Welcome

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presenting:

The organization of R&D and environmental policy

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Background...

The issue of R&D Cooperation vs R&D Competition has received sizable attention in recent years.

- D'Aspremont and Jacquemin (1988),
- De Bondt and Wu (1997),
- Kamien et al. (1992),
- Perez-Castrillo and Sandonis (1996),
- and Vilasuso and Freascatore (2000), among others.

As is well known from the R&D literature, there are fundamental market failures in the innovation process stemming from the public good nature of knowledge and information.

So, several policy instruments have been used to address these market failures

- Intellectual Property Rights (patents),
- Licensing,
- R&D subsidies and
- The encouragement of Cooperative R&D.

Market failures in some detail...

Suppose **No Leakages of Information**

"Spillovers are absent"

- A very effective patent system. "Reason"
- Firms choose their R&D strategically "Action"
  (Choose R&D first, followed by output)
- Firms have a tendency to over-invest in R&D "Result"

This is **a strategic over-investment effect.** "Concept"

Market failures in some detail...

Leakages of Information

"Positive Spillovers"

Suppose

- ~~A very effective patent system~~. "Reason"
- Firms choose their R&D strategically "Action"

  The larger the spillover the smaller the incentive for R&D (Choose R&D first, followed by output)
- Firms under-invest in R&D "Result"

This is a strategic under-investment effect. "Concept"

Market failures in some detail...

Both strategies are signs of an R&D market failure. Firms will choose the wrong level of R&D relative to the social optimum for a range of reasons.

Market failures in some detail...

The patent system, by addressing some of the fundamental market failures, introduces additional twists as it rewards firms for discoveries but not for sharing these with other firms.

"Result"

Information-Sharing Market Failure.

In the present paper

the author consider the case where R&D efforts are not directed towards cost-reduction or product quality enhancement, as is the case of the literature referred to in the first slide, but instead R&D is directed towards emission reduction of harmful pollutants.

In this context, the introduction of pollution, an environmental externality, gives rise to a third market failure as firms tend to over-produce. As is well known this type of market failure can be addressed by an emission tax.

In the present paper

She consider a setting allowing for oligopolistic interaction and focus on the case of a government or regulator who holds limited commitment power.

The key assumption here is that the R&D decision is made before the regulator chooses the level of the emission tax.

The questions she addresses as received limited attention in the literature, apart from Petrakis and Poyago-Theotoky (2002), Sandon´s and Mariel (2004) and Scott (1996).

Petrakis and Poyago-Theotoky take the view that environmental policy is inactive, in the sense that the emission tax is fixed and beyond the control of the regulator and compare the relative merits of two popular technology policies, R&D subsidization and the promotion of R&D cooperation when R&D is of the cost-reducing type and production generates pollution.

In contrast, in the present paper environmental policy is active (emission tax), and technology policy is concerned with the relative performance of R&D cooperation versus R&D competition.

Let us start with the model:

Basically, she examine two regimes with respect to the organization of environmental R&D:

i. Independent R&D and

ii. An environmental R&D cartel (ERC).

This terminology is adapted from Kamien et al. (1992).

(in the absence of pollution effects)

We study this in the context of:

A multi-stage game as follows:

In the first regime :

1) Firms choose their emission-reducing R&D non-cooperatively;
2) The regulator (or government) sets the emission tax; and
3) Firms compete in the market by choosing quantities.

In the second regime:

1) The first stage firms “Cartel (ERC)” cooperatively undertakes environmental R&D.
2) The regulator (or government) sets the emission tax; and
3) Firms compete in the market by choosing quantities.

