Optimal environmental policies in a heterogeneous product market under research and development competition and cooperation

By

Olusegun Oladunjoye

University of Guelph, Ontario, Canada

September 20, 2005

Introduction

- Pollution externality requires environmental policies
- Firms respond to environmental policies by either:

  Reducing output or Increasing pollution abatement

- Some policies may not induce Environmental Research and Development (ER&D) => the need for a technology (specific) inducing instrument
- Pigouvian tax => Optimal Tax = Marginal Damage (MD) holds under perfect competition and full information
- Under imperfect competition => Tax < MD

  - output under production due to market power and

  - output over production due to pollution

- Adapt from R&D literature: D'Aspremont and Jacquemin (1988), Kamien, Muller and Zang (1992), Katsoulacos and Xepapadeas (1996a)

This paper attempts to answer the following questions:

- If there is an existing emissions tax in place and there is constant MD from pollution, how should the regulator subsidize ER&D under both ER&D arrangements?
- Under what circumstances should the regulator encourage ER&D cooperation and competition?
- Is a combination of emissions tax and an ER&D inducing subsidy socially desirable?

Model

- 2 firms producing differentiated products, facing an inverse demand function $p_i = \alpha - q_i - \gamma q_j$ where $i \neq j$, $\alpha > 0$ and $0 \leq \gamma \leq 1$.

- As $\gamma \to 1$ => goods become very similar (homogeneous at $\gamma = 1$) and as $\gamma \to 0$ => goods are perfectly differentiated (and independent).

- Emissions per unit of output is given by $e_i = \beta - z_i - \lambda z_j$, where $i \neq j$, $z_i \geq 0$ is firm i's ER&D level, $0 \leq \lambda \leq 1$ is the degree of technological knowledge spillover and the baseline emission intensity $\beta \geq z_i + \lambda z_j$.

- ER&D expenditure $R_i = \dfrac{\delta z_i^2}{2}$, with $\delta > 0$ and total cost $C(q_i, z_i) = cq_i + \dfrac{\delta z_i^2}{2}$.

- Firm i in the final stage chooses its quantity to maximize profit

$$\pi_i = (\alpha - q_i - \gamma q_j)q_i - \tau e_i q_i - cq_i - (1-s)\frac{\delta z_i^2}{2}$$

3.1. Under competitive ER&D symmetric equilibrium ER&D is:

$$z_e = \frac{2\tau(\alpha - c - \tau\beta)(2-\gamma\lambda)}{\delta(2+\gamma)^2(1-s)(2-\gamma) - 2\tau^2(1+\lambda)(2-\gamma\lambda)}$$

where $\alpha - c - \tau\beta > 0$ and $\delta(2+\gamma)^2(1-s)(2-\gamma) - 2\tau^2(1+\lambda)(2-\gamma\lambda) > 0$

$\tau = 0 \Rightarrow z_e = 0$. $\frac{\delta z_e}{\delta s} > 0$ only if $\tau > 0$, and $\frac{\delta z_e}{\delta \tau} > 0$

$q_e = \frac{\alpha - c - \tau\beta + (1+\lambda)\tau z_e}{(2+\gamma)}$, $\quad p_e = \alpha - (1+\gamma)q_e \quad$ and $\quad e_e = \beta - (1+\lambda)z_e$

$\frac{dz_e}{ds} > 0$ for $\tau > 0 \Rightarrow \frac{\delta q_e}{\delta s} > 0$ and $\frac{dq_e}{d\tau} < 0$. $\frac{de_e}{ds} < 0$ and $\frac{de_e}{d\tau} < 0$

- In the first stage, the regulator chooses the tax and subsidy rates to maximize social welfare $W_e(\tau, s) = 2\alpha q_e - (1+\gamma)q_e^2 - 2cq_e - \delta z_e^2 - D(2e_e q_e)$

Using the first order conditions of the welfare maximization combined with the firm's first order conditions and after some manipulations we get:

- Optimal competitive ER&D tax => $\tau^* = D' - (q_e / e_e)$

- Optimal competitive ER&D subsidy => $s^* = 1 - \frac{\tau^*}{D'} \frac{2}{(4-\gamma^2)} \frac{(2-\lambda\gamma)}{(1+\lambda)}$

3.2. Cooperative ER&D leads to full information sharing => $e_i = \beta - z_i - z_j$.

- Firms jointly choose z_i and z_j to maximize second stage joint profit

$\Pi = q_i^2 + q_j^2 - (1-s)\frac{\delta}{2} z_i^2 - (1-s)\frac{\delta}{2} z_j^2$ which gives symmetric equilibrium cooperative

