ASYMMETRIC INFORMATION IN PUBLIC PROVISION MECHANISMS

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Abstract

An optimal mechanism for the provision of impure public inputs to oligopolistic firms is investigated using a three stage game where in the first stage the public agency which provides the public input fixes a non-linear price schedule. In the second stage the private firms decide the amount of public input to demand knowing its strategic, cost reducing and signalling effects on the third stage competition. In the last stage the two firms compete in the output levels. The features of the public agency's price mechanism are described. In this respect we show that the linear term of the price represents either a subsidy (if the input is purely public) or a tax (if it is purely private).

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1 Introduction

The object of this paper is the analysis of the provision of public inputs to private firms that compete in oligopolistic markets[1]. In the literature this issue has been firstly tackled by Groves and Loeb (1976) who derive an optimal mechanism to induce truthful revelation of the public input's marginal productivity by private firms. Successively only Radner (1987) has investigated an extension of the Groves and Loeb paper designing a self-financing incentive-compatible mechanism of provision. These authors adopt a partial equilibrium model in order to avoid the analytical problems arising in dealing with the optimal mechanisms in a general equilibrium context. However they do not consider any strategic interaction between the private firms. It is however clear that most public inputs - privately or publicly provided - involve the presence of some monopoly power because they require fixed costs in order to be produced or introduced in the productive processes[2]. Here therefore a partial equilibrium framework is used mainly because our focus is on the strategic and signalling role of the public input in oligopolistic markets[3]. In order to model such markets a three stage game is analyzed where in the first stage the public agency fixes an optimal non-linear price schedule for the public input. Such schedule is obtained maximizing the net surplus and solving forward the game played by the private firms. We assume that the public agency which produces the public input is informed about the cost functions of the private firms. One can think that the public agency observes directly the private firms' technology before designing the price schedule of the public input. In the second stage the private firms decide the amount of public input to demand knowing its strategic, cost reducing and signalling effects on the third stage competition. In the last stage the two firms compete in the output levels.

The model is structured as follows. In section 2 the welfare maximizing non-linear price schedule is derived. In section 3 the features of the public agency's price mechanism are described with special reference to its relation with the degree of publicness of the public input. Section 4 concludes with some comments on the role of incomplete information in the provision of public inputs in oligopolistic markets.

2 The price schedule

In what follows use is made of a solution to Bayesian games for quadratic objective functions firstly derived by Radner (1962)[4]. Adopting this solution it is possible to express the firms' decision rules as linear generic functions of both the signal and the second stage strategic variable. Since the public input is also the choice variable in the first stage of the game, this technique allows for an explicit solution in terms of its equilibrium level[5]. A linear deterministic demand is assumed such as:

$$p^i = a - b(q^i + q^j)q^i \qquad \text{where} \qquad a, b > 0 \qquad i \neq j = 1,2$$

and a stochastic linear cost function:

$$C^i = [c^i - \gamma(g^i + \theta g^j) + u^i]q^i \qquad \text{where} \qquad \gamma > 0 \qquad \text{and} \qquad u^i \sim N(0,\sigma) \qquad i = 1,2$$

The private signal x^i is defined as an unbiased estimator of the mean of the random process that generates u^i. The following distributional properties are assumed:

$$x^i = u^i + \epsilon^i \quad \text{where} \quad \epsilon^i \sim N(0,\mu).$$

It is also assumed that the random processes generating u^i and u^j are independent. The posterior expected values are the following:

$$E(u^i \mid x^i, x^j) = E(u^i \mid x^i) = \frac{\sigma x^i}{\sigma + \mu} \qquad i = 1,2$$

