest about investment issues, we consider partial privatization through an increase of the corporation stock, to be completly suscribed by private shareholders entering the company. Partial privatization may be necessary in order to compensate for the elimination of public susbsidies, especially if the growth of debt is constrained as well.[19] In the meantime, the participation of private shareholders is also constrained by local governments, generally not willing to reduce public ownership under the treshold of 51% of corporation stock.[20] However, we suppose that private investors, by financing new investments are also delegated investment decisions, while leaving price decisions to public shareholders.

6.1 Corporatization with Partial Privatization

We consider partial privatization as a tranformation of a government owned corporation into a mixed joint-stock company, through an increase of the corporation stock. The resort to private shareholders may be either a choice of the corporation or the effect of constraints on the maximum share of debt which amounts to $c \leq \overline{c}$.[21] Before partial privatization the corporation stock amounts to S°. Given the amount of debt cK, the residual share of investment $(1-c)K$ can be financed by the contribution ΔS° of private shareholders to the corporation stock, to get

[16] To the extent that "off-budget enterprises" were exempted from limits imposed on municipal budgets, an important wave of corporatizations affected countries like Italy and Germany as a result.

[17] As corporatization consists in the creation of a firm subject to corporate laws, common wisdom has frequently consider the benefits of exempting management from public administration rules and political influence, with the opportunity of introducing more powerful incentives both for managers and workers. However, to the best of our knowledge, it is hard to find theoretical and empirical conclusions about the benefits of pure corporatization in the economic literature. Moreover, one should also be cautios about the reduction of political influence after corporatization, as local governments are just transformed into shareholders and may continue to control the firm, possibly enjoying private benefits due to reduced accountability with respect to their costituency. We neglect these issues here as we analyze them in a separate paper where the assumption of a benvolent governemnt is removed (Cavaliere et al., 2015).

[18] Actually, some empirical evidence concerning the Italian water sector, shows that partial privatization after corporatization was frequently associated with an increase of investments (Bognetti and Robotti, 2007).

[19] Once a corporation has been created, the amount of debt is generally constrained by the value of firm assets, to the extent that firms can borrow external funds up to a multiple of firm assets. In the particular case of water utilities, a significant portion of ancient networks may be already depreciated and the value of firm assets could be particluarly low, until new investments are carried out.

[20] See Bognetti and Robotti (2007) and Grossi and Reichard (2008) for some evidence about the governance of local public utilities transformed into mixed corporations.

[21] If constraints on debt arise from the value of existing assets, then the increase of the corporation stock due to new investments will contribute to increase the share of debt, though we suppose that some constraint will persist.

$K = cK + \Delta S^{\circ}$, with $\Delta S^{\circ} = (1-c)K$. As partial privatization implies a scarcity of financial resources for the local government, we exclude further contributions by public shareholders to the corporation stock. We also neglect the opportunity of self-financing through dividends not distributed to shareholders. After partial privatization, corporation stock increase to $S = S^{\circ} + (1-c)K$. Therefore the share of the local government reduces to $p = \frac{S^{\circ}}{S}$, so that the public and private shares are, respectively,

$$p = \frac{S^{\circ}}{S^{\circ} + (1-c)K}, \qquad (1-p) = \frac{(1-c)K}{S^{\circ} + (1-c)K}. \tag{17}$$

Under mixed ownership, in order to keep the control of water prices,the local government needs to hold the majority of shares, i.e. $p \geq 0.51$. Given this governance constraint, the (approximate) upper bound on the the increase of corporation stocks due to private investors is $\Delta S^{\circ} = (1-c)K \leq 0.96\, S^{\circ}$.

The financing support of private sharholder entitles them to choose the amount of investments, which are carried out by a private manager. Through the investment choice, private shareholders are able to affect the ownership structure of the company and then also the local government share (cfr. (17)). The benevolent politician retains the right to choose the amount of debt and the price, to maximize social welfare. Price regulation, as in the previous section, sets a revenue-cap $\overline{P}^{C}$ that grants a rate of return ρ on firm assets, including in this case both new investments K and the pre-exisiting corporation stock S°:

$$\overline{P}^{C} = \beta \left(1 + L_0 - 2\underline{i}K + \frac{(\underline{i}K)^2}{L_0} \right) + (1+\rho)K + \rho S^{\circ}. \tag{18}$$

As the benevolent politician maximizes local welfare, private shareholders run the ex-ante risk that their public partner will not maximize the corporation profits. Therefore, in order to attract private investors, the local government should assure them a minimum profit π (a participation constraint), sufficient to recover the opportunity cost of capital:

$$\pi = (1-c)\alpha\rho K, \quad c \leq \overline{c}, \tag{19}$$

where ρ is the rate of return set by the regulator and α results from the correction of ρ in order to account for the opportunity cost of capital; we can easily assume that $\alpha < 1$. As with muncipalization, we assume that $r < \rho$.

More generally, the profit of the firm will be

$$\Pi^{C} = P - \beta \left(1 + L_0 - 2iK + \frac{(iK)^2}{L_0} \right) - K - crK, \tag{20}$$

and from (19) we obtain

$$\Pi^{C} \geq \pi = (1-c)\alpha\rho K.$$

As private stockholders are assured a minimum profit, total dividends U are shared between private U_{1-p} and public U_p stockholders as follows:

$$\begin{array}{lcl} U_{1-p} & = & \max\left\{(1-p)\Pi^{C}; (1-c)\alpha\rho K\right\}, \\ U_p & = & \Pi^{C} - U_{1-p}. \end{array} \tag{21}$$

It is possible to define the minimum price P_0 which covers the cost of debt and the opportunity cost of capital for private investors, assuming that the local politician may give up its rights to a portion of dividends (including the remuneration of the local goverment stock S°):

$$P_0 = \beta\left(1 + L_0 - 2iK + \frac{(iK)^2}{L_0}\right) + K + (cr + \alpha\rho(1-c))K.$$

Actually, if $P = P_0$ then $U_p = 0$, as $\Pi^C = U_{1-p} = (1-c)\alpha\rho K$.

While prices increase above P_0, profit growth assures a share of profits also to the local government, though still assuring that the participation constraint be satisfied. Then we can define a price interval $(P_0, P_S]$, with

$$P_S = \left(\frac{1-c}{1-p}\,\alpha\rho + 1 + cr\right)K + \beta\left(1 + L_0 - 2iK + \frac{(iK)^2}{L_0}\right),$$

where P_S is the price level such that, for $P = P_S$:

$$\begin{aligned}(1-p)\Pi^C &= (1-c)\alpha\rho K\\ U_{1-p} &= (1-c)\alpha\rho K,\\ U_p &= \Pi^C - U_{1-p} = \alpha\rho S^\circ.\end{aligned}$$

Then at $P = P_S$, the local government obtains a rate of return on its assets equal to the opportunity cost of capital granted to private shareholders. For any $P > P_S$, the dividends cashed by private stockholders exceed their participation constraint π and are equal to $U_{1-p} = (1-p)\Pi^C$. Likewise, the local government will get $U_p = p\Pi^C$. In this last case, if $P = \overline{P}^C$ the regulator grants a rate of return on assets $\rho > \alpha\rho$.

6.1.1 Equilibrium Analysis

We assume that borrowing, investment and pricing decisions are taken sequentially, given symmetric information between the politician and private shareholders (managers). Therefore, strategic interaction can be represented as a sequential three stage game with perfect information. The timing is the following:

1. In the first stage the benvolent politician decides the optimal share of debt c by welfare maximization, given the constraint $c \leq \overline{c}$.

2. In the second stage (privatization stage), private shareholders act as a Stackelberg leader with respect to the price-maker politician, by choosing the optimal amount of K, accounting for the subsequent choice of P by the politician. At this stage, we assume that private investors will dispose of all the bargaining power and make a take-it or leave-it offer to the politician concerning the amount of investment K, accounting for the share of investment cK to be financed by debt.

3. In the third stage (price-setting stage), given the share c of debt, the amount of K previously chosen and the resulting ownership shares p, $(1-p)$ - which depend on K and c - the local government will maximize welfare by choosing $P \leq \overline{P}^C$.

The game can then be solved by backward induction. Firsly we solve the third stage to determine the welfare maximizing price for any amount of K previously chosen by the private manager and any share of debt cK. Then we solve the second stage, where the private manager commits to a level of K, taking into account the subsequent pricing choice of the politician. Finally, we consider the welfare maximizing level of debt in the first stage, according to the choice of the benevolent politician.