The model:

We consider a model where two firms produce a homogeneous good under a linear demand specification

Inverse demand function :

$$p = a - q_i + q_j, \quad i \neq j, \ \ i,j = 1,2, \quad a > c$$

Cost function:

$$c(q_i, z_i) = cq_i + \frac{1}{2}\gamma z_i^2 \ , \ \ \gamma > 0$$

Total emission:

$$e_i(q_i, z_i) = q_i - z_i - \beta z_j, \quad 0 \leq \beta \leq 1$$

Environmental damage:

$$D = \frac{1}{2} dE^2, \quad d > \frac{1}{2}, \mathrm{E} = e_i + e_j,$$

2.1 Non-cooperative R&D

In the last (third) stage: firm i chooses output to maximize profit;

$$\max_{q_i} (a - q_i - q_j)q_i - cq_i - \frac{\gamma z_i^2}{2} - t(q_i - z_i - \beta z_j)$$

$$a - c - t - 2\,qi - q_j = 0$$

$$q_i(q_j) = \frac{1}{2}(a\ - c - t - q_j)$$

Imposing symmetry $q_i = q_j = q$ to obtain equilibrium output per firm

$$q = \frac{A - t}{3}, \qquad A \equiv a - c$$

$$\pi_i = (a - 2q - c)q - \frac{\gamma z_i^2}{2} - t(q - z_i - \beta z_j)$$

$$\pi_i = q^2 + t(z_i + \beta z_j) - \frac{\gamma z_i^2}{2}$$

2.1 Non-cooperative R&D

In the second stage: The regulator sets the emission tax, t, to maximize social welfare:

$$\max_t \underbrace{\int_0^{2q}(a-c-x)dx-\frac{1}{2}\gamma\left(z_i^2+z_j^2\right)}_{CS+PS}-\underbrace{\frac{1}{2}d\left[2q-(1+\beta)\,(z_i+z_j)\right]^2}_{negative\ externatlies}$$

$$\max_t \int_0^{2q}(A-x)dx-\frac{1}{2}\gamma\left(z_i+z_j\right)-\frac{1}{2}\,d\left[2q-(1+\beta)\left(z_i^2+z_j^2\right)\right]^2$$

$$\max_t \quad 2Aq-\frac{1}{2}(2q)^2\ -\frac{1}{2}\gamma\left(z_i+z_j\right)-\frac{1}{2}\,d\left[2q-(1+\beta)\left(z_i^2+z_j^2\right)\right]^2$$

2.1 Non-cooperative R&D

Cont. of the second stage

$$\max_t \quad 2Aq - \frac{1}{2}(2q)^2 - \frac{1}{2}\gamma(z_i + z_j) - \frac{1}{2}\, d\left[2q - (1+\beta)\left(z_i^2 + z_j^2\right)\right]^2$$

$$\max_t \quad 2A\left(\frac{A-t}{3}\right) - \frac{1}{2}\left(2\left(\frac{A-t}{3}\right)\right)^2 - \frac{1}{2}\gamma(z_i + z_j) - \frac{1}{2}\, d\left[2\left(\frac{A-t}{3}\right) - (1+\beta)\left(z_i^2 + z_j^2\right)\right]^2$$

$$\frac{1}{9}\left[A(-2+4d) - 4(1+d)t - 6d(1+\beta)(z_i + z_j)\right] = 0$$

Rearranging

$$t = \frac{A(-1+2d\,) - 3d(1+\beta)(z_i + z_j)}{2(1+d)}$$

$$\frac{\partial t}{\partial z_i} = -\frac{3d(1+\beta)}{2(1+d)} < 0$$

2.1 Non-cooperative R&D

Cont. of the second stage

$$q = \frac{A - t}{3} = \frac{A}{3} - \frac{1}{3}\overbrace{\frac{A(-1 + 2d) - 3d(1 + \beta)(z_i + z_j)}{2(1 + d)}}^{t}$$

After simplification

$$q = \frac{A + d(1 + \beta)(z_i + z_j)}{2(1 + d)}$$

$$\pi_i = q^2 + t\left(z_i + \beta z_j\right) - \frac{\gamma z_i^2}{2}$$

$$\pi_i = \left[\frac{A + d(1 + \beta)(z_i + z_j)}{2(1 + d)}\right]^2 + \left[\frac{A(-1 + 2d) - 3d(1 + \beta)(z_i + z_j)}{2(1 + d)}\right]\left(z_i + \beta z_j\right) - \frac{\gamma z_i^2}{2}$$

