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Technological Asymmetry and Cooperative Environmental R&D: A Game-Theoretic Analysis

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INTRODUCTION & AIM

Environmental pollution, now a major global concern, has become one of the main drivers of climate change. In response, green innovation has attracted growing attention, particularly through environmental research and development (E-R&D), which is considered a key lever to mitigate ecological impacts and promote a sustainable transition ([1], [2]). However, investment in E-R&D remains costly and risky, limiting individual initiatives. Therefore, the implementation of effective public policies to support these efforts represents a major challenge for policymakers. Among the available instruments, environmental taxation is often viewed as an effective means of encouraging firms to reduce emissions and adopt greener technologies [3]. In this context, cooperation in environmental R&D has emerged as a strategic approach to share costs, pool risks, and benefit from technological spillovers. Industrial partnerships such as BMW–Toyota (hydrogen fuel cells), Tesla–Panasonic (electric batteries), and Renault–Nissan–Mitsubishi (electric vehicles) clearly illustrate this growing trend.

Building on the framework of Poyago-Theotoky (2007) [4], this paper extends the analysis of environmental R&D coalitions by introducing asymmetry in firms' production costs. The objective is to examine how technological spillovers affect the profitability of such coalitions and how they influence investment decisions and emission levels in a context of asymmetric firms.

METHOD

We develop a **three-stage game-theoretic model** of a **duopoly** with environmental R&D and technological spillovers, where two asymmetric firms produce a polluting good.

Stage 1: Each firm *i* chooses its level of environmental R&D investment, $z_i > 0$, incurring quadratic R&D costs, $z_i^2(\gamma/2)$, and benefiting from technological spillovers at rate $\beta \in [0,1]$ generated by the rival's effort. This investment decision can be made either cooperatively or independently. The net pollution emitted by firm *i* is given by:

$$e_i = q_i - z_i - \beta z_j \quad i,j = 1,2 \text{ with } i \neq j$$

Stage 2: The regulator sets a tax t on net emissions to maximize social welfare, $SW = CS + \pi_1 + \pi_2 - D(E)$, as the sum of consumer surplus, firms' profits, and environmental damages, $D(E) = \left(\frac{1}{2}\right) dE^2$, where: $E = e_1 + e_2$ and $d > 0$.

Stage 3: Firms compete `a la Cournot under the inverse demand $P(Q) = a - Q$, facing asymmetric unit costs $c_1 \neq c_2$, with production that generates emissions.

Two scenarios are analyzed:

1. **Non-cooperative R&D (Scenario NC)**: each firm independently determines its level of investment in environmental R&D in order to maximize its own profit.
2. **Cooperative R&D (Scenario C):** firms coordinate their environmental R&D investments within a joint lab (β =1) to maximize joint profits.

RESULTS & DISCUSSION

The game is solved using a backward induction approach to determine the Subgame Perfect Nash Equilibrium (SPNE). It allows us to derive analytical expressions for output levels, investments, taxe and profits under both scenario.

Element	Scenario NC	Scenario C
R&D (Firm 1)	$z_1^* = \frac{2a - 2c_1 + c_2}{\gamma D_N}$	$z_1^C = \frac{2a - 2c_1 + c_2}{\gamma D_C}$
R&D (Firm 2)	$z_2^* = \frac{2a - 2c_2 + c_1}{\gamma D_N}$	$z_2^C = \frac{2a - 2c_2 + c_1}{\gamma D_C}$
Quantité (Firme 1)	$q_1^* = \frac{a - 2c_1 + c_2 - t^*}{3}$	$q_1^C = \frac{a - 2c_1 + c_2 - t^C}{3}$
Quantité (Firme 2)	$q_2^* = \frac{a - 2c_2 + c_1 - t^*}{3}$	$q_2^C = \frac{a - 2c_2 + c_1 - t^C}{3}$
Taxe	$t^* = \frac{2a - S - 3(1+\beta)Z_N}{2}$	$t^C = \frac{2a - S - 3(1+\beta)Z_C}{2}$
Profit (Firme 1)	$\pi_1^* = f(a, c_1, c_2, \gamma, \beta)$	$\pi_1^C = f(a, c_1, c_2, \gamma, \beta)$
Profit (Firme 2)	$\pi_2^* = f(a, c_1, c_2, \gamma, \beta)$	$\pi_2^C = f(a, c_1, c_2, \gamma, \beta)$

Where:
- $D_N = 3 + 3\beta + 2\gamma(1+\beta)^2$
- $D_C = 3 + 3\beta + \gamma(1+\beta)^2$
- $S = c_1 + c_2$
- $Z = z_1 + z_2$

The theoretical analysis yields the following key findings:

Higher Investment & Welfare: Cooperation in environmental R&D leads to higher investments, lower pollution, and greater social welfare compared to non-cooperative R&D.

Spillover Mitigation: spillovers reduce investment incentives under non-cooperation, but this negative effect is mitigated when firms cooperate.

Cooperation is efficient when firms are similar, but high cost asymmetry weakens incentives and can make cooperation less effective.

Optimal Policy Design: The optimal emission tax t is set to neutralize residual pollution, aligning private firm incentives with collective welfare objectives.

CONCLUSION

Environmental R&D cooperation, combined with emission taxation, effectively promotes green innovation, reduces pollution, and improves welfare in asymmetric markets.

Note: This paper is a work in progress. Several extensions and robustness checks are currently under development, and additional results are being validated to further generalize these findings.

FUTURE WORK / REFERENCES

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