III stage In case of mixed ownership local welfare is given by net consumer surplus, minus environmental damages, plus the social gain related to the amount of dividends distributed to the local government. Actually, these dividends will accrue to the public budget as a tax reduction (or as an increase of expenditure without any tax increase). By assumption, we do not include in social welfare the gains of private shareholders, to the extent that they are external to the local community. Such an assumption can capture the fact that private firms involved in the bussiness of water provision (through partial or complete privatization) are mainly multinational firms. Them, the welfare function is:

$$W^C = P^{\max} - P - d\left[L_0 - 2iK + \frac{(iK)^2}{L_0}\right] + (1+\lambda)U_p. \tag{22}$$

Consider the following maximization problem

$$\begin{aligned}
\max_P W^C = \max_P &\left\{ P^{\max} - P - d\left(L_0 - 2iK + \frac{(iK)^2}{L_0}\right) + (1+\lambda)U_p \right\}, \\
\text{s.t. } P \le \overline{P}^C &= \beta\left(1 + L_0 - 2\underline{i}K + \frac{(\underline{i}K)^2}{L_0}\right) + (1+\rho)K + \rho S^\circ, \\
P \ge P_0 &= \beta\left(1 + L_0 - 2iK + \frac{(iK)^2}{L_0}\right) + K + (cr + \alpha\rho(1-c))K,
\end{aligned}$$

where U_p is given by (21) and $p = \frac{S^\circ}{S^\circ + (1-c)K}$.

Write now the welfare function, using (21) for U_p, and (1) for the losses

$$W^C = P^{\max} - P - d\,L(i,K) + (1+\lambda)\begin{cases} \Pi^C - (1-c)\alpha\rho K, & \text{if } \Pi^C \le \frac{1-c}{1-p}\alpha\rho K, \\ p\,\Pi^C, & \text{if } \Pi^C > \frac{1-c}{1-p}\alpha\rho K. \end{cases}$$

where $\Pi^C \le \frac{1-c}{1-p}\alpha\rho K$, for $P \le P_S$ and $\Pi^C > \frac{1-c}{1-p}\alpha\rho K$ for $P > P_S$.

Since $\frac{\partial \Pi}{\partial P} = 1$ we get

$$\frac{\partial W^C}{\partial P} = \begin{cases} -1 + (1+\lambda) = \lambda, & \text{if } P \le P_S, \\ -1 + (1+\lambda)p, & \text{if } P > P_S. \end{cases} \tag{23}$$

Any price increase has a twofold effect on social welfare: a reduction of consumers' surplus, an increase in dividends accruing to local governments and then to tax-payers. Since when $P \le P_S$ any increase in price is cashed by the local government (as private shareholders stick to their participation constraint), the social benefit due to fiscal gains more than compensate the loss in consumer surplus. Therefore, social welfare is increasing with price (as $\lambda > 0$) and the politician never finds it optimal to fix a price lower than P_S. Also notice that it is never optimal

for the local goverment to give up its right to a remuneration of its share of the corporation stock in order to benefit consumers.

Instead, for $P > P_S$ any profit increase is shared between the local government and the private shareholder in proportion to ownership shares p and $(1-p)$ respectively, and the welfare effect of a price increase depends on the relationship between p and λ. More precisely, thanks to (17),

$$\frac{\partial W^C}{\partial P} = (1+\lambda)p - 1 \begin{cases} > 0, & \text{if } p > \frac{1}{1+\lambda}, \Longrightarrow P^C = \overline{P}, \\ < 0, & \text{if } p < \frac{1}{1+\lambda}. \Longrightarrow P^C = P_S. \end{cases}$$

The greater the local governent stock share and the greater the marginal cost of public funds, the more it is likely that the benefits for tax-payers can overcome the cost for final consumers, leading the benevolent politician to choose the maximum price $\overline{P}^C$, in order to use revenues within the public budget. On the contrary, with a low marginal cost of public funds, the government would find it better to minimize prices to the benefits of consumers and set $P^C = P_S$.

As $p = \frac{S^\circ}{S^\circ + (1-c)K}$, the above price rule will depend on the value of K, to be chosen by private shareholders in the second stage of the model: for $K \leq \frac{S^\circ \lambda}{1-c}$ the politician will increase the price to the maximum allowed level $\overline{P}^C$, whereas for $K > \frac{S^\circ \lambda}{1-c}$ welfare is decreasing with prices, as soon as the price is larger than P_S, implying an optimal price

$$\begin{cases} P^C = \overline{P}^C, & \text{if } p = \frac{S^\circ}{S^\circ + (1-c)K} > \frac{1}{1+\lambda}, \quad \text{i.e. } K < \frac{S^\circ \lambda}{1-c}, \\ P^C = P_S, & \text{if } p = \frac{S^\circ}{S^\circ + (1-c)K} < \frac{1}{1+\lambda}, \quad \text{i.e. } K > \frac{S^\circ \lambda}{1-c}. \end{cases} \tag{24}$$

II stage The previous price rule is common knowledge and makes optimal prices a function of the local government share of the corporation stock and the marginal cost of public funds. To the extent that the local government share p, depends both on the share of debt (to be decided by the politician) and on the amount of investment (to be decided by the manager), we can notice that the private manager, through his choice of K can strategically affect the choice of P by the benevolent politician. In what follows, we firsly analyze the choice of K, by private shareholders interested in the maximization of their profit share.

Given the politician's price selection rule (24), the manager will maximize the private dividends in excess over its opportunity cost $(1-c)\alpha\rho K$:

$$V = \begin{cases} (1-p)\left[\beta(i-\underline{i})K\left(2 - \frac{(i+\underline{i})K}{L_0}\right) + (\rho - rc)K + \rho S^\circ\right] - (1-c)\alpha\rho K, \\ \qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad \text{if } K \leq S^\circ \frac{\lambda}{1-c}, \\ 0, \qquad\qquad\qquad\qquad\qquad\qquad \text{if } K > S^\circ \frac{\lambda}{1-c}. \end{cases} \tag{25}$$

where in the first line, the squared brackets include the profit for $P^C = \overline{P}^C$, while in the second line the price is $P^C = P_S$.

So the function V is composed by a positive branch (null for $K = 0$) and an identically null branch. Therefore, to maximize V, private shareholders will select $K \leq S^\circ \frac{\lambda}{1-c}$. Actually, $K \leq S^\circ \frac{\lambda}{1-c}$ assures that the investment is suffciently low to let the local governemnt share grow enough to lead the welfare maximizing politician to choose $P^C = \overline{P}^C$ in the third stage.

Beyond $K \leq S^{\circ}\frac{\lambda}{1-c}$, one should also consider the technological constraint $\frac{L_0}{i}$ and the governance constraint $p \geq 0.51$, to be stated as $K \leq \frac{0.96S^{\circ}}{1-c}$. Then, by substituting (17) into (25), it is possible to show (Appendix II) that V is strictly increasing in K, for $0 \leq K \leq \min\left\{\frac{\lambda S^{\circ}}{1-c}, \frac{L_0}{i}, \frac{0.96S^{\circ}}{1-c}\right\}$, and being $V = 0$ for $K > S^{\circ}\frac{\lambda}{1-c}$, the global maximum is then $K^C = \min\left\{\frac{\lambda S^{\circ}}{1-c}, \frac{L_0}{i}, \frac{0.96S^{\circ}}{1-c}\right\}$.

Now we can distinguish three cases according to which constraint is binding:

1. $K^C = \frac{\lambda S^{\circ}}{1-c}$; in this case it is straightforward to obtain the equilibrium ownership shares as: $p = \frac{1}{1+\lambda}$, $1-p = \frac{\lambda}{1+\lambda}$ which just depend on λ.[22]

2. $K^C = \frac{L_0}{i}$; this case is more likely to occur the higher the value of the efficiency of capital is.

