Environmental policies in private and mixed duopolies: Emission taxes versus green R&D subsidies

2021 경제학 공동학술대회

2021. 2. 4.

이상호 (전남대학교 경제학부 교수)

박철희 (전남대학교 BK21연구교수)

2021 Korea's Allied Economic Association Annual Meeting

Contents

1. Introduction: Motivation and Literature Review
2. The Model
3. Private Market: taxes versus R&D subsidies
4. Mixed Market: taxes versus R&D subsidies
5. Discussion: Privatization and Time Consistency
6. Conclusion: Policy Implicatins

Environmental policies

- Environmental policies have been implemented in polluting industries across the world given the global concern about climate change.
- As part of the Paris COP21 (2015) agreement, an important number of countries in the world submitted independent nationally determined contributions along with environmental policies, including market-oriented mechanisms and stricter emission standards.
- Many progressive countries (mostly OECD countries) have already adopted market-based environmental regulation by using emission taxes, cap-and-trades, and pollution abatement (green R&D) subsidies such as green manufacturing and green consumption.

- emission taxes: carbon tax in EU
- cap-and-trades: EU ETS (2005), USA, China, Australia
- green R&D subsidies: Clean Technology Fund in the World Bank, Low Carbon Innovation Fund in Canada

Environmental concerns in mixed oligopolies

- In transition economies and developing countries, many state-owned industries are reliant on highly polluting technologies.
- From the administrative perspective of the ownership of the firms, environmental concerns and governmental incentives in public domains have shown the possible benefits/costs of public ownership in polluting industries: private incentive vs. public interest.
- Research encouraging the development of cleaner technologies is being paid more attention by governments with mixed markets where private firms compete against public firms which care for environment.
- Mixed markets exist in a broad range of industries that emit pollutants in the production process, such as oil, gas, automobile, steel, chemical, electricity, power generation, and healthcare.

Literature review

- Environmental regulations with single policy and comparisons
  - Emission Tax: Buchanan(1969) and Barnett (1980) for monopoly, Levin (1985) and Shaffer (1989, 1995) for oligopoly, Katsoulacos and Xepapadeas (1995) and Lee (1998) for endogenous oligopoly
  - Tradable Permits: Borenstein (1988), Malueg (1990), Requate (1993) and Stavins (1998) for imperfect permits market, Sartzetakis (1997, 2004) and Lee and Park (2005) for comparisons with emission tax
  - Green R&D Subsidy: Lerner (1972) and Polinsky (1979) for monopoly, Stranlund (1997) and Poyago-Theotoky (1999, 2003) for oligopoly and comparisons with emission tax
  - market allocation of tradable permits (quantity regulation) or emission taxes (price regulation) can minimize abatement costs when there are differences with respect to the abatement technologies among regulated firms.
  - green R&D subsidy can accelerate the adoption and diffusion of cleaner technologies and help support environment-friendly products.

Literature review

- Environmental regulations with policy mix
  - Subsidy and Tax: David and Sinclair-Desgagne (2005, 2010) and Lee and Park (2013, 2019) with eco-industry
  - Subsidy and Emission Trading: Eichner and Pethig (2014) and Cao et al. (2017, 2019) for Chinese hybrid regulations
  - Emission Tax and Emission Trading: Garcia et al. (2018)
- Environmental regulations in mixed markets
  - The environmental effect of public ownership and privatization: Beladi and Chao (2006), Bárcena-Ruiz and Garzon (2006) and Ohori (2006)
  - The environmental effect of public ownership (i) with emission tax: Pal and Saha (2015), Xu et al. (2016), Lee and Xu (2018); (ii) with emission trading: Kato (2013); (iii) with green R&D subsidies: Tsai et al. (2016), Xing et al. (2019); (iv) with green technology licensing: Kim et al. (2018); (v) with emission taxes and green R&D subsidies: Haruna and Goel (2019)