2.1 Non-cooperative R&D

The first stage: The two firms choose their environmental R&D anticipating the choice of tax by the regulator and the subsequent product market competition.

$$\pi_i = \frac{1}{4}\left[\frac{[A+d(1+\beta)(z_1+z_2)]^2}{(1+d)^2} - \frac{2(z_1+\beta z_2)[A-2Ad+3d(1+\beta)(z_1+z_2)]}{1+d} - 2\gamma z_1^2\right]$$

$$\frac{\partial \pi_i}{\partial z_i} = \frac{[A(-1+d(2+2d+\beta)]}{2(1+d)^2} + \frac{[d(-6+d(-5+\beta))(1+\beta)-2(1+d)^2\gamma]z_i}{2(1+d)^2} - \frac{d(3+2d)(1+\beta)^2 z_j}{2(1+d)^2} = 0$$

In the symmetric equilibrium, $z_i = z_j = z_{nc}$, $\quad nc \equiv non\_cooperative\ R\&D$

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

$z_{nc} > 0\ implies\ that$: $\frac{[(1+d)(2d-1)+d(1+\beta)]A}{2\gamma(1+d)^2+d(1+\beta)[3(3+\beta)+d(7+\beta)]} > 0 \rightarrow\ [(1+d)(2d-1)+d(1+\beta)] > 0$

$$d > \frac{1}{4}\left(-2-\beta-\sqrt{12+4\beta+\beta^2}\right) or\ d > \frac{1}{4}(-2-\beta+\sqrt{12+4\beta+\beta^2})$$

Since d is decreasing in β it will be sufficient to assume $\beta = 0 \rightarrow$ d > 0.366

2.1 Non-cooperative R&D

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

$$t = \frac{A(-1+2d\,)-3d(1+\beta)(z_i+z_j)}{2(1+d)}, \qquad q = \frac{A+d(1+\beta)(z_i+z_j)}{2(1+d)}$$

$$\pi_i = q^2 + t\left(z_i+\beta z_j\right) - \frac{\gamma z_i^2}{2}$$

$$SW = 2Aq - 2q^2 - \frac{1}{2}\gamma\left(z_i+z_j\right) - \frac{1}{2}\,d\left[2q-(1+\beta)\left(z_i^2+z_j^2\right)\right]^2$$

2.1 Non-cooperative R&D

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

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

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

$$SW = 2Aq_{nc} - 2q_{nc}^2 - 2\,d\,[q_{nc} - (1+\beta)\,(z_{nc}^2)]^2 - \gamma z_{nc}^2$$

$$SW_{nc} = -\frac{(Ad(7+4d-3\beta)(1+\beta)-2A(-1+d)\gamma)^2}{2(d(1+\beta)(9+7d+(3+d)\beta)+2(1+d)^2\gamma)^2}$$
$$-\frac{A^2\gamma(-1+d+2d^2+d[1+\beta])^2}{\left(2(1+d)^2\gamma+d[1+\beta](9+3\beta+d[7+\beta])\right)^2}+\frac{A^2(-2(-1+d)\gamma+(7+4d-3\beta)d[1+\beta])}{2(1+d)^2\gamma+d[1+\beta](9+3\beta+d[7+\beta])}$$
$$-2d\left(\frac{A(d(7+4d-3\beta)(1+\beta)-2(-1+d)\gamma)}{2d(1+\beta)(9+7d+(3+d)\beta)+4(1+d)^2\gamma}-\frac{A(1+\beta)(-1+d+2d^2+d[1+\beta])}{2(1+d)^2\gamma+d[1+\beta](9+3\beta+d[7+\beta])}\right)^2$$

2.2 Cooperative R&D-environmental R&D Cartel

In the last (third) stage: firm i chooses output to maximize profit;

$$\max_{q_i} (a - q_i - q_j)q_i - cq_i - \frac{\gamma z_i^2}{2} - t(q_i - z_i - \beta z_j)$$

$$q = \frac{A - t}{3}, \qquad \pi_i = q^2 + t(z_i + \beta z_j) - \frac{\gamma z_i^2}{2}$$