3. $K^C = \frac{0.96S^{\circ}}{1-c}$; the private sharholder finds it proifitable to increase K (together with its ownership share $(1-p)$) until $p = 0.51$. Please notice that in this last case $\lambda \geq 0.96$.[23]

I stage Let us consider the decision of the politician about the optimal share of debt c,

$$\max_c W^C = \max_c \left\{ P^{\max} - P - d\left[L_0 - 2iK + \frac{(iK)^2}{L_0}\right] + (1+\lambda)U_p \right\},$$
$$\text{s.t. } c \leq \overline{c}.$$

Considering that the solution of this problem depends on P, to be chosen by the politician in the third stage, for any K chosen in the second stage by the private manager, one can show (check Appendix III) that the assumption that the opportunity cost of equity is greater than the cost of debt, $\alpha\rho > r$, ensures that the politician always finds it convenient to choose the maximum share of debt, $c = \overline{c}$, both in case $P = P_S$ and in the case $P = \overline{P}^C$.[24]

The results of equilibrium analysis are summarized in the following Proposition.

[22] For example, with $\lambda = 0.01$ the ownership share of the local govrnement into the mixed firms will be around 77%.

[23] Such an high value for λ appears to be at odds with empirical findings. According to them λ is not expected to be greater than 0.3 (Snow and Warren, 1996)

[24] The intuition about welfare being strictly increasing in c - for any P - can be explained as follows. Let us consider firstly the case of $P = P_S$. In this case $U_p = \alpha\rho S^{\circ}$ (cfr. (21)), the variation of c affects welfare only through its effect on P_S, which can be conveniently written as $P_S = S^{\circ}\alpha\rho + (1-c)K\alpha\rho + K + crK + \beta\left(1 + L_0 - 2iK + \frac{(iK)^2}{L_0}\right)$. One can easily check that an increase of c has two opposite effects on P_S. On the one hand, it increases the cost of capital in proportion to r; on the other hand, by reducing the private shareholders contribution to the corporation stock, it reduces their ownership share and the minimum dividends to be granted to them in proportion to $\alpha\rho$. If the second effect more than compensates the first, due to $\alpha\rho > r$, then any increase of c leads to a price reduction and thereby to an increase of welfare. Now let us consider the case of $P = \overline{P}^C$. The regulator rewards all the amount of capital at a rate of ρ, regardless of the financial source (cfr. (24)), so a variation of c affects welfare only through the effect on the local government dividends U_p, as they are devoted to the reduction of distortionary taxes. By considering that $U_p = p\Pi$, with $\Pi = \overline{P}^C - \beta\left(1 + L_0 - 2iK + \frac{(iK)^2}{L_0}\right) - K - crK$, one can check that an increase of c has two opposite effects on the dividends cashed by the local government, and thereby on welfare. On the one hand, it increases the share of profits gained by the local government through, p, which in turn leads to an increase of U_p, a reduction of distortionary taxation and, thereby, to a welfare increase. On the other hand, any increase of

Proposition 3 *The sequential game with perfect information has a sub-game perfect Nash equilibrium characterized as follows: In the first stage, the benevolent politician chooses the maximum share of debt $c = \overline{c}$ regardless of K and P. In the second stage, private shareholders choose a level of investment $K^C \leq \frac{\lambda S^\circ}{1-\overline{c}}$, sufficiently low to lead the benevolent politician to choose the price-cap in the third stage; K^C will be equal to $\frac{\lambda S^\circ}{1-\overline{c}}$ provided the tecnological constraint, $K^C \leq \frac{L_0}{i}$, and the governance constraint, $K^C \leq \frac{0.96 S^\circ}{1-c}$, are satisfied, i.e. $\frac{\lambda S^\circ}{1-\overline{c}} \leq \min\left\{\frac{L_0}{i}, \frac{0.96 S^\circ}{1-c}\right\}$.*

6.2 Government Owned Corporation

Government owned corporations (GOC) may be the result of the transformation of municipal undertakings into joint-stock companies. Eventually they represent the first step toward the creation of a mixed firms. With public ownership, the local government is the sole shareholder of the joint-stock company. By considering the previous subsection, GOC results to be consistent with the case where there are no constraints on debt: $0 \leq c \leq 1$. Full ownership by the local governemnt implies that the politican will select $P^C = \overline{P}^C$, as $p = 1$, and then the condition $p > \frac{1}{1+\lambda}$ holds.

When considering the choice of K by a GOC we get the same result obtained in case of of municipalization when $c = 1$ (case one in previous section), as shown in Appendix IV. Therefore, with a benevolent politician, GOC results to be indifferent with respect to municipal undertakings, provided investments are completely financed by debt. This indifference result suggests that the adoption of a GOC as an institutional solution for water supply, may depend from variables that are exogneous to this model. For example differences between municipalization and GOC could arise when removing the assumption of a benevolent govermnent, considering changes in political accountability. Actually, with a GOC, the control by the municipal council is expected to be lighter with respect to municipalization, and frequenly reduced to compliance with corporate laws.

7 Privatization

In case of complete privatization of the water service, the local government looses control on both prices and investments. Therefore, the private firm in charge of the service will be just subject to price regulation by the national agency, according to the revenue-cap mechanism. We assume that the firm will finance investments by resorting to both debt and equity. For the sake of simplicity, we consider the weighted average cost of capital w corresponding to the financial choices of the firm assumed as exogenously given. Where $w = cr + (1-c)\alpha\rho$, being r and $\alpha\rho$ the cost of debt and the cost of equity respectively, and c the share of debt. The private water undertaking will decide the amount of investments and the price which maximixe

c reduces the amount of corporation profits in proportion to r, leading to a lower reduction of distortionary taxation which negatively affects welfare. Notice that $\rho > r$ is a sufficient condition for making the first effect greater than the second one, and thereby letting social welfare to increase in c.

the profit, given the revenue-cap constraint:

$$\max_{P,K} \Pi^P = \max_{P,K} \left\{ P - \beta \left[1 + L_0 - 2iK + \frac{(iK)^2}{L_0} \right] - (1+w)K \right\},$$
$$\text{s.t. } P \leq \overline{P} = \beta \left[1 + L_0 - 2\underline{i}K + \frac{(\underline{i}K)^2}{L_0} \right] + (1+\rho)K.$$

The profit function is strictly increasing in P, therefore, in the optimum, the constraint holds with the equality sign. By substitution of the price-cap in the profit function the maximization problem becomes

$$\max_{K} \Pi^P = \max_{K} \left\{ \beta \left[1 + L_0 - 2\underline{i}K + \frac{(\underline{i}K)^2}{L_0} \right] + (1+\rho)K \right.$$
$$\left. - \beta \left[1 + L_0 - 2iK + \frac{(iK)^2}{L_0} \right] - (1+w)K \right\},$$

that simplifies into

$$\max_{K} \Pi^P = \max_{K} \left\{ \beta(i-\underline{i})K \left[2 - \frac{(i+\underline{i})K}{L_0} \right] + (\rho - w)K \right\}.$$

The f.o.c. is

$$\frac{\partial \Pi^P}{\partial K} = 2\beta(i-\underline{i}) \left(1 - \frac{(i+\underline{i})K}{L_0} \right) + (\rho - w) = 0,$$

and remembering that $w = cr + (1-c)\alpha\rho$, the f.o.c. can be rewritten as

$$2\beta(i-\underline{i}) \left(1 - \frac{(i+\underline{i})K^P}{L_0} \right) + [\rho - c(r - \alpha\rho)] = \alpha\rho.$$

As the cost of investment is completely reimbursed through price regulation, the marginal cost is just the opportunity cost of capital for private investors, while marginal benefits arise from the appropriation of the marginal information rent in proportion to hydiosincratic effciency and from a rate of return greater than the cost of debt.[25]

The optimal investment is then $K^P = \min \left\{ \frac{L_0}{i},\ \frac{L_0}{i+\underline{i}} \left(1 - \frac{\alpha\rho - [\rho - c(r-\alpha\rho)]}{2\beta(i-\underline{i})} \right) \right\}$ positive and decreasing in i.

8 Calibration exercise

Some relations obtained throughout this paper may be difficult to analyze from a qualitative point of view. For instance, ver/under-investment with respect to the social optimum, in the municipalization case, depends on the parameter values. We expect however, that in most real situations, with credible parameter values, this distortion can be well defined. For this reason, in this section we calibrate the

[25] Even though we assume c as exogenous, remark that the objective function is increasing in c, i.e. the private firms have an incentive to expand the debt. This fact is consistent with the trend towards debt expansion in regulated private firms noticed by Spiegel and Spulber (1994), and followed more recently by some empirical literature devoted to the analysis of the capital structure within regulated firms (Spiegel and Spulber, 1994; Cambini and Rondi, 2010).

model to a plausible real case. Due to the difficulty to retrive real data, we use a couple of studies to find the parameter values, and to cross check the consistence of some common parameter estimates. Calibration data are obtained from South-West France (Garcia and Thomas, 2003) and Norway (Venkatesh, 2012). Total demand is normalized to 1, so every water quantity is rescaled accordingly; we assume that, without any investment, water leaks would amount to 40% of the total demand, i.e. $L_0 = 0.4$. Monetary values in millions of Euros, M€.

	minimum (F)	maximum (F)	average (F)
total demand (Mm^3)	0.012	3	0.40
leaks (Mm^3)	0.001	10	0.15
total variable cost (M€)	0.010	2	0.25
damages (€/Mm^3)	–	–	0.10

Table 1: Extrapolated data from Garcia and Thomas (2003), approximated figures. The original costs were in FRF and has been transformed to current Euros applying a deflator.

