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The impact of productive efficiency and quality of a regulated local public utility on final goods prices

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Abstract
In this note we reconstruct the process by a which the decisions of a regulated local public utility, in terms of productive efficiency and quality of the service provided, impact on prices of final consumption goods, supplied in a oligopolistic market operating in the same geographic area. We obtain some formula for these effects which can be quantified by estimating firms' conditional input demand function of the public service and firms' inverse demand function for the public good, non-rival, component of this.

Keywords: regulation, x-efficiency, oligopoly

JEL Classifications: L51, D11, D21

1. Introduction

Local public services, like water distribution, sewerage treatment and disposal, waste collection and disposal, gas and electricity distribution, local public transport, by road as well by rail, not only supply *consumption goods* to resident households but also act as *inputs* in local firms production processes by influencing their costs and consequently their final prices. This insertion in the productive processes occurs, first of all, throughout the level and the dynamics of tariffs, so a crucial role is played by the productive efficiency entering the costs of the firm producing the service. Secondly, this enters production processes of firms supplying final goods throughout the quality of provision, that, combined with specific environmental characteristics of the area, determines the degree by which this spreads positive externalities all around.

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Indeed, local public services, although in general excludable and rival ones, have often also some public good component. For instance, waste collection and disposal, sewerage service have positive external effects by cleaning the area and by reducing water and air pollution. Gas and electricity distribution can be organised in order to save exhaustible resources and to supply clean energy. Public transport, reducing the use of private cars, can limit urban congestion costs and air pollution. All those effects create in some way a favourable environment for sales and exchanges of final consumption goods, thus rising local firms productivity[1].

Aim of this note is to enlighten the process by which the decisions of a regulated local public utility (RLPU), a natural monopoly producing and providing a service, can determine, via cost-efficiency and quality, a shift on final goods prices set in markets operating in the same geographic area. In section 2 we describe the technology and the subsequent cost function of the firms involved in the game. In section 3 we analyse the RLPU choices upon tariffs, quality and managerial effort. In section 4 we find a Cournot equilibrium price for a consumption good and we determine the impact on this of decisions taken, in the first stage, by the RLPU. Section 5 concludes.

2. Firms technology and cost functions

We consider an economic district where n local firms, $l=1\ldots,n$, are competing in supplying a final good j and a RLPU is serving local population and firms. We imagine the technology of the Public utility is represented by the following cost function, separable on fixed and variable costs:

$$C_{PU}(Y,,m, a, \boldsymbol{A})= F(m, \boldsymbol{A})+[c(m)+a]Y \qquad (1)$$

where $Y=y^h+y^f$ is the total output respectively supplied to households (*domestic customers*) - $y^h=D^h(.)$ - and to firms (*business customers*) - $y^f=D^f(.)$. m is an index

[1] In this respect we may think at an enlarged notion of "accessibility" of the area, a well known concept introduced into modern regional economics (Behrens and Thisse 2007).

of service provision quality. It could be an index of organoleptic properties of drinking water gushing out of the aqueduct or an index of supply continuity and safety for water, gas, electricity distribution. It could give a measure of time frequency of buses stops in the urban area or a measure of the extension and capillarity of a metro network or of the share of buses in the fleet using clean fuel. It could be an index related to the technological level of waste disposal plants and so on. These indexes are often inserted in the contract signed by the firm and the regulator as some standard level the former has to achieve. Formally we have $\partial F/\partial m>0$: an increase of quality provokes an increase of fixed costs by asking for higher infrastructural investments[2]. $\boldsymbol{A}$ is a vector of environmental variables – population density, altitude, orographical characteristics of the soil, level of precipitations, etc. – which influences production costs of the RLPU, $\partial F/\partial \boldsymbol{A}$, with a sign depending on the specific variable considered. $c(m)+a$ is the marginal cost of the service, where $c(m)$ is the minimum cost, given the technology, supposed to be an increasing function of quality, $c'(m)>0$, as higher quality may require more labour and maintenance costs, while a is a variable of x-efficiency. It could be $a=c[(1/e)-1]$, with $e \in (0,1]$ the managerial effort increasing productivity of labour in a Leontief technology[3]. Alternatively a could be a measure of perk and wasteful expenditures carried on by the manager. Of course, if the regulated firm is fully x-efficient $a=0$, otherwise $a>0$.

Let G be the public good component or the externality spread by the service, whose benefit extends to all citizens and firms in the area. We may reasonably imagine that this will come through by connecting service quality and environmental variables in this way:

$$G=\xi(m,\boldsymbol{A}) \qquad (2)$$

[2] For the recent and relevant strand of literature linking the quality of the service to investment costs of a public utility, see Bennett and Iossa (2006).

with $\partial\xi/\partial m>0$ and with a sign of $\partial\xi/\partial \boldsymbol{A}$ depending, once again, on the specific variable considered.

