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A note on environmental R&D under time-consistent emission tax

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1. Motivation

In a recent publication in *Journal of Economic Behavior and Organization*, Poyago-Theotoky (2007) developed a three-stage game model, and also derived theoretical findings and important policy implications for environmental R&D under a time-consistent emission tax. Among the conclusions presented in that paper, it was stated that with inefficient environmental R&D technology and small environmental damage, cooperative environmental R&D engenders larger environmental R&D efforts and greater social welfare than noncooperative environmental R&D does. This note describes that the results of Professor Poyago-Theotoky's (2007, 2010) works are still robust in a relaxed wider parameter range of the environmental damage coefficient. Furthermore, we provide the generalized sufficient condition of damage coefficient to guarantee an interior solution for R&D in an extended framework.

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The characteristics and time structure of the model are as follows. For details of the model and the solution procedure, see Poyago-Theotoky (2007).

(i) Two homogeneous firms (i and j) are engaging in quantity competition.

(ii) Linear demand is $p(q_i, q_j) = a - (q_i + q_j), \quad (i, j = 1,2; i \neq j)$.

(iii) They have the same cost structure of $C_i(q_i) = cq_i$.

(iv) They have the same emissions-reducing technology.

(v) Spillover effects ($\beta \in [0,1]$) occur from the rival firm's environmental R&D.

(vi) The emission function is $e_i(q_i, z_i) = q_i - z_i - \beta z_j$.

(vii) R&D expenditures are $(\gamma / 2) z_i^2$.

(viii) The environmental damage is $D(E) = (d/2)E^2, E \equiv e_i + e_j$.

(ix) Regulator's inability to precommitment to an emission tax rate.

Timeline:

Stage 1: Firms determine environmental R&D efforts (abatement levels).

Stage 2: The regulator determines the emission tax rate.

Stage 3: Firms determine production levels.

Furthermore, Poyago-Theotoky (2010) provides a corrigendum, showing that the negative emission tax (emission subsidy) can improve the market inefficiency caused by Cournot duopolists. These works, especially welfare comparison under two regimes of cooperative R&D and noncooperative R&D, constitute significant contributions for competition policy.

However, an unnecessarily strict assumption related to the environmental damage coefficient has remained. The purpose of this note is to point out that oversight. In fact, Poyago-Theotoky (2010) provides the following correction. `... To guarantee an interior solution for R&D and a positive emission tax, we will assume that $d > 1/2$ ...'. where $d$ captures environmental damage. Instead, it should be read as `..To guarantee an interior solution for R&D, we will assume that $d > 1/2$ ...'.

2. Investigation and result

The reason of our note is described below. Indeed the assumption of $d > 1/2$ guarantees an interior solution for R&D, but it is too strict. From (4) and (9) in Poyago-Theotoky (2007), the equilibrium values of environmental R&D efforts in two R&D regimes (noncooperative R&D and cooperative R&D) are, respectively,

$$z_{\text{nc}} = \frac{[(1+d)(2d-1)+d(1+\beta)]A}{2\gamma(1+d)^2 + d(1+\beta)[3(3+\beta)+d(7+\beta)]},$$
$$z_{\text{erc}} = \frac{(1+\beta)[(1+d)(2d-1)+2d]A}{2\gamma(1+d)^2 + 4d(3+2d)(1+\beta)^2},$$

where γ and $A(\equiv a-c)$ are both positive parameters. As shown in footnotes 10 and 13 in Poyago-Theotoky (2007), the assumption related to the environmental damage coefficient ($d > 1/2$) is sufficient to ensure that z_{nc} and z_{erc} are both positive.

However, careful investigation reveals that even if $d > (-1+\sqrt{3})/2$, then z_{nc} and z_{erc} are simultaneously positive irrespective of the value of spillover parameter $\beta(\in[0,1])$. Therefore, to clarify the exact truth, we should relax the assumption of $d > 1/2$ to the following correct assumption.

Assumption (symmetric duopoly): $d > \dfrac{-1+\sqrt{3}}{2}$.

The results of Poyago-Theotoky (2007, 2010) retain their robustness in this relaxed wider parameter range. Accordingly, this relaxation of damage parameter indicates that previous arguments are still valid in a regulatory environment of the lower environmental damage.

3. An extension

Our note is necessary for related future research. As an example, let us consider the case of product differentiation between the duopolists' products. Presuming that the inverse demand function is $p_i(q_i, q_j) = a - (q_i + \theta q_j), (i, j = 1,2; i \neq j)$. The degree of product differentiation is captured by $\theta \in [0,1]$. When $\theta = 1 (\theta = 0)$, the products are perfect substitutes (independent). This linear demand is used by Spence (1976) and Dixit (1979). The rest of the model are identical. Then, the equilibrium values of environmental R&D efforts under two R&D regimes (noncooperative R&D and cooperative R&D) are derived as follows.

$$\hat{z}_{\mathrm{nc}} = \frac{[(2d+1+\theta)(2d-1)+2d(1+\beta)]A}{\gamma(2d+1+\theta)^2 + d(1+\beta)[(2d+1+\theta)(2+\theta)(3+\beta)-4d(1+\beta)]},$$
$$\hat{z}_{\mathrm{erc}} = \frac{(1+\beta)[(2d+1+\theta)(2d-1)+4d]A}{\gamma(2d+1+\theta)^2 + d(1+\beta)^2[(2+\theta)(2d+1+\theta)-2d]}.$$

The next step is to derive the condition to guarantee that $\hat{z}_{\mathrm{nc}} > 0$ and $\hat{z}_{\mathrm{erc}} > 0$. After some manipulation, we understand that, in the case of a differentiated Cournot duopoly, the interior solution of R&D stage is guaranteed by the following assumption.

Assumption (differentiated duopoly): $d > \underline{d}(\theta) \equiv \dfrac{-(1+\theta)+\sqrt{(1+\theta)(5+\theta)}}{4}$.

The critical value $\underline{d}(\theta)$ is the increasing function in $\theta \in [0,1]$. Figure 1 shows the function $\underline{d}(\theta)$.

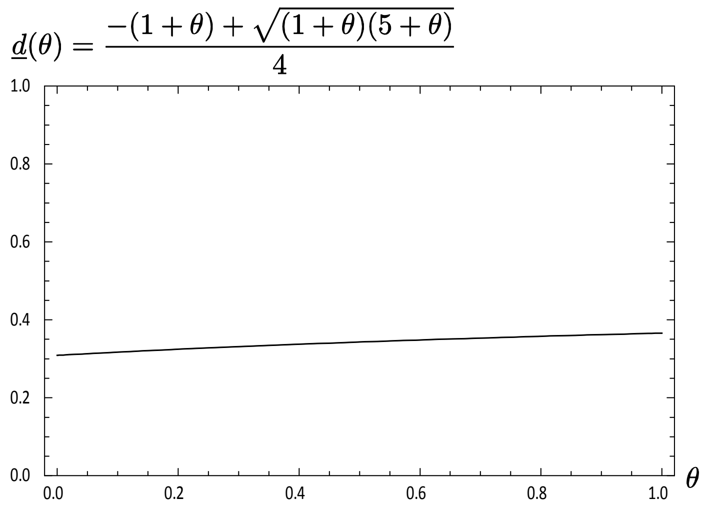

Figure 1: The critical value of environmental damage coefficient.

Therefore, it is apparent that when $\theta \to 0$, then the parameter set we must analyze expands. This result states that the regulatory environment we must examine widens as the degree of product differentiation becomes larger.

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