France Table 1 presents the main figures from the French case. We use the average values for calibration. The variable cost is equal to $\beta(1 + L)$, therefore $\beta \simeq 0.18$.

Norway The study presents many data from which we can infer technical and economic values. We use the extrapolated data concerning: total demand, leaks volumes, rehabilitation cost, avoided leaks, cost savings. Monetary values are converted to Euros and considered in current terms. We obtain the following values: $i \simeq 0.15$, variable costs can be estimated $0.568\,\text{M€}/\text{Mm}^3$, therefore, in our normalized example, $\beta \simeq 0.227$.

Summing up, we obtain reasonably close values for β. Moreover, we can set $i \simeq 0.15$ and $d \simeq 0.04$,[26] corresponding to $0.1\,€/\text{m}^3$. Therefore, we consider a "current" settings with parameters values

$$\begin{array}{llll} P^{\max} = 8; & L_0 = 0.4; & \lambda = 0.065; & \rho = 0.06. \\ E = 24; & \beta = 0.227; & \bar{c} = 0.5; & = \\ \overline{T} = 0.05; & i = 0.15; & \alpha = 0.9; & = \\ S^{\circ} = 4; & \underline{i} = 0.074925; & r = 0.03; & = \end{array}$$

Starting from this reference settings, we explore a wide set of scenarios, for i ranging from 0.075 to 1.8 and β from 0.016 to 3.178. All cases are evaluated for λ from 0.01 to 0.3 (Snow and Warren, 1996). This means that, for robustness check, we extend the parameter values well beyond a reasonably realistic range. For purposes of concision, we present what we consider more interesting and illustrative; the full

[26] Estimation of social damages due water leaks appears to be quite difficult. To the best of our knowledge, there are no references in the literature, and evaluating the value of wasted water may be an arbitrary excercise. Our estimation is then based on the the sum of: 1) Environmental costs due to the increase of energy use implied by greater pumping effort. This part of the damage can be evaluated by resorting to carbon prices or more generally to carbon values. 2) The value of a tax imposed by the French government on all water users to finance a national fund devoted to investments in water supply. According to Dore et al. (2004) this tax was set at a rate of FF $0.105/\text{m}^3$ in 1992.

results are available upon request. Figure 1 shows the optimal investment for the various institutional forms. The values are plotted with respect to the efficiency parameter i in the cases of current/high variable cost and low/regular/high cost of public funds.

9 Investment Distortions

In this section we compare optimal investments arising from different organizational structures with the social optimum. We consider different values for the technolgical and financial parameters. Theoretical analysis will be supported by numerical simulations, which will be helpful in assessing not only the profile, but also the size of investment distortions.

Let us firstly compare K^* and K^M, by considering marginal social benefits and costs arising from the f.o.c., given that in both cases investment decisions depend on the maximization of a social welfare function. Let us recall relations (4) and (12), defining the f.o.c. respectively, for the social optimum:

$$2(\beta + d)i \left(1 - \frac{(iK^*)}{L_0}\right) = 1, \tag{26}$$

and for municipalization (in sub-case I, $c^M = 1 \Leftrightarrow \lambda > r/(1 + \rho - r)$):

$$2(\beta + d)i \left(1 - i\frac{K^M}{L_0}\right) + \lambda \left[2\beta(i - \underline{i}) \left(1 - \frac{(i + \underline{i})K^M}{L_0}\right)\right] = 1 + r - \lambda(\rho - r). \tag{27}$$

By comparing marginal social benefits (left-hand side of (26) and (27)), we observe that, with muncipalization, investments imply an additional marginal benefit due to the welfare gain arising from the reduction of distortionary taxation allowed by the increase of the information rent (second term in square brackets). Turning then to marginal costs (the left-hand side of both expressions), we observe that with municipalization the net cost of capital $1 + r - \lambda(\rho - r)$ increases with the interest rate and decrease with the saving on public funds due to the financial profit. In the social optimum, the marginal cost is just given by one Euro of revenue, that can be indifferently be raised through (non distortionary) pricing or taxation. Therefore, either *(i)* $r - \lambda(\rho - r) < 0$ and net marginal cost will be lower with municipalization; or *(ii)* $r - \lambda(\rho - r) > 0$ and net marginal costs will be lower in the social optimum. Thanks to the fact that the left-hand side of (27) is strictly decreasing in K, in case *(i)* both higher marginal benefits and lower marginal costs lead to overinvestment in municipalization. In case *(ii)* both overinvestment or underinvestment are possible, depending on the size of the increase of marginal benefits with respect to the size of the increase of marginal costs

$$\lambda 2\beta(i - \underline{i}) \left(1 - \frac{(i + \underline{i})K^M}{L_0}\right) \lessgtr r^M - \lambda(\rho - r^M).$$

We can also consider the same comparison under municipalization in sub-case II (when $\lambda < r/(1 + \rho - r)$ and $c^M = 0$). In that case, the f.o.c. presented in relation (14) is

$$(\beta + d)2i \left(1 - i\frac{K^M}{L_0}\right) + \lambda \left[2\beta(i - \underline{i}) \left(1 - \frac{(i + \underline{i})K_1^M}{L_0}\right)\right] = 1 + \lambda,$$

and the financial profit disappears due to $c^M = 0$. We can observe both an additional marginal benfit and an additional marginal cost in municipalization with respect to the social optimum. Therefore, again both overinvestment and underinvestment are possible.

Both the additional marginal benefits and the additional marginal costs in muncipalization depend on the marginal cost of public funds λ, hence, given proper values for ρ and r, the size of overinvestment and underinvestment with respect to the first best depends on λ as well.

Result 4 *The optimal investments in the municipalization case closely follow the optimal investment chosen by a social planner; deviations are expected to be small in size and directly related to the value of* λ.

The results of numerical simulations in Figure 1: *(i)* show that both with a social planner and municipalization investments are positive only if variable costs increase significantly (check also Appendix 1), as they appear to be null or negligible with lower costs; *(ii)* confirm that the difference between K^M and K^* is small and increasing in λ. Underinvestment occurs in case of low cost of public funds, that is when $\lambda < \frac{r}{1+\rho-r}$: sub-case II, with $c^M = 0$. Overvestment occurs for $\lambda > \frac{r}{1+\rho-r}$: sub-case I, with $c^M = 1$.

We compare then the social optimum K^* with optimal investments carried out with corporatization and privatization. For the sake of simplicity, we firstly consider the comparison between the social optimum and the privatization case.

Result 5 *With a revenue cap mechanism, privatization leads to overinvestment with respect to the social optimum for credible parameters values characterizing water undertakings.*

As already remarked, from (26) it follows that $K^* < \frac{L_0}{i}$, so the constraint $K \leq \frac{L_0}{i}$ is never binding. Furthermore, since K^P is always positive, while for $i < \frac{1}{2(\beta+d)}$, K^* is null, then for $i < \frac{1}{2(\beta+d)}$ privatization implies overinvestment with respect to the social optimum. For larger i, simulations show that overinvestment persists. If $K^P = \frac{L_0}{i}$, as $K^* < \frac{L_0}{i}$, privatization still implies overinvestment with respect to the social optimum. Figure 1 shows a reduction of the size of the investment distortion with the increase of the efficiency of investments, such that for very high values of i differences vanish and $K^P \simeq K^*$.

Actually for a profit maximizing firm the marginal benefits of investments are given by the marginal information rent and marginal financial profits. Therefore, the reduction of variable costs affects only the marginal information rent, while social damages are completely neglected. On the contrary, the social planner finds it worthwhile to invest only when the value of operational expenses and social damages are such to justify the investment cost. Moreover, with privatization the marginal cost of investments is just due to the opportunity cost of capital ($\alpha\rho < 1$), as the investment cost is completely reimbursed through price regulation and therefore it is not accounted as a cost by a profit maximizing firm (though it represents a cost for the local collectivity). Therefore, a profit maximizing firm is lead to invest for any value of variable costs and independently from social damages and investment costs.