In the second stage: The regulator sets the emission tax, t, to maximize social welfare:

$$\max_t \underbrace{\int_0^{2q} (a - c - x)dx - \frac{1}{2}\gamma(z_i^2 + z_j^2)}_{CS+PS} - \underbrace{\frac{1}{2}d\left[2q - (1 + \beta)\,(z_i + z_j)\right]^2}_{negative\ externatlies}$$

$$t = \frac{A(-1 + 2d\,) - 3d(1 + \beta)(z_i + z_j)}{2(1 + d)}, \qquad q = \frac{A + d(1 + \beta)(z_i + z_j)}{2(1 + d)}$$

2.2 Cooperative R&D-environmental R&D Cartel

In the first stage: the R&D Cartel chooses $z_i, i = 1,2$ to maximize the sum of their profit;

$$\max_{z_i} \underbrace{2q^2 + t(1+\beta)(z_i + z_j) - \frac{\gamma}{2}(z_i^2 + z_j^2)}_{\pi_i + \pi_j}$$

$$\max_{z_i} \left[2\left(\frac{A + d(1+\beta)(z_i + z_j)}{2(1+d)}\right)^2 + \frac{A(-1+2d) - 3d(1+\beta)(z_i + z_j)}{2(1+d)}(1+\beta)(z_i + z_j) - \frac{\gamma}{2}(z_i^2 + z_j^2) \right]$$

$$\frac{\partial \pi_{i+j}}{\partial z_i} = -\frac{2\left(d(3+2d)(1+\beta)^2 + (1+d)^2\gamma\right)z_i + (1+\beta)\left(A - Ad(3+2d) + 2d(3+2d)(1+\beta)z_j\right)}{2(1+d)^2} = 0$$

Setting $z_i = z_j = z_{erc}$, $erc \equiv$ *environmental R&D Cartel*

$$z_{erc} = \frac{A(-1 + d(3+2d))(1+\beta)}{4d(3+2d)(1+\beta)^2 + 2(1+d)^2\gamma}$$

2.2 Cooperative R&D-environmental R&D Cartel

$$z_{erc} = \frac{A(-1 + d(3 + 2d))(1 + \beta)}{4d(3 + 2d)(1 + \beta)^2 + 2(1 + d)^2\gamma}$$

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

$$q_{erc} = \frac{[d(5 + 2d)(1 + \beta)^2 + \gamma(1 + d)]\, A}{2(1 + d)^2\gamma + 4d(3 + 2d)(1 + \beta)^2}$$

$$SW_{erc} = 2Aq_{erc} - 2q_{erc}^2 - 2d(q_{erc} - (1 + \beta)z_{erc})^2 - \gamma z_{erc}^2$$

2.3 A comparison: Independent R&D vs ERC

Is cooperative R&D effort higher than non cooperative R&D effort?

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

$$z_{erc} - z_{nc} = \frac{A(1+d)^2\varphi}{\Gamma\Delta}$$

$$\varphi \equiv d(3-2d)(1+\beta)^2(1-\beta) + 2\gamma(2d^2\beta + 2d\beta - \beta + d)$$

$$\Gamma \equiv 2\gamma(1+d)^2 + d(1+\beta)[3(3+\beta+d(7+\beta)]$$

$$\Delta \equiv 2\gamma(1+d)^2 + 4d(3+2d)(1+\beta)^2$$

2.3 A comparison: Independent R&D vs ERC

Is cooperative R&D effort higher than non cooperative R&D effort?

$$z_{erc} - z_{nc} = \frac{\overbrace{A(1+d)^2}^{(+)}\ \varphi}{\underbrace{\Gamma}_{(+)}\ \underbrace{\Delta}_{(+)}}$$