For firm i, the first period strategy is $g^i(x^i)$ and the second period strategy is $q^i(x^i, g^i, g^j)$. Those strategies are chosen to maximize:

$$\underset{g^i,q^i}{\text{Max}} \; k^i = E[(a - b(q^i + q^j) - (c - \gamma g^i - \gamma\theta g^j + u^i)q^i \mid x^i] - (\alpha + \beta g^i)g^i$$

where $(\alpha + \beta g^i)$ is the quadratic price of g. The non linearity is needed in order to insure an interior maximum and a positive equilibrium demand for the public input in the first stage game. Given the linear structure that we have assumed for both demand and cost functions the decision rules for g^i and q^i can be derived as linear functions such as[6]:

$$g^i = C_0^i + C_1^i x^i$$

and

$$q^i = D_0^i + D_1^i x^i + D_2^i g^i + D_3^i g^j \tag{1}$$

At the second stage of the game firm i chooses q^i in order to:

$$\underset{q^i}{\max} \; \Pi^i = E[(a - b(q^i + q^j) - (c^i - \gamma g^i - \gamma\theta g^j) + u^i)q^i \mid x^i, g^i, g^j] + (\alpha - \beta g^i)g^i =$$

$$= [(a - b(q^i + q^j) - (c^i - \gamma g^i - \gamma\theta g^j) + E\left[u^i \mid x^i, \frac{g^j - C_0}{C_1}\right]q^i + (\alpha - \beta g^i)g^i$$

From which the first order conditions are:

$$a-2bq^i-bq^j-(c^i-\gamma g^i-\gamma\theta g^j)+E\left[u^i\,|\,x^i,\frac{g^j-C_0}{C_1}\right]=0$$

or equivalently (2)

$$\left[a-2bq^i-bq^j-(c^i-\gamma g^i-\gamma\theta g^j)+\frac{\sigma x^i}{\sigma+\mu}\right]=0$$

Substituting (1) into (2) and using the distributional properties of u^i yields:

$$a-2b[D_0+D_1x^i+D_2g^i+D_3g^j]-b\left[D_0+D_1\frac{g^j-C_0}{C_1}+D_2g^j+D_3g^i\right]-c^i+\gamma g^i+\gamma\theta g^j-\frac{\sigma x^i}{\sigma+\mu}=0$$

Since the decision rules specified above hold for any values of x^i, g^i and g^j, expression (2) can be used to get the following system of four equations:

$$D_0=\frac{a-c}{3b}-\frac{\sigma C_0}{6b(\sigma+\mu)C_1}$$

$$D_1=-\frac{\sigma}{2b(\sigma+\mu)} \qquad (3)$$

$$D_2=\frac{\gamma(2-\theta)}{3b}-\frac{\sigma}{6b(\sigma+\mu)C_1}$$

$$D_3=\frac{\gamma(2\theta-1)}{3b}+\frac{\sigma}{3b(\sigma+\mu)C_1}$$

In D_0 the first term indicates the non-input related amount of q^i that is produced in absence of uncertainty. It is directly related to the size of the market and inversely to the cost level and the slope of the demand curve. The second term is the quantity of q^i produced under uncertainty. The first term in D_2 gives the effect of g^i on the output level under certainty. It is positive because $0<\theta<1$ and b, γ>0. Such effect is then directly related to the level of external effects of g on the rival's cost function (θ). In fact, if the firm producing g completely appropriates the reduction in costs, in the second stage its output grows reducing the share of the rival firm. The second term in D_2 indicates the effect of the own production of public input on the output due to its signalling role. This is again positive and, as before, positively related to the amount of g used to send signals to the rival firm. The first term in D_3 represents the effect of the rival production of g on its own output level under certainty. It can be either positive or negative depending on the value of θ. More precisely, when the latter is greater than ½, the cross effect of g is to increase the equilibrium level of output and viceversa. The share of the output market is however reduced unless $\theta = 1$. The second term defines the effect on output of that portion of the rival public input production that is realized in order to misinform on its real costs. This is negative because an increase of the production of g^j signals that the rival has lower costs (its reaction function has shifted outward) and the equilibrium output level is accordingly reduced.