In the corporatization case (with partial privatization), investment comparisons appear to be harder. Actually, investments are the result of a strategic choice

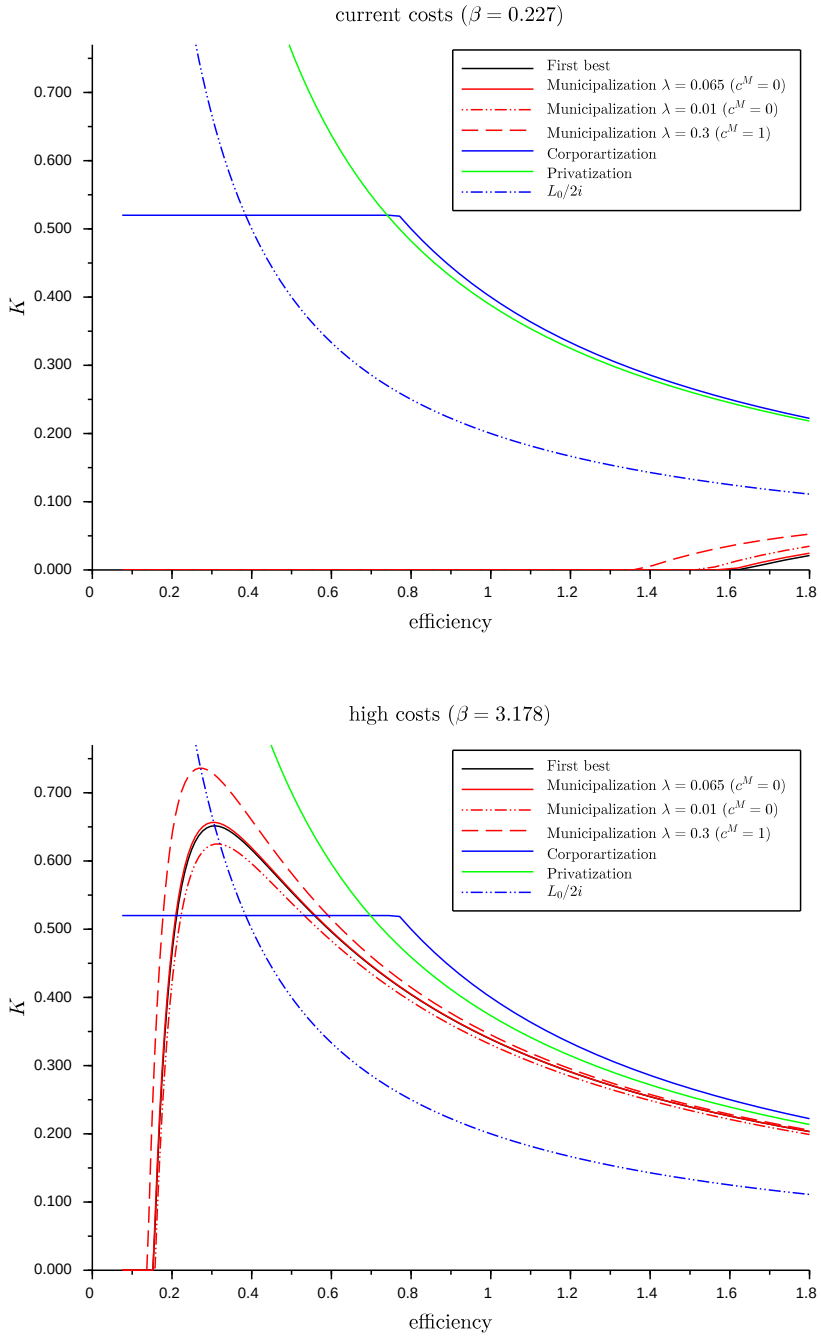

Figure 1: Optimal investment with respect to efficiency i. Two variable costs' values are considered: current, ($\beta = 0.227$, top), high, ($\beta = 3.178$, bottom)

aimed to affect ownership shares in order to avoid investment expropriation by the politician. The optimal investment are given by $K^C = \min\left\{\frac{\lambda S^\circ}{1-c}, \frac{L_0}{i}, \frac{0.96S^\circ}{1-c}\right\}$. The numerical comparison is shown in Figure 1, assuming $\lambda < 0.96$ (i.e. $\frac{\lambda S^\circ}{1-c} < \frac{0.96S^\circ}{1-c}$, so the governance constraint $\frac{0.96S^\circ}{1-c}$ is never binding). We can conclude that the investment is larger in corporatization than in any other institutional form when the public majority constraint is not effective and $K^C = \frac{L_0}{i} < \frac{\lambda S^\circ}{1-c} < \frac{0.96S^\circ}{1-c}$. In this last case private shareholders are lead to expand investment as much as possible, though K^C decreases when efficiency increases (as in Figure 1). When lower values of efficiency would lead to greater values of K^C, then $K^C = \frac{\lambda S^\circ}{1-c} < \frac{L_0}{i}$, and, accordingly K^C becomes flat as it is independent from i. It may then be possible that $K^C < K^P$. Moreover, given high values of variable costs β (to be coupled with lower values of the effciency parameter), we can also observe that $K^C < K^*$, i.e. with corporatization optimal investments may also be lower with respect to the social optimum and muncipalization then (check again Figure 1).

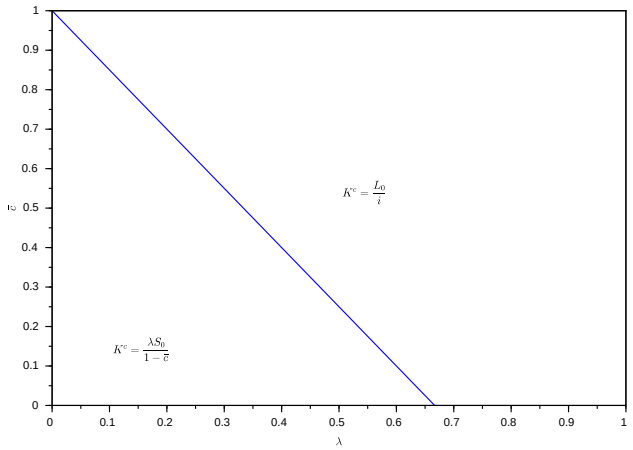

Figure 2: Optimal investment K^C for corporatization, with respect to λ and $\bar{c}$. The line has equation $\bar{c} = 1 - \frac{S^\circ i}{L_0}\lambda$. The efficiency parameter i is set to its current value 0.15, and it is assumed that $\lambda < 0.96$.

Furthermore in Figure 2 one can check that, still assuming $\lambda < 0.96$, the optimal solution $K^C = \frac{\lambda S^\circ}{1-c}$ is more likely, the higher λ is and the lower the constraint on debt $\overline{c}$ is. When the latter increases (for example $\overline{c} > 0.5$), the constraint on the ownership share of the politician (to be satisfied by a lower level of investments and leading to $K^C = \frac{\lambda S^\circ}{1-c}$) becomes less and less important (the greater part of new investments are financed by debt, so that an increase of K affects ownership shares to a lesser extent, thereby relaxing the constraint $K^C = \frac{\lambda S^\circ}{1-c}$) and private shareholders can expand investments as much as possible so that just the (zero-leaks) constraint $K^C = \frac{L_0}{i}$ becomes effective (as shown in Figure 2).

10 Conclusions

Investments to reduce network leaks is a central issue for the water industry. We analized the effect of alternative organizational solutions for water undertakings, as observed across different countries, assuming centralized regulation and a common regulatory mechanism.

One can hardly contend that water supply is an essential service, as shown by demand inelasticity to prices. Further features of water supply are: provision at a local level, implying a great variability of costs and efficiency across water undertakings; and some political control on water prices. As far as regulation with asymmetric information is concerned, we considered a fix-price mechanism, whereby even utilities with the lowest efficiency can feasibly supply water and most efficient one are left information rents. Due to a perfectly inelastic demand, price-caps and revenue caps coincide and information rents have no cost as far as allocative efficiency is concerned.