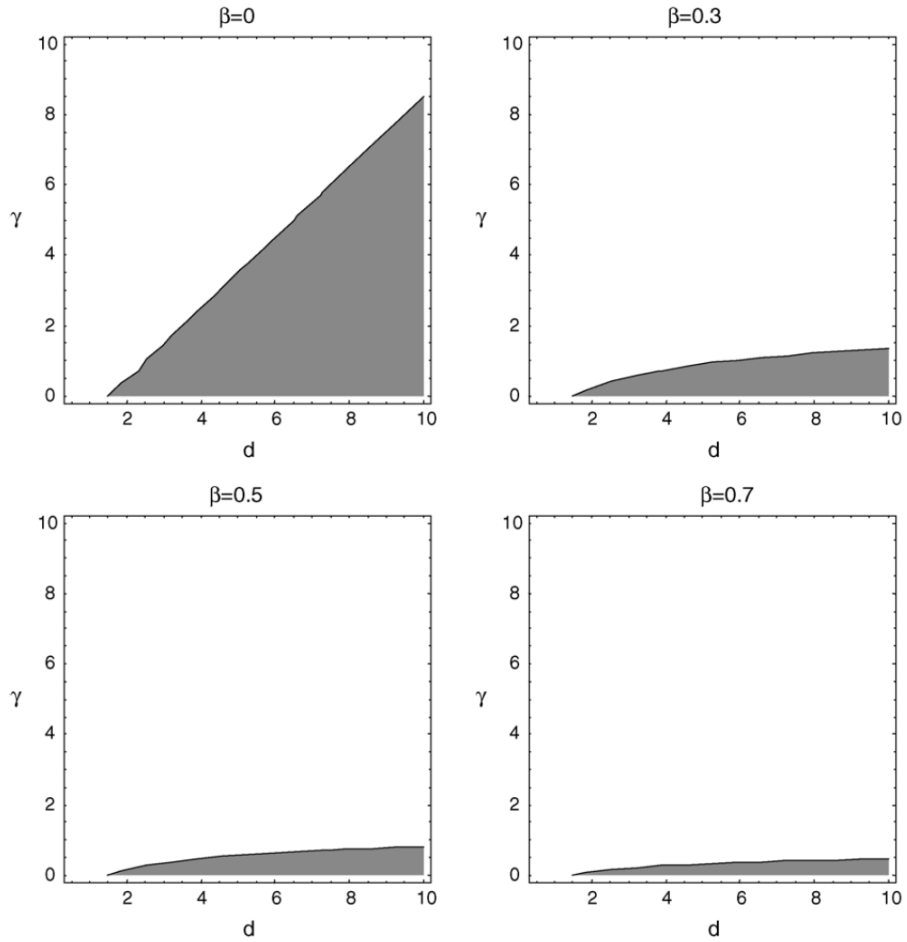
$$\varphi \equiv \overbrace{d(3-2d)(1+\beta)^2(1-\beta)}^{(+)\ if\ d<\frac{2}{3}} + \underbrace{2\gamma(2d^2\beta+2d\beta-\beta+d)}_{(+)\ \forall\ value\ of\ d\ and\ \beta}$$

$$\bar{\gamma} = \frac{(1-\beta)(1+\beta)^2}{2\beta}, \qquad \bar{d} = \frac{-3+3\beta(-1+\beta+\beta^2)-2\gamma-4\beta\gamma+\sqrt{16\beta\gamma((-1+\beta)(1+\beta)^2+2\beta\gamma)+(3-3\beta(-1+\beta+\beta^2)+2\gamma+4\beta\gamma)^2}}{4(\beta\,(2\gamma+\beta^2+\beta-1)-1)}$$

$if\ d > \frac{3}{2}\ and\ \gamma > \bar{\gamma} \rightarrow\ (+)$

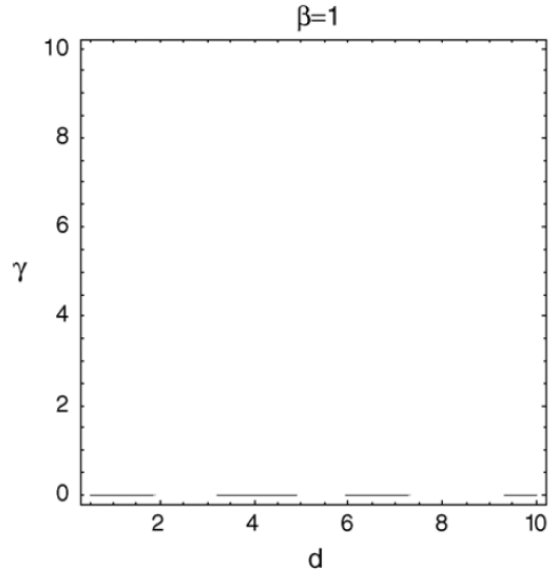
$if\ \gamma > \bar{\gamma}\ then\ for\ any\ value\ of\ d < \bar{d} \rightarrow\ (+)$