Given the reaction functions in the second stage, in the previous stage firm i:

$$\underset{g^i}{\mathrm{Max}} \quad k^i = [a - b(q^i + E(q^j)) - c + \gamma g^i + \gamma\theta g^j - E(u^i \mid x^i)]q^i + (\alpha - \beta g^i)g^i \qquad (4)$$

At the first stage firm i computes the expected value of its' rival strategy (g^j,q^j) since at that time the realization of x^j is unknown to i. The first order conditions, using the envelope theorem, are:

$$\left[\gamma - b\frac{dq^i}{dg^j}\right]q^i + \alpha - 2\beta g^i = 0 \qquad (5)$$

Substituting (1) into (5) and using the distributional properties of x^j and u^i, the expression above can be written as:

$$(\gamma - bD_3)(D_0 + D_1 x^i + D_2 C_0 + D_2 C_1 x^i + D_3 C_0) + \alpha - 2\beta(C_0 + C_1 x^i) \qquad (6)$$

Substituting for D_i i=0,1,2,3 from (3) into (6) and requiring that (6) holds for every realization of x^i, yields the following system of two equations:

$$\left[\frac{2\gamma(2-\theta)}{3}-\frac{\sigma}{3(\sigma+\mu)C_1}\right]\left[\frac{a-c}{3b}+\frac{\gamma(1+\theta)C_0}{3b}\right]+\alpha-2\beta C_0=0 \tag{7}$$

and $$2[\gamma^2(2-\theta)^2-9b\beta](\sigma+\mu)^2C_1^2-5\gamma\sigma(2-\theta)(\sigma+\mu)C_1+2\sigma^2=0 \tag{8}$$

expression (8) is a quadratic equation with the following two roots:

$$C_1=\frac{5\gamma(2-\theta)\pm\sqrt{9\gamma^2(2-\theta)^2+12^2b\beta}}{4(\gamma^2(2-\theta)^2-9b\beta)}\frac{\sigma}{\sigma+\mu}$$

Differentiating (6) once again with respect to g^i we derive the second order condition:

$$2\gamma(2-\theta)L[\gamma(2-\theta)L-4H]+8H^2-18b\beta L^2<0$$

where:

$$H=[\gamma^2(2-\theta)^2-9b\beta]$$

and $$L=[5\gamma(2-\theta)\pm\sqrt{9\gamma^2(2-\theta)^2+12^2b\beta}]$$

Substituting C_1 in (7) we can solve explicitly for C_0 obtaining:

$$C_0=\frac{(2\gamma(2-\theta)L-4H)(a-c)+9b\alpha L}{18b\beta L-(2\gamma(2-\theta)L-4H)\gamma(1+\theta)}$$

To insure that this expression is positive and that the second order condition holds we need that $H<0$ and $L>0$ so that the only acceptable solution of C_1 is:

$$C_1=\frac{5\gamma(2-\theta)+\sqrt{9\gamma^2(2-\theta)^2+12^2b\beta}}{4(\gamma^2(2-\theta)^2-9b\beta)}\frac{\sigma}{\sigma+\mu}$$

whose sign is negative. This is hardly surprising since the coefficient C_1 indicates the effect of the signal x^i, that is an unbiased estimator of the cost parameter, on g^i. The sign of C_1 allows one to draw some implications on the signalling role of g in modifying the second stage equilibrium. In fact, an increase in the production of g signals low costs of production and thus rises the private incentives for its production. Without the quadratic term in the price function for g then, the sum of the strategic and the signalling effects would make it impossible to have an interior solution for the maximand. Now we can solve the system (3) and write the decision functions of the firm i as:

$$g^i = \frac{(2\gamma(2-\theta)L-4H)(a-c)+9b\alpha L}{18b\beta L-(2\gamma(2-\theta)L-4H)\gamma(1+\theta)} + \frac{L}{H}\frac{\sigma}{\sigma+\mu}x^i$$

and

$$q^i = \left\{\frac{a-c}{3b} - \frac{2HC_0}{3bL}\right\} - \left\{\frac{\sigma}{2b(\sigma+\mu)}\right\}x^i + \left\{\frac{\gamma(2-\theta)}{3b} - \frac{2H}{3bL}\right\}g^i + \left\{\frac{\gamma(2\theta-1)}{3b} + \frac{4H}{3bL}\right\}g^j \tag{9}$$

where the last term indicates the dynamic conjectural variation term. The part of it that is due to the strategic effect of the production of the public input can be either positive or negative depending on the value of θ. The part that indicates the signalling effect is negative, because an increase of the rival firm's public input production signals that the latter is characterized by low costs.