Actually, even considering the same regulatory mechanism, we found that the incentive to invest mainly depends on the different objective functions of benvolent politicians and private firms. In a social optimum it is wise to invest resources to reduce leaks only when the reduction of costs and social damages justify the investment cost. Still in a social optimum it is indifferent to finance investment by raising revenues through public funds or market revenues, as both taxation and prices are non distortionary. With municipalization, investment finacing is not neutral, due to public subsidies raised through distortionary taxation. Since investment choices are still driven by a social welfare function, the total cost of investment affects welfare, as it represents a cost for the local collectivity, though it is reimbursed to the municipal undertaking through price-cap regulation.

Our results about the effects of the fix-price mechanism imposed on public water undertakings had shown that, even if benevolent politicians (in municipal undertakings and mixed firms) could reduce price below the price-cap - to benefit consumers - they are always lead to maximize fiscal gains, by increasing prices up to the price-cap. However, information rents are valued by benevolent politicians according to the marginal costs of public funds, being a source of revenue for the local goverment. Therefore, the incentive-effect of the price-cap is diluted. In municipalization, despite the fix-price mechanism, the incentive to invest to reduce leaks is not substantially different with respect to the social optimum.

On the contrary, in case of partial or full privatization, only the opportunity cost of capital is accounted for in investment decisions driven by profit maximization. Actually, the reimbursement of the investment cost granted by regulation leads firms not to internalize it in its decision. Not surprisingly, we can observe overinvestment by private firms with respect to the social optimum (and muncipalization as well). Even though private firms do not account for the positive effects of investment on social damages, both the perspective to cash information rents and the reduced capital costs lead to excess investments.

Our conclusions about corporatization and partial privatization deserve a separate treatement. The lack of rigourosus theoretical analysis about government sponsored corporations and mixed firms is at odds with the importance they have assumed in many countries. For the case of a joint stock company completely owned by the government, we just find an indifference result with respect to municipalization. Overcoming this indifference result probably requires to introduce

the assumption of a malevolent governemnt, as we conjecture that corporatization and municipalization differ from the accountability point of view. On the contrary, we have provided a theory of partial privatization and mixed firms keeping the assumption of a benevolent politician. Our theory is based on strategic interaction beween the local government, and private shareholders (managers) who are entitled to decide about investments and the increase of the corporation stock. Private shareholders, in order to avoid investment expropriation, choose investments with the aim of affecting the ownership share of local government. The latter is then led to maximize welfare by caring more about fiscal gains than consumer surplus. Due to the committment effect of investment, the local governent in equilibrium will not deviate from the price-cap, despite its power to set lower prices, with a benefit for private shareholders too. As the investment choice will be just driven by strategic governance decisions, both overinvenstemnt and underinvestment with respect to the social optimum could result in equilibrium.

We are conscious that the assumption of a benevolent government providing water services may appear a strong one. For this reason, we will remove this assumption in a further paper where we will consider investment decisions by local governments driven by political consensus dependent on the level of both water prices and local taxation (Cavaliere et al., 2015).

Though our analysis is devoted to the water industry, we think that it may be also extended to other local public utilities like waste collection and disposal or urban transport, to the extent they are also characterized by price inelastic demand, local provision and vertical integration. Once accounting for the proper change about the assumptions concerning technology.

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Appendix I

10.1 Social Optimum

The network losses function is

$$L = L(i,K) = L_0 - 2iK + \frac{(iK)^2}{L_0},\ K \leq \frac{L_0}{i}, \tag{28}$$

where L_0 is the initial amount of losses, and $\frac{L_0}{i}$ is the level of investments reducing the losses to 0. We indicate explicitely de dependence on i because in subsequent models this will be useful.

The consumer surplus S, the producer profits Π and the welfare maximization problem are

$$\begin{aligned}
S &= P^{\max} - P - d\,L(i,K) - T \\
\Pi &= P - \beta\,[1 + L(i,K)] - K + T \\
\max_{K,P,T} W &= \max_{K,P,T} \{S + \Pi\} = \max_{K,P,T} \{P^{\max} - (\beta + d)L(i,K) - K - \beta\} \\
\text{s.t. } & K \geq 0,\ K \leq \frac{L_0}{i},\ P \geq 0,\ P \leq P^{\max}, \\
& \Pi = P - \beta\,[1 + L(i,K)] - K + T \geq 0,
\end{aligned} \tag{29}$$

We remark that the objective function does not depend on P and T because the demand is perfectly unelastic and taxation is non-distortionary ($\lambda = 0$). Therefore, we can only obtain the optimal investment K^* from

$$\begin{aligned}
\frac{\partial W}{\partial K} &= -(\beta + d)\left(-2i + \frac{i^2}{L_0}K\right) - 1 = 0 \\
K_1 &= \frac{L_0}{i}\left(1 - \frac{1}{2i(\beta + d)}\right).
\end{aligned}$$

Remark that $K_1 < \frac{L_0}{i}$, so the technical constraint $K \leq \frac{L_0}{i}$ is never binding. Moreover, if $2i(\beta + d) < 1$, i.e. if for $K = 0$ the marginal benefit of investment for is lower than its marginal cost, then $K^* = 0$. Therefore the optimal investment in the first best case is

$$K^* = \max\left\{\frac{L_0}{i}\left(1 - \frac{1}{2i(\beta + d)}\right), 0\right\}$$

10.2 Municipalization

In the case of municipalization we introduce:

- an upper bound $\overline{T} > 0$ to the expenditure T;
- a regulated upper bound (price-cap)

  $$\overline{P} = \beta\left(1 + L_0 - 2\underline{i}K + \frac{(\underline{i}K)^2}{L_0}\right) + (1 + \rho)cK \leq P^{\max},\ \underline{i} \leq i$$

  to price P, where $\underline{i}$ is the minimum investment efficiency in reducing losses, and ρ is the risk adjusted cost of capital for the water sector;

- the possibility to resort to debt for a fraction c of the investments K, at an interest rate r.

So the consumer surplus, the profits and the welfer maximization problem become

$$\begin{aligned}
S &= P^{\max} - P - d\,L(i,K) - T(1+\lambda) - \lambda E \\
\Pi &= P - \beta\,[1 + L(i,K)] - (1+cr)K + T \\
\max_{K,P,c,T} W &= \max_{K,P,c,T} \{P^{\max} - (\beta+d)L(i,K) - (1+cr)K - \lambda T - \beta - \lambda E\} \\
&\text{s.t. } K \geq 0,\ K \leq \frac{L_0}{i},\ P \geq 0,\ T \leq \overline{T},\ c \geq 0,\ c \leq 1 \\
&\quad P \leq \overline{P} = \beta\,[1 + L(\underline{i},K)] + (1+\rho)cK \qquad (30) \\
&\quad \Pi = P - \beta\,[1 + L(i,K)] - (1+cr)K + T \geq 0 \qquad (31)
\end{aligned}$$

Following the same argument as for the previous problem, W is decreasing in T, so its optimal value is the one which yields a null profit, provided it is admissible by the constraint system. Therefore, the constraint (31) should hold with the equality sign, hence we use it to explicitate T:

$$T = \beta\,[1 + L(i,K)] + (1+cr)K - P.$$

Substituting for T yields:

$$\begin{aligned}
\max_{K,P,c} W &= \max_{K,P,c} \{P^{\max} - (\beta(1+\lambda)+d)L(i,K) - (1+\lambda)(1+cr)K\} \qquad (32) \\
&\quad + \lambda P - (1+\lambda)\beta - \lambda E \\
&\text{s.t. } K \geq 0,\ K \leq \frac{L_0}{i},\ P \geq 0,\ c \geq 0,\ c \leq 1 \\
&\quad P \leq \beta\,[1 + L(\underline{i},K)] + (1+\rho)cK \\
&\quad \beta\,[1 + L(i,K)] + (1+cr)K - P \leq \overline{T} \qquad (33)
\end{aligned}$$

Now remark thet the welfare is increasing in P, so that the constraint (30) should saturate and we use it to explicitate P

$$P = \overline{P} = \beta\,[1 + L(\underline{i},K)] + (1+\rho)cK,$$

and we susbstitute it to get:

$$\begin{aligned}
\max_{K,c} W &= \max_{K,c} \{P^{\max} - \beta - ((1+\lambda)\beta + d)L(i,K) + \lambda\beta L(\underline{i},K)\} \\
&\quad - (1+\lambda)K + [\lambda(1+\rho-r) - r]\,cK - \lambda E \\
&\text{s.t. } \beta\,[1 + L(\underline{i},K)] + (1+\rho)cK \geq 0 \qquad (34) \\
&\quad \beta\,[L(i,K) - L(\underline{i},K)] + [1 - c(1+\rho-r)]\,K \leq \overline{T} \qquad (35) \\
&\quad K \geq 0,\ K \leq \frac{L_0}{i},\ c \geq 0,\ c \leq 1
\end{aligned}$$