ER&D as: $z_c = \frac{2t(\alpha - c - t\beta)}{\delta(1-\rho)(2+\gamma)^2 - 4t^2}$, $\alpha - c - t\beta > 0$, and $\delta(1-s)(2+\gamma)^2 - 4t^2 > 0$

$q_c = \frac{1}{2+\gamma}[\alpha - c - t\beta + 2tz_c]$, $p_c = \alpha - (1+\gamma)q_c$ and $e_c = \beta - 2z_c$

- Optimal cooperative ER&D tax => $t^* = D' - (q_c / e_c)$

- Optimal cooperative ER&D subsidy => $\rho^* = 1 - \frac{t^*}{D'} \frac{1}{(2+\gamma)}$

Proposition 1: *If* $\tau = t$, *for any* $\gamma \in (0,1)$, *constant marginal damage* $D' = d$, *and sufficiently low spillover* λ, $\rho^* > s^*$. *Also, when* λ *is high enough and* γ *is sufficiently low,* $\rho^* > s^*$ *while for sufficiently high* λ *and* γ, $\rho^* < s^*$.

Corollary 1: *If* $\tau = t$, *for* $\gamma = 1$ *with constant marginal damage* $D' = d$, *for* $\lambda = 0.6, s^* = \rho^*$, *for* $0 < \lambda < 0.6$, $s^* < \rho^*$ *and for* $0.6 < \lambda < 1, s^* > \rho^*$.