As far as the technology of the firms supplying the consumption good, let the production function of firm l given by:

$$X_{lj}=f_l(\boldsymbol{r}_l,q_l,G),\ l=1,\ldots n \tag{3}$$

$\boldsymbol{r}_l$ is the vector of private inputs and q_l is the direct use of the public service as input in producing good j, whose total supply in the area is $X_j=\sum_l X_{lj}$. G enters the production process as a (non-rival) public input. The corresponding cost function of firm l is:

$$C_l(\boldsymbol{w},t^f,G,X_{lj}) = \{\min_{\boldsymbol{r},q}\ \boldsymbol{w}\ \boldsymbol{r}_l + t^f q_l \,|\, X_{lj}\leq f_l(\boldsymbol{r}_l,q_l,G)\} \tag{4}$$

where $\boldsymbol{w}$ is the private input prices vector.

From (4), by Shephard's Lemma, we get the following conditional input demand structure:

$$\partial C_l(.)/\partial \boldsymbol{w}\equiv \boldsymbol{r}_l(\boldsymbol{w},t^f,G,X_{lj}); \tag{5}$$

$$\partial C_l(.)/\partial t^f\equiv q_l(\boldsymbol{w},t^f,G,X_{lj}) \tag{6}$$

Notice that $\Sigma_l q_l(\boldsymbol{w},t^f,G,X_{lj})\equiv D^f(.)$ is the aggregate demand of business customers. Moreover, by extending the notion of "virtual price" of a consumption public good (or externality) (Cornes 1992, p. 239) to the public input G, we have the following:

$$-\partial C_l(.)/\partial G\equiv\varphi_l(\boldsymbol{w},t^f,G,X_{lj}) \tag{7}$$

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[3] We could imagine for the RLPU a production function like this $Y = Min\left\{\frac{eL}{c(m)}, F(m,A)\right\}$ where we suppose, for simplicity, both wage rate and productivity of capital normalised to

$\varphi_l(.)$ represents the marginal willingness to pay of firm *l* for the externality of the public service favouring the production process of *j*. This function, as the first derivative w.r. to *G* of cost function, depends on prices of private inputs, the tariff, the output scale and the level of the externality itself. Consequently $\Sigma_l \varphi_l(\boldsymbol{w}, t^f, G, X_{lj})$, the sum over the firms of the marginal valuations, gives the aggregate marginal willingness to pay for the public input by all the firms in the area. An increase of *m* creates, according to function (2), this social benefit which tends to compensate the effect of a higher quality on RLPU production costs, $\frac{\partial C_{PU}(.)}{\partial m} > 0.$

3. The regulated local public utility choices

Let us suppose that our RLPU is constrained by a *Price-Cap* rule putting a limit to unitary revenues[4] and by the duty to reach at least a given standard of quality[5]. It then chooses tariffs, quality and managerial effort by maximising the profit, given by revenues $R(y^h, y^f)=t^h y^h + t^f y^f$, less production costs, $C_{PU}(Y,, m, a, \boldsymbol{A})$, and plus the benefit function of perk and wasteful expenditures (less the cost function of the managerial effort), $\psi(a)$, $\psi'>0$, $\psi''<0$. The pursuit of the latter goal could be in some way limited by the pressure of regulation, represented by the parameter μ. In other words we have:

$$\max_{(t^h, t^f, m, a)} \quad R(y^h, y^f) - [F(m, \boldsymbol{A}) + (c(m) + a)Y] + \mu\, \psi(a) \qquad (8)$$

s.t.

one.

[4] This is only one of the several ways to apply *Price-Cap* regulation. See Guthrie (2006) for a recent survey of those typologies.

[5] This constraint could be considered as an application of sustainable development duties which are recently specifying new roles for regulation in some European countries (Owen 2006).

$$\frac{R(y^h, y^f)}{Y} \leq P° \qquad (\sigma)$$

$$m \geq m^* \qquad (\rho)$$

The correspondent Lagrangean is given by the following expression:

$$\Psi = R(y^h, y^f) - [F(m, \boldsymbol{A}) + (c(m) + a)Y] + \mu\, \psi(a) - \sigma\, [R(y^h, y^f) - P°(y^h + y^f)] + \rho\, (m - m^*) \tag{9}$$

Notice that, by envelope theorem, we have $\frac{\partial \Psi}{\partial P°} = \sigma Y \geq 0, -\frac{\partial \Psi}{\partial m^*} = \rho \geq 0$, i.e. if both constraints are relaxed, by allowing a greater average tariff and a lower quality standard, the maximum value of the (indirect) objective function does not decrease.