The public agency maximizes the net surplus minus the cost of providing the public input:

$$\max_{\alpha,\beta} \int_0^{Q^*} (a-bQ)dQ - \sum_{i\neq j}\left(c^i - \gamma(g^i+\theta g^j) + \frac{\sigma x^i}{\sigma+m}\right) - k(g^i+g^j) \tag{10}$$

where $Q=q^i+q^j$ and x^i is now the component of firm i's cost structure that is known by the public agency but not by the rival firm. The revenues from the sale of g do not appear because they decrease the profits of the private firms to the same extent. Here the possibility of reselling the public input to firms operating in different sectors is excluded. For simplicity, the costs for the production of g are supposed to be linear, with an average and marginal cost equal to k. Assuming that $c^i = c^j$ and differentiating (10) with respect to α and β, the first order conditions can be written as:

$$\frac{\partial W}{\partial \alpha} = (a - c - Q)\frac{\partial Q}{\partial \alpha} + \gamma(1+\theta)G\frac{\partial q}{\partial \alpha} + \gamma(1+\theta)Q\frac{\partial g}{\partial \alpha} - \frac{\sigma(x^i + x^j)}{\sigma + m}\frac{\partial q}{\partial \alpha} - 2k\frac{\partial g}{\partial \alpha} = 0 \quad (11)$$

and

$$\frac{\partial W}{\partial \beta} = (a - c - Q)\frac{\partial Q}{\partial \beta} + \gamma\left[(g^i + \theta g^j)\frac{\partial q^i}{\partial \beta} + (g^j + \theta g^i)\frac{\partial q^j}{\partial \beta} + (q^i + \theta q^j)\frac{\partial g^i}{\partial \beta} + (q^j + \theta q^i)\frac{\partial g^j}{\partial \beta}\right] - \frac{\sigma}{\sigma + m}\left(\frac{\partial q^i}{\partial \beta}x^i + \frac{\partial q^j}{\partial \beta}x^j\right) - 2k\left(\frac{\partial g^i}{\partial \beta} + \frac{\partial g^j}{\partial \beta}\right) = 0 \quad (12)$$

where $G = g^i + g^j$. Substituting (11) in (12) and using the expressions for C_0 and C_1, we can solve (12) for β as:

$$\beta = \frac{2 + 16\gamma^2(2-\theta)^2 z^2 - 5\gamma(2-\theta)z \pm u}{36 b z^2}$$

where

$$z = \frac{3\gamma\sigma(1-\theta)(x^i - x^j)^2 - 2bk(\sigma + m)}{3\gamma^2\sigma(1-\theta)^2(x^i - x^j)^2}$$

and

$$u = \sqrt{4 + 16\gamma(2-\theta)^2 z^2 - 20\gamma(2-\theta)z}.$$

Deriving (12) once again with respect to β, the second order conditions are:

$$\beta < \frac{2 + 16\gamma^2(2-\theta)^2 z^2 - 5\gamma(2-\theta)z}{36 b z^2}$$

so that the only acceptable solution for β is:

$$\beta = \frac{2 + 16\gamma^2(2-\theta)^2 z^2 - 5\gamma(2-\theta)z - u}{36 b z^2}. \quad (13)$$

Introducing (13) in (11), the latter can be explicitly solved for α as:

$$\alpha = \left[\frac{\theta\sigma(x^i + x^j)}{9b\gamma(1-\theta)^2(\sigma+m)} - \frac{bkw}{108b\gamma^2} \right] y - \frac{2(a-c)\beta}{\gamma(1+\theta)} \tag{14}$$

where $$w = \frac{4(x^i+x^j)^2(1+\theta)^2 + 27(x^i-x^j)^2(1-\theta)^2}{(1+\theta)^2(x^i-x^j)^2(1-\theta)^2}$$

and $$y = (4\gamma^2(2-\theta)(2\theta-1)z^2 + \gamma(2-13\theta)z - 2 + u).$$

Since z is negative we can derive the sign of α and β. The latter is always positive for $0 < \theta < 1$. On the contrary α can be either positive or negative depending on the sign of y. More precisely, when $\theta \to 1$, y is positive, so that α is negative because both the term in square brackets and the second term are negative. When $\theta \to 0$, then the sign of α becomes uncertain. However, if the cost of producing the public input (k) is relatively high or alternatively the consumer surplus increase generated by raising its production is relatively low, α becomes positive.