Figure 1: Optimal Tax Plot

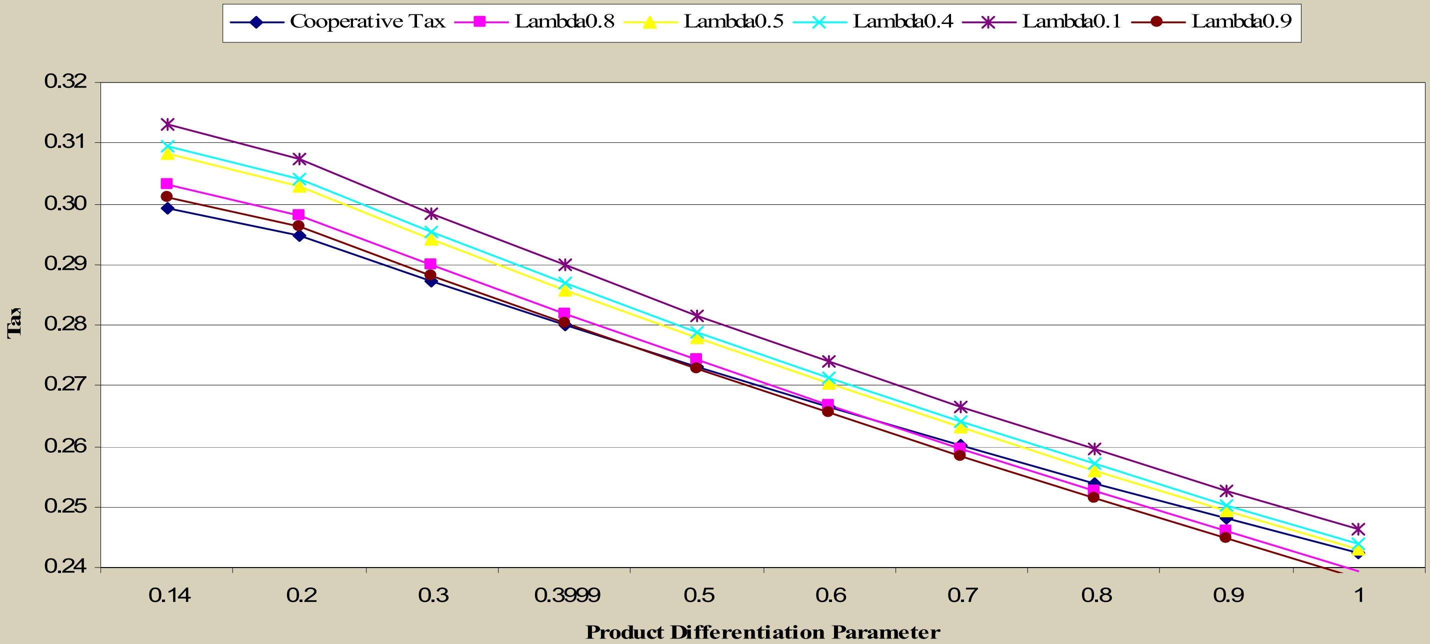
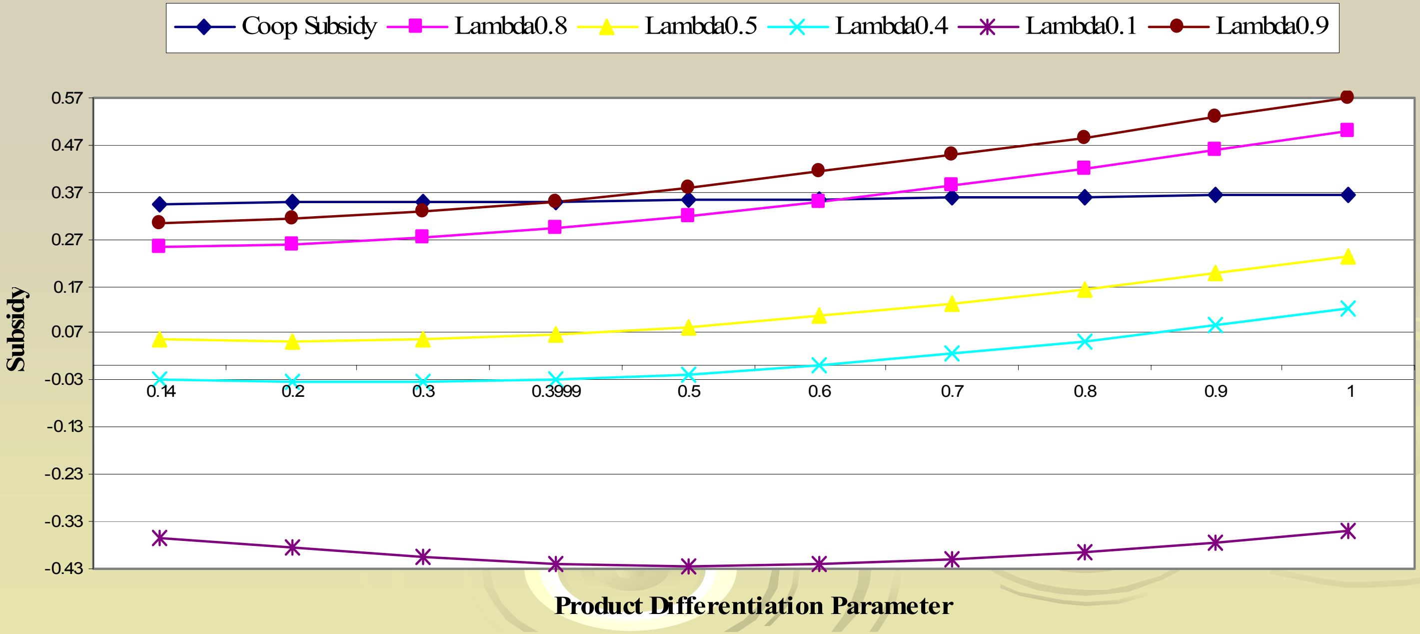


Figure 2: Optimal Subsidy Plot



The numerical simulations give the following results:

(i) *For* $0 < \gamma < 0.3999$ *and* $\lambda \in (0,1)$, $\tau^* > t^*$, *while* $s^* < \rho^*$

(ii) For $0.3999 \leq \gamma \leq 1$, *and low spillovers* λ, $\tau^* > t^*$, *while* $s^* < \rho^*$ *while for sufficiently high spillovers* $\tau^* < t^*$ *and* $s^* > \rho^*$.

Proposition 2: *For any* $\gamma \in (0,1)$, *optimal environmental policy under cooperative ER&D is a combination of emission tax and subsidy, while under competitive ER&D optimal environmental policy will consist of an emission tax and subsidy for a high ER&D spillover* λ, *while for a sufficiently low* λ *it could be an emission tax and a tax on ER&D.*

Conclusion

- Coordination in ER&D is not always socially desirable.
- ER&D cooperation is socially desirable when

  (i) Products are highly differentiated and

  (ii) Products are less differentiated and spillover effects are small
- Competitive ER&D will be socially desirable when products are less differentiated and there is high spillover effect.
- Depending on the perceived level of product differentiation in an industry, regulator monitoring and inspection are necessary to ensure technological spillovers exist. Based on this, a regulator should encourage the appropriate ER&D arrangement by imposing on the industry lower emissions tax coupled with high subsidy.
- A combination of an emissions tax and ER&D subsidy is socially desirable.