The constraint (34) is always satisfied, because all terms are non-negative.
About the constraint (35):

- for $K = 0$ the constraint (35) is satisfied $\forall c \in [0,1]$;

- for $c = 1$ the constraint (35) is satisfied $\forall K$ admissible;
- for every given $c \in [0,1]$ it exists a $K \geq 0$ small enough to satisfy (35);
- for every given admissible K it exists a $c \in [0,1]$ large enough to satisfy (35);

After these adjustments, and using the definition (28), the maximization problem can be written in the following form

$$\begin{aligned}
\max_{K,c} W = \max_{K,c} & \left\{ P^{\max} - \beta - L_0(\beta + d) + ((1+\lambda)\beta + d) \left(2iK - \frac{(iK)^2}{L_0} \right) \right\} \\
& - \lambda\beta \left(2\underline{i}K - \frac{(\underline{i}K)^2}{L_0} \right) - (1+\lambda)K + [\lambda(1+\rho-r) - r]\, cK - \lambda E \\
\text{s.t.} \; & - \beta(i-\underline{i})K \left[2 - \frac{(i+\underline{i})K}{L_0} \right] + [1 - c(1+\rho-r)]\, K \leq \overline{T} \\
& K \geq 0, \; K \leq \frac{L_0}{i}, \; c \geq 0, \; c \leq 1
\end{aligned}$$

and the corresponding Lagrange function is

$$\begin{aligned}
\mathcal{L} = & P^{\max} - \beta - L_0(\beta + d) + [(1+\lambda)\beta + d] \left(2iK - \frac{(iK)^2}{L_0} \right) \\
& - \lambda\beta \left(2\underline{i}K - \frac{(\underline{i}K)^2}{L_0} \right) - (1+\lambda)K + [\lambda(1+\rho-r) - r]\, cK - \lambda E \\
& - \mu_1 \left[-\beta(i-\underline{i})K \left[2 - \frac{(i+\underline{i})K}{L_0} \right] + [1 - c(1+\rho-r)]\, K - \overline{T} \right] \\
& - \mu_2(-K) - \mu_3 \left(K - \frac{L_0}{i} \right) - \mu_4(-c) - \mu_5(c-1)
\end{aligned}$$

Standard Kuhn-Tucker first order conditions are reported in the following system

$$\nabla\mathcal{L} = \begin{bmatrix}
(K): & [(1+\lambda)\beta + d] \left(2i - \frac{2i^2}{L_0} K \right) - \lambda\beta \left(2\underline{i} - \frac{2\underline{i}^2}{L_0} K \right) \\
 & -(1+\lambda) + [\lambda(1+\rho-r) - r]\, c \\
 & + \mu_1 \left[2\beta \left(i - \underline{i} + \frac{\underline{i}^2 - i^2}{L_0} K \right) - [1 - c(1+\rho-r)] \right] + \mu_2 - \mu_3 \\
(c): & [\lambda(1+\rho-r) - r]\, K + \mu_1(1+\rho-r)K + \mu_4 - \mu_5
\end{bmatrix} = 0$$

$$\begin{bmatrix}
(\mu_1): & \left(-\beta(i-\underline{i})K \left[2 - \frac{(i+\underline{i})K}{L_0} \right] + [1 - c(1+\rho-r)]\, K - \overline{T} \right) \mu_1 \\
(\mu_2): & K\mu_2 \\
(\mu_3): & \left(\frac{L_0}{i} - K \right) \mu_3 \\
(\mu_4): & c\mu_4 \\
(\mu_5): & (1-c)\mu_5
\end{bmatrix} = 0$$

$$\mu_1, \ldots \mu_5 \geq 0$$

We start exploring the solution from the condition about partial derivative with respect to c

$$[\lambda(1+\rho-r) - r]\, K + \mu_1(1+\rho-r)K + \mu_4 - \mu_5 = 0$$

rewritten in the two following ways

$$[(1+\rho-r)(\lambda+\mu_1)-r]K = \mu_5 - \mu_4 \tag{36}$$

$$\mu_1 = \frac{r}{1+\rho-r} - \lambda + \frac{\mu_5-\mu_4}{(1+\rho-r)K} \tag{37}$$

where $1+\rho-r>0$, thanks to our assumptions.

Solutions

CASE I $\lambda > \frac{r}{1+\rho-r}$, that is $\frac{\partial W}{\partial c} > 0$

The coefficient of K in the (36) is positive, therefore, for positive K it is necessary that $\mu_5 > 0$, and from K-T conditions, $c^M = 1$. From the partial derivative of W with respect to K, with $c=1$ if the solution is internal in K, then the optimal K is

$$K_1^M = \frac{L_0}{i}\left(1 - \frac{(1+\lambda) - [\lambda(1+\rho-r)-r] + 2\lambda\beta\underline{i}\left(1-\frac{\underline{i}}{i}\right)}{2i[(1+\lambda)\beta+d] - 2\lambda\beta\frac{\underline{i}^2}{i}}\right). \tag{38}$$

(a) if $K^M < 0$, then $K^M = 0$ and c makes no sense.

(b) else $c^M = 1$

$$K^M = \min\left\{K_1^M, \frac{L_0}{i}\right\}$$

The constraint (35) is satisfied with the strict sign for $c=1,\ \forall K>0$ (thus $\mu_1 = 0$).

CASE II $\lambda = \frac{r}{1+\rho-r}$, that is $\frac{\partial W}{\partial c} = 0$

In case of internal solution for K, it is

$$K_1^M = \frac{L_0}{i}\,\frac{(1+\lambda) + 2\lambda\beta\underline{i} - 2i[(1+\lambda)\beta+d]}{\lambda\beta\frac{2\underline{i}^2}{L_0} - [(1+\lambda)\beta+d]\frac{2i^2}{L_0}}. \tag{39}$$

(a) if $K_1^M < 0$, then $K^M = 0$ and c makes no sense.

(b) else

$$K^M = \min\left\{K_1^M, \frac{L_0}{i}\right\}$$

and the constraint (35) allows to find the admissible range of values for c: $c \in [c_{\min}, 1]$, with $c_{\min}$ the value for which (35) holds with the equality sign for $K = K^M$.

CASE III $\lambda < \frac{r}{1+\rho-r}$ that is $\frac{\partial W}{\partial c} < 0$

An internal solution for c, i.e. $c^M \in (0,1)$, implies that $\mu_4 = \mu_5 = 0$ and from (36) and (37) we get $\mu_1 = \frac{r}{1+\rho-r} - \lambda$, so

$$K^M = \max\left\{\frac{L_0}{i}\,\frac{2i(\beta+d) + \frac{2r\beta(i-\underline{i})}{1+\rho-r} - \frac{1+\rho}{1+\rho-r}}{2i(\beta+d) + \frac{2\beta r}{1+\rho-r}\frac{(i^2-\underline{i}^2)}{i}}, 0\right\}$$

where, thanks to the fact that $(i-\underline{i}) < \frac{i^2-\underline{i}^2}{i}$, the fraction multiplying $\frac{L_0}{i}$ is smaller than 1, therefore $K^M < \frac{L_0}{i}$. Then $c^M = c_{\min}$, as defined above, should be internal. Otherwise the following cases will occur.

(a) If $c_{\min} \leq 0$, then $c^M = 0$ and in case of internal solution for K, it is given by (39).

(b) If $c_{\min} \geq 1$, then $c^M = 1$ and in case of internal solution for K, it is given by (38).