An interesting result is therefore that the linear term of the pricing structure may represent either a subsidy (for pure public inputs) or a tax (for pure private inputs with relatively little impact on the consumer surplus). The quadratic term is always positive and therefore compatible with the conditions for an interior solution of the second stage maximization problems for the private firms.

Moreover, from (8) we can notice that α is directly related to the costs of the private firms $(x^i + x^j)$ when $\theta \to 0$ and inversely when $\theta \to 1$. It follows that the price schedule determines - ceteris paribus - a relatively higher demand of the public input by inefficient private firms when the social benefits from the production of such inputs are greater $(\theta \to 1)$. In such a case, in fact, the net surplus can be significantly increased by a greater demand of the public inputs by relatively inefficient private firms. On the contrary, when the social benefits from the demand of public input are lower ($\theta \to 0$), the price schedule penalizes the private firms characterized by high costs of production.

3 Some features of the provision mechanism

In order to better understand the structure of the pricing rule, we analyze how α and β are modified by changes in the degree of publicness of the input and in the difference between the reports made by the two private firms. The derivative of z with respect to $\Delta = (x^i - x^j)^2$ is:

$$z_\Delta = \frac{4bk(\sigma + m)}{3\gamma^2(1-\theta)^2\Delta}$$

that is positive. Now we can obtain the derivative of β with respect to Δ as:

$$\beta_\Delta = \left(\frac{z_\Delta}{36bz^3}\right)[8\gamma^2(2-\theta)^2 z^2(u-3) + 5\gamma(2-\theta)z(4-u) + (2u-4)] \qquad (15)$$

and that of alpha as:

$$\alpha_\Delta = \frac{bky}{3\gamma^2(1-\theta)^2\Delta} + \left[\frac{\theta\sigma(x^i + x^j)}{9b\gamma(1-\theta)^2(\sigma+m)} - \frac{bkw}{108b\gamma^2}\right] y_\Delta - \frac{2(a-c)\beta_\Delta}{\gamma(1+\theta)}$$

where

(16)

$$y_\Delta = (8\gamma^2 z(2-\theta)(2\theta-1)z_\Delta + \gamma(2-13\theta)z_\Delta + (16\gamma^2 z(2-\theta)^2 z_\Delta - 10\gamma(2-\theta)z_\Delta)/u)$$

Expression (15) is unambiguously negative, whereas (16) is positive for $\theta \to 0$. When the input is purely public (16) is still positive only when the costs of producing such input are relatively high with respect to its impact on the consumer surplus. It follows that the price of the public input is directly related to the difference between the private firms' cost. An economic interpretation of this is the following. We know from (2) that - ceteris paribus - the more efficient between the two firms demands more public input and that, through (3), it determines a larger market share for such a firm. Accordingly the asymmetry between market shares is proportional both to the difference between the cost parameters and to the quantity of input demanded. The inverse relation between such difference and the linear term of the price schedule reduces the asymmetries between market shares when they are likely to become greater due to a large difference between the cost parameters.

To investigate the relation between α and β and the degree of publicness of the public input we take the derivative of z with respect to θ:

$$z_\theta = \frac{1}{\gamma(1+\theta)} - \frac{4bk(\sigma+m)(x^i+x^j)}{3\gamma^2\sigma(1-\theta)^3\Delta}$$

that is negative for values of k relatively high. The derivatives of β and α with respect to θ are:

$$\beta_\theta = \left(\frac{1}{36bz^3}\right)\left(\frac{u_\theta^2(u-2)}{2u} - [4+8\gamma^2(2-\theta)^2z^2 - 10\gamma(2-\theta)z - 2u]\right) \qquad (17)$$

where $u_\theta^2 = (8\gamma^2(2-\theta)^2z^2 - 5\gamma(2-\theta)z)z_\theta + (8\gamma^2(2-\theta)z^3 - 5\gamma z^2) < 0$