Necessary conditions for optimum are:

- *Productive efficiency* (a)

$$\frac{\partial C_{PU}(.)}{\partial a} = Y = \mu\, \psi'(a) \tag{10}$$

By (5), in general $a^*>0$. However $a=0$ when the regulation pressure is hard, i.e. when $\mu \to 0$. In general, we may say that policies for improving the efficacy and strength of regulation, for carrying on pro-competitive liberalization measures, and for pursuing the competition by franchise bidding, should in some way reduce a [6].

- *Tariffs* (t^h,t^f)

If the *Price-Cap* constraint is binding, we obtain, after usual manipulations, the following structure of optimal tariffs, for households and firms:

$$t^u = \frac{c(m) + a - \sigma P^\circ}{1-\sigma} \frac{1}{1 - 1/\varepsilon^u}; \quad u = h, f \tag{11}$$

where $\varepsilon^u \equiv -\frac{\partial D^u(.)}{\partial t^u}\frac{t^u}{y^u}$ is the elasticity of demand for the service by domestic and business users. From condition (11), the optimal tariff is an increasing function of quality and productive inefficiency[7]

$$t^u(m,a) = b^u[c(m) + a - \sigma P^0] \tag{12}$$

where $b^u \equiv \frac{1}{(1-\sigma)(1-\frac{1}{\varepsilon^u})}$ is the mark-up allowed to the RLPU for tariff *u, u=h, f,* with $b^u > 1$, as, for regularity, it must be $\varepsilon^u > 1, \sigma < 1$.

- *Quality* (*m*)

As far as the choice of quality index is concerned, we have the following condition linking the marginal revenue to the marginal cost of quality:

$$(1-\sigma)MR_m + \sigma P^\circ \frac{\partial Y}{\partial m} + \rho = MC_m \tag{13}$$

where

$$MR_m \equiv \frac{\partial R(.)}{\partial m} = \sum_{u=h,f} t^u \frac{\partial D^u(.)}{\partial G}\frac{\partial \xi}{\partial m} > 0;$$

$$MC_m \equiv \frac{\partial C_{PU}(.)}{\partial m} = \frac{\partial F}{\partial m} + c'(m)Y + (c(m)+a)\frac{\partial Y}{\partial m} > 0; \frac{\partial Y}{\partial m} = \sum_{u=h,f}\frac{\partial D^u(.)}{\partial G}\frac{\partial \xi}{\partial m} > 0$$

Thus, an increase of quality level firstly increases fixed costs and variable costs, then produces an externality which increases domestic and business users' demand and consequently revenues. If neither constraints are binding, and then

[6] See Armstrong and Sappington (2006) for clear explanations of the several ways by which these policies can indeed improve the cost-efficiency of a Public utility.

[7] See, for instance, the role of changes in costs and quality in determining the changes in average water users bills taken into account by OFWAT in UK (Zabel 2007).

$\sigma=\rho=0$, condition (13) implies the usual equality of MR_m and MC_m. If the *Price-Cap* constraint is not binding, while standard quality constraint it is and then $m=m^*$, $\rho>0$, condition (13) implies $MR_m<MC_m$. However no comparison can be made when also $\sigma>0$. Notice, in any case, that if the price limit P^0 increases quality level also increases, given that more proceeds might be devoted to cover the cost of a higher quality.

4. Final goods prices, tariffs and quality of the local public service

Let us now suppose that the final good *j* is supplied in a Cournot oligopolistic market where each firm consider as given, besides the output produced by others, also the variables chosen by the RLPU. Thus Lerner index is represented by the following well known expression:

$$\frac{p_j - MC_{lj}}{p_j} = \eta_{lj} / \varepsilon_j \tag{14}$$

Where now

$$MC_{lj} \equiv \frac{\partial C_l(t^f, \xi(m,A), X_{lj})}{\partial X_{lj}};\ \eta_{lj} \equiv X_{lj} / X_j; 1/\varepsilon_j \equiv -\frac{P'(X_j)X_j}{p_j};\ p_j \equiv P(X_j)$$

Therefore the price of the final good *j* is given by:

$$p_j = \frac{MC_{lj}}{1-(\eta_{lj}/\varepsilon_j)} \tag{15}$$

If we suppose a symmetric oligopoly, we have $X_j= n\ X_{lj}$ with $X_{lj} =x_j$. Thus the equilibrium price becomes:

$$p_j = MC_j\left(\frac{1}{1-(1/n)/\varepsilon_j}\right) \equiv \gamma_j MC_j(t^f, \xi(m,A), x_j) \tag{16}$$

where the mark-up γ_j is constant as long as the demand elasticity is constant, at least during the time lag the public service tariffs structure and externality are changing, and the marginal cost of the average firm is a function of the variables chosen by the LRPU.