2.3 A comparison: Independent R&D vs ERC



The white area corresponds to

$z_{erc} > z_{nc}$



2.3 A comparison: Independent R&D vs ERC

Is the optimal tax in the case of ERC lower than the one in non cooperative R&D?

$$t_{erc} - t_{nc} = \frac{\overbrace{-3A(1+d)^2(1+\beta)}^{-}\,\varphi}{\underbrace{2\Gamma}_{+}\ \underbrace{\Delta}_{+}}$$

$$\varphi \equiv \overbrace{d(3-2d)(1+\beta)^2(1-\beta)}^{(+)\ if\ d<\frac{2}{3}} + \underbrace{2\gamma(2d^2\beta+2d\beta-\beta+d)}_{(+)\ \forall\ value\ of\ d\ and\ \beta}$$

$$\bar{\gamma} = \frac{(1-\beta)(1+\beta)^2}{2\beta}, \qquad \bar{d} = \frac{-3+3\beta(-1+\beta+\beta^2)-2\gamma-4\beta\gamma+\sqrt{16\beta\gamma((-1+\beta)(1+\beta)^2+2\beta\gamma)+(3-3\beta(-1+\beta+\beta^2)+2\gamma+4\beta\gamma)^2}}{4(\beta\,(2\gamma+\beta^2\ +\beta-1)-1)}$$

$if\ d > \frac{3}{2}\ and\ \gamma > \bar{\gamma} \rightarrow\ (+)$

$if\ \gamma > \bar{\gamma}\ then\ for\ any\ value\ of\ d < \bar{d} \rightarrow\ (+)$

2.3 A comparison: Independent R&D vs ERC

Is the profit in the case of ERC lower than the one in non cooperative R&D?

$$\pi_{erc} - \pi_{nc} = \frac{\overbrace{A^2(1+d)^2}^{(+)}\,\kappa^2}{\underbrace{4\Delta\Gamma^2}_{(+)}}$$

$$\kappa \equiv d(3-2d)(1-\beta)(1+\beta)^2 + 2\gamma[d+\beta(2d^2+2d-1)]$$

2.3 A comparison: Independent R&D vs ERC

Is the Social welfare in the case of ERC lower than the one in non cooperative R&D?

$$SW_{erc} - SW_{nc} = \frac{\overbrace{A^2(1+d)^2}^{(+)}\,\Omega\,\varphi}{\underbrace{4\mathrm{K}^2\Lambda^2}_{(+)}}$$

$$\Omega \equiv 2d^2(1+\beta)^4\omega_1 + 2d^2(1+\beta)^2\omega_2 + 2(1+d)^2\omega_3$$
$$\omega_1 \equiv \left[3(7+\beta) + d\left(51 + 13\beta + d(26+6\beta)\right)\right]$$
$$\omega_2 \equiv \left[29 + 7\beta + d\left(36 + 28\beta + d(29 + 55\beta + 2d(7+13\beta))\right)\right]\gamma$$
$$\omega_3 \equiv [2 + \beta + d(2d\beta - 1)]\gamma^2$$

3. Concluding remarks

We have examined this in the context of a setting where the regulator/government is unable to commit to the environmental policy instrument (in this case an emission tax) credibly.

We have shown that environmental R&D is higher in the case of an environmental R&D cartel (ERC) compared to independent R&D, except in the case of relatively large damages and efficient R&D when the opposite is true. The same ranking applies to the comparison of social welfare.

“ If you can’t explain it simply, you don’t understand it well enough. “

4. Questions

Thank you!