and

$$\alpha_\theta = \left[\frac{\sigma(x^i+x^j)-w_\theta}{9b\gamma(\sigma+m)\Delta}\right]y - \left[\frac{\theta\sigma(x^i+x^j)}{9b\gamma(1-\theta)^2(\sigma+m)} - \frac{bkw}{108b\gamma^2}\right]y_\theta - \frac{2(a-c)\beta_\theta}{\gamma(1+\theta)} - \frac{2(a-c)\beta}{\gamma(1+\theta)^2}$$

where

(18)

$$y_\theta = (8\gamma^2z^2(2-\theta) + 8\gamma^2z(2-\theta)(2\theta-1)z_\theta - 4\gamma^2z^2(2\theta-1) - 13\gamma z + \gamma(2-13\theta)z_\theta + u_\theta^2/2u)$$

and $$w_\theta = \frac{bk(4(x^i+x^j)^2(1+\theta)^3 - 27(x^i+x^j)(1-\theta)^3)}{6\gamma^2(1-\theta)^3(1+\theta)^3\Delta}$$

Expression (17) is positive since $w_\theta < 0$ and u>2. As before, however, the sign of (18) is unambiguous only for $\theta \to 0$. In that case, in fact, y and y_θ are negative, so that (18) is also negative. When $\theta \to 1$, the sign of (18) depends on the relative weight of the last two terms (embodying the negative effect on α of the increase in the net surplus due to the public input) and of the terms in square brackets that are both positive. The price for the public input is then an inverse function of its degree of publicness only for the linear term.

4 Conclusions

In this paper we have examined the features of an optimal pricing schedule for the public provision of a public input to oligopolistic firms that use such input as a signalling device in the output competition. It is assumed that the public agency which provides the public inputs is informed about the cost parameters of the private firms.

The most relevant results are the following. First, the price schedule for the public input is quadratic in order to allow for an interior solution for its demand by the private firms in the second stage of the game. Second, the linear term of the price represents either a subsidy (if the input is purely public) or a tax (if it is purely private), whereas the quadratic term is always positive. Accordingly, the linear, but not the quadratic term of the price schedule is an inverse function of its degree of publicness. Third, the linear term of the price schedule is directly related to the difference between the costs of the private firms. This because high values of such difference, in presence of high demand of the public input, generate asymmetries between the market shares of the private firms. Finally the price schedule is such as to determine a relatively higher demand of the public input by inefficient private firms when the positive externalities arising from such input are high. The opposite holds when the size of the spillovers is relatively small because then the price schedule penalizes the private firms characterized by high costs of production.

Extensions of this model can be obtained analyzing the case of a public agency that supplies the public input ignoring the cost structure of the private firms. In this case the latter that know the objective function of the agency can use the quantity of input supplied as a signal (with two audiences) of its cost reducing properties. On the other hand the public agency may be interested in randomizing its objective function in order to misinform the private firms and therefore to increase its objective function[7]. In this line more interesting would be the analysis of a sequential structure where the public agency chooses the quantity of the public input to be supplied taking into account the creation in time of a reputation effect.

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Endnotes

1. Most papers concerned with the public provision of public inputs have been worked out in a general equilibrium framework. This created analytical problems to the explicit introduction of informational issues. Laffont (1975) claims that such issues are less severe for the provision of public inputs than for the consumer's public goods. It is difficult to agree with this thesis in an oligopolistic framework in which firms behave strategically.

2. Among the best known example of pure and impure public inputs we find: basic and applied R&D, training programs, communication and information networks, flood control programs and activities against environmental pollution.

3. The analogy between this strategic behaviour and the so called "free rider" problem is clear. However in the public consumer good context the interaction between the private consumers is rarely modelled explicitly. Here the strategic element for the optimal provision of the public input is paramount.

4. According to Radner (1962) it is possible to restrict attention to decision rules of a very generic form since with linear demand and cost structures the decision rules have to be affine in the vector of observations.

5. A more complete analysis of these signalling games with either a private and common value structure of the stochastic terms and of both Bertrand and Cournot equilibrium is discussed in Fiorentini (1988).

6. See Gal-Or (1986)

7. The randomization of price schedules in the insurance markets or of tax schedules in the optimal income taxation literature is now developing quite rapidly. For a survey on these two applications see Arnott and Stiglitz (1989) and Stiglitz (1987) respectively.