Now we can settle the following two summarising Propositions.

Proposition 1

The impact on price of final good j of a reduction of productive efficiency of the service provided by the RLPU is given by the following expression:

$$\Delta p_j = \gamma_j \frac{\partial q(.)}{\partial x_j} b^f \Delta a \qquad (17)$$

Proof

The impact of a change of the tariff on marginal cost of good *j* is given by the second cross-derivative of cost function: $\frac{\partial MC_j}{\partial t^f} = \frac{\partial^2 C(.)}{\partial x_j \partial t^f}$. Therefore, taking into account the symmetry result $\frac{\partial^2 C(.)}{\partial x_j \partial t^f} = \frac{\partial^2 C(.)}{\partial t^f \partial x_j}$, the expression (6), according to which $\frac{\partial C(.)}{\partial t^f} = q(\mathbf{w}, t^f, G, x_j)$ is now the conditional demand by the average firm of the public service as an input in production process of *j,* and condition (16), we have $\Delta p_j = \gamma_j \frac{\partial q(.)}{\partial x_j} \Delta t^f$. Thus the inflationary push on price of good *j* of the tariff is proportional to the derivative of factor demand of the public service. On the other hand, from (12) we have $\Delta t^f = b^f \Delta a$, i.e. the change on the tariff is proportional to the change in the efficiency parameter *a*. Thus, by substituting, we obtain expression (17). □

In order to obtain a more tractable, for estimation aims, functional form for expression (17) it is useful to refer to a homethetic technology by which the cost function is separable in this way: $C(\mathbf{w}, t^f, G, x_j) = f(G, x_j)\, g(\mathbf{w}, t^f)$. In this case, by (6), we have $q(\mathbf{w}, t^f, G, x_j) = f(G, x_j)\, [\partial g(\mathbf{w}, t^f)/\partial t^f]$, so the *inflationary push* effect of (17) is simply proportional to $\partial f(G, x_j)/\partial x_j$. If, for instance, the sub-function cost is a linear function w.r. to the output in this way $f(G, x_j) = c_j(G) x_j$, the effect is simply proportional to the constant unitary cost of the average firm $c_j(G)$.

Proposition 2

The impact on price of final good j of a reduction of quality of the service provided by the RLPU is given by the following expression:

$$\Delta p_j = -\gamma_j \left[\frac{\partial q(.)}{\partial x_j} b^f c'(m) - \frac{\partial \varphi(.)}{\partial x_j} \frac{\partial \xi}{\partial m} \right] \Delta m \qquad (18)$$

Proof

A reduction of quality firstly reduces variable costs and then the marginal cost of the RLPU. Consequently from (12) we have a reduction of the tariff: $\Delta t^f = -b^f c'(m) \Delta m$. This explains the first term in the square bracket of (18), giving an effect of final price reduction from (16). Secondly, we have an externality effect created by the change on quality on marginal cost of producing good *j*, given by $\frac{\partial MC_j}{\partial G} \frac{\partial \xi}{\partial m} = \frac{\partial^2 C(.)}{\partial x_j \partial G} \frac{\partial \xi}{\partial m}$. From (13) it is $-\frac{\partial C(.)}{\partial G}$ = $\varphi(\boldsymbol{w}, t^f, G, x_j)$, i.e. the marginal willingness to pay by the average firm for the public good input component of the service. Thus, by substituting into (16), we have the second term in expression (18), giving the inflationary push of a lower quality. □

5. Conclusions

The two Propositions of the previous section point out that in order to ascertain the impact of efficiency and quality in final good prices is crucial to analyse the conditional demand function of the public service, *q*(.), and the inverse demand for the public good (non-rival) component of this, $\varphi(.)$. It is a task of empirical estimation of these functions to derive numerically the dimension of this impact. Indeed, Proposition 1 clarifies that the inflationary push of productive inefficiency directly depends, as it is intuitive, both on the mark-up realised in the market of final goods and the mark-up allowed to the RLPU. According to Proposition 2, instead, the effect on final price *j* of a quality reduction in general cannot be signed, as it depends on two opposite forces: a reduction of RLPU variables cost and a decrease of the externality, the latter depending on function ξ(.) which describes the way by which quality gives rise to a public input. When this effect is relevant the impact of quality reduction may be indeed inflationary.

For both impact effects on the final price, a relevant role is played by the degree of competition on market of final goods – here represented by the term ($1/n$) - and of regulation pressure on the public utility management – here enlightened by the parameters μ, P^0 and $m*$.

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