In both cases

$$K^M = \max\left\{\min\left\{K_1^M, \frac{L_0}{i}\right\}, 1\right\}.$$

Appendix II

In this appendix we study the monotonicity of the function $U_{1-p}$with respect to K.

$$U_{1-p} = \begin{cases} (1-p)\left[\beta(i-\underline{i})K\left[2-\frac{(i+\underline{i})K}{L_0}\right]+(\rho-rc)K+\rho S^\circ\right]-(1-c)\alpha\rho K, & \\ & \text{if } K \leq S^\circ\frac{\lambda}{1-c} \\ 0, & \text{if } K > S^\circ\frac{\lambda}{1-c} \end{cases}$$

When $K \leq S^\circ\frac{\lambda}{1-c}$ the complete form of U_{1-p} is

$$U_{1-p} = \frac{(1-c)K}{S^\circ+(1-c)K}\left[\beta(i-\underline{i})K\left[2-\frac{(i+\underline{i})K}{L_0}\right]+(\rho-rc)K+\rho S^\circ\right]-(1-c)\alpha\rho K$$

which can be written as

$$U_{1-p} = \frac{(1-c)K}{S^\circ+(1-c)K}\left[\beta(i-\underline{i})K\left[2-\frac{(i+\underline{i})K}{L_0}\right]+(\rho-rc-(1-c)\alpha\rho)K+\rho(1-\alpha)S^\circ\right]$$

where the two factors are positive:

$$\frac{(1-c)K}{S^\circ+(1-c)K} = 1-p > 0,$$

$$\beta(i-\underline{i})K\left[2-\frac{(i+\underline{i})K}{L_0}\right] > 0 \text{ if } K < 2\frac{L_0}{i+\underline{i}}, \text{ where } 2\frac{L_0}{i+\underline{i}} > 2\frac{L_0}{i+i} = \frac{L_0}{i},$$

$$(\rho-rc-(1-c)\alpha\rho) = \rho[1-(1-c)\alpha]-rc\underbrace{>}_{\rho>r}r[1-(1-c)\alpha-c] = r(1-\alpha)(1-c) > 0,$$

$$\rho(1-\alpha)S^\circ > 0$$

The first factor $\frac{(1-c)K}{S^\circ+(1-c)K}$ has a positive derivative $\frac{(1-c)S^\circ}{[S^\circ+(1-c)K]^2}$, whereas the second factor has the derivative

$$2\beta(i-\underline{i})+\rho-rc-(1-c)\alpha\rho-2\beta\frac{i^2-\underline{i}^2}{L_0}K,$$

which is positive when

$$K < \frac{2\beta(i-\underline{i})+\rho-rc-(1-c)\alpha\rho}{2\beta\frac{i^2-\underline{i}^2}{L_0}} = \frac{L_0}{i+\underline{i}}+\frac{\rho-rc-(1-c)\alpha\rho}{2\beta(i^2-\underline{i}^2)}.$$

This show that an analytical conclusion about the monotonicity of U_{1-p} cannot be easily found. A sufficient condition is that for $K < \frac{L_0}{i+\underline{i}}$, the function U_{1-p} is strictly increasing in K. However, we obtained an interesting result by simulation as follows:

- We randomly generate 100,000 parameter sets in the ranges, $\underline{i} = 0.074925$;

$$\begin{array}{lll} S^\circ \in (1,20); & i \in (\underline{i}, \underline{i}+2); & \alpha \in (0.1,1); \\ L_0 \in (0.1,20); & \lambda \in (0.001, 0.35); & r \in (0.001, 0.1); \\ \beta \in (0.01,3); & \bar{c} \in (0.01,1); & \rho \in (r/\alpha, r/\alpha + 0.1). \end{array}$$

- We computed the K° that maximizes U^C_{1-p} in the range $K \in \left(0, 2\frac{L_0}{i}\right)$.

- We computed the number of times when $K^\circ < \frac{S^\circ \lambda}{1-c}$ and $K^\circ < \frac{L_0}{i}$. We found that this number is 0.

Therefore, we are reasonably sure that the function U^C_{1-p} is strictly increasing for $K \in \left(0, \frac{S^\circ \lambda}{1-c}\right)$.

11 Appendix III

In this appendix we formally proove that in case of corporatization social welfare is strictly increasing in c for any P.

1. $P = P_S$. By substituting and $U_p(P_S) = \alpha\rho S^\circ$ (see eq 21)) in (22) we get the maximization problem

$$\begin{aligned} \max_c W^C = \max_c & \left\{ P^{\max} - P_S - d\left[L_0 - 2iK_m + \frac{(iK)^2}{L_0}\right] + (1+\lambda)\alpha\rho S^\circ \right\} \\ \text{s.t. } P_S = & \left(\frac{1-c}{1-p}\alpha\rho + 1 + cr\right)K + \beta\left(1 + L_0 - 2iK + \frac{(iK)^2}{L_0}\right) \\ & c \le \overline{c}. \end{aligned}$$

   By substitution of $(1-p) = \frac{(1-c)K}{S^\circ + (1-c)K}$ in P_S we obtain

$$P_S = S^\circ\alpha\rho + (1-c)K\alpha\rho + K + crK + \beta\left(1 + L_0 - 2iK + \frac{(iK)^2}{L_0}\right),$$

   and differentiating W^C w.r.t. P_S, we get

$$\frac{\partial W^C}{\partial c} = -\frac{\partial P_S}{\partial c} = (\alpha\rho - r)K > 0 \text{ for } \alpha\rho > r.$$

2. $P^C = \overline{P}^C$, then the welfare maximization problem is

$$\begin{aligned} \max_c W^C = \max_c & \left\{ P^{\max} - \overline{P}^C - d\left[L_0 - 2iK + \frac{(iK)^2}{L_0}\right] + (1+\lambda)p(c,K)\Pi^C\left(\overline{P}^C, K\right) \right\} \\ \text{s.t. } \overline{P}^C = & \beta\left(1 + L_0 - 2\underline{i}K + \frac{(\underline{i}K)^2}{L_0}\right) + (1+\rho)K + \rho S^\circ \\ \Pi^C(\overline{P}^C) = & \beta(i-\underline{i})K\left[2 - \frac{(i+\underline{i})K}{L_0}\right] + (\rho - cr)K + \rho S^\circ \\ p(c,K) = & \frac{S^\circ}{S^\circ + (1-c)K}. \end{aligned}$$

By differentiating w.r.t. to c, we get

$$\begin{aligned}\frac{\partial W}{\partial c} &= \frac{\partial p}{\partial c}(1+\lambda)\Pi^C(\overline{P}^C,K)+p(c,K)(1+\lambda)\frac{\partial \Pi^C(\overline{P}^C,K)}{\partial c}= \\ &= \frac{Kp(c,K)}{S^\circ+(1-c)K}(1+\lambda)\Pi^C(\overline{P}^C,K)-p(c,K)(1+\lambda)rK.\end{aligned}$$

By giving prominence to $(1+\lambda)Kp(c,K)$ and by substition of $\Pi^C(\overline{P}^C,K)$, we get

$$\frac{\partial W}{\partial c}=\frac{\beta K(i-\underline{i})}{S^\circ+(1-c)K_m}\left[2-\frac{(i+\underline{i})K}{L_0}\right]+\frac{(\rho-cr)K+\rho S^\circ}{S^\circ+(1-c)K}-r$$

Notice that

$$\frac{(\rho-cr)K+\rho S^\circ}{S^\circ+(1-c)K}-r>0\Longrightarrow\frac{\partial W}{\partial c}>0\Longrightarrow c=\overline{c}.$$

By solving we obtain

$$\frac{(\rho-cr)K+\rho S^\circ}{S^\circ+(1-c)K}-r=\frac{(\rho-r)(S^\circ+K)}{S^\circ+(1-c)K}>0.$$

Appendix VI

We can then consider the choice of K by a GOC, by substitution of $P^C=\overline{P}^C$ into the welfare maximization problem, as follows:

$$\begin{aligned}\max_{K^C} W^C = \max_{K^C}\Big\{&P^{\max}-\beta-(\beta+d)\,L_0+[(1+\lambda)\beta+d]\left[2iK-\frac{(iK)^2}{L_0}\right]\\ &-\lambda\beta\left[2\underline{i}K-\frac{(\underline{i}K)^2}{L_0}\right]+(1+\lambda)(\rho-r)K-(1+\rho)K+\lambda\rho S^\circ\Big\},\\ \text{s.t. } &K\geq 0,\ K<\frac{L_0}{i}.\end{aligned}$$

By considering the f.o.c., and with some simplifications we obtain:

$$(\beta+d)2i\left(1-i\frac{K_1^M}{L_0}\right)+\lambda 2\beta(i-\underline{i})\left(1-\frac{(i+\underline{i})K_1^M}{L_0}\right)+\lambda(\rho-r^M)=1+r.$$

The expression above is identical to the one obtained in case of municipalization when $c=1$.