Our contribution

- Policy comparisons have attracted insufficient attention in contrast to the key role of regulation in facilitating environmental innovation.
- We investigate and compare an emission tax with a green R&D subsidy in both of private and mixed markets, concerned with the R&D spillovers.
- We show that government might prefer to adopt green R&D subsidy in the presence of public firm under certain conditions
  - (i) Government should adopt green R&D subsidy and keep the public firm when R&D cost is low, irrespective of R&D spillovers. Thus, when R&D cost is efficient, privatization is not desirable.
  - (ii) Government should adopt emission tax and determine privatization policy depending on R&D spillovers when R&D cost is high. Thus, when R&D cost is inefficient, privatization with lower emission tax is better if R&D spillovers are weak. Otherwise, privatization is not a good policy choice.

2. Model

- Assumptions on the markets
  - linear inverse demand with duopoly, $P = A - Q$, where $Q = q_0 + q_1$
  - quadratic production cost of output, $c(q_i) = {q_i}^2/2$
  - emission function is modified as $e_i(q_i, z_i, z_j, \beta) = q_i - z_i - \beta z_j$
    where green R&D, z_i, has spillover effect, $\beta \in [0,1]$
  - quadratic green R&D cost, $c(z_i) = \gamma {z_i}^2/2$, where $\gamma \geq \underline{\gamma}$

  - Without any environmental regulation, each firm has private incentive to maximize its profits:

$$\pi_i = (A - Q)q_i - \frac{1}{2}{q_i}^2 - \frac{\gamma}{2}{z_i}^2$$

2. Model

- Assumptions on the welfare
  - quadratic environmental damage function, $D(E) = dE^2$, where $E = e_0 + e_i$
  - The social welfare can be calculated as aggregated sum of consumer and producer surplus less the environmental damage:

$$W = \int_0^Q (A - u)\,\mathrm{d}u - \frac{1}{2}\sum_{i=0}^{1}({q_i}^2 + \gamma {z_i}^2) - dE^2$$

  - If we normalize *d* as 1, the public incentive for maximizing welfare yields the first-best (FB) outcomes: $Q^{\mathrm{FB}} = \frac{2A(4(1+\beta)^2+\gamma)}{12(1+\beta)^2+7\gamma}$ and $Z^{\mathrm{FB}} = \frac{8A(1+\beta)}{12(1+\beta)^2+7\gamma}$

- We compare private and mixed markets under the timing of games:
  - 1st stage: Government sets the environmental regulation to maximize the social welfare.
  - 2nd stage: Both firms choose its level of green R&D to maximize its regulated profit.
  - 3rd stage: Both firms compete in output to maximize its regulated profit.

3. Private market

3.1. Emission Tax

- Under the emission tax, the objective function of private firm becomes as

$$T_i = \pi_i - t\left(q_i - z_i - \beta z_j\right)$$

- Equilibrium outputs in the 3rd stage: $q_i = (A - t)/4$
- Equilibrium level of green R&D in the 2nd stage: $z_i = t/\gamma$

- The optimal emission tax can be derived from the F.O.C at the 1st stage:

$$\left(A - Q(t)\right)\frac{\mathrm{dQ}}{\mathrm{dt}} - \sum_{i=0}^{1} q_i(t)\frac{\mathrm{dq}_i}{\mathrm{dt}} - \gamma \sum_{i=0}^{1} z_i(t)\frac{\mathrm{dz}_i}{\mathrm{dt}} - \mathrm{MD}\left(\frac{\mathrm{dQ}}{\mathrm{dt}} - (1+\beta)\frac{\mathrm{dZ}}{\mathrm{dt}}\right) = 0$$

3. Private market

- The optimal emission tax in private market (TP) is as follows:

$$t^{TP} = \frac{A\gamma(16(1+\beta)+3\gamma)}{4(4(1+\beta)+\gamma)^2+\gamma(16+3\gamma)}$$

- The comparison with the first-best outcomes: $Q^{\mathrm{FB}} > \mathrm{Q}^{TP}$ and $\mathrm{Z}^{FB} > Z^{TP}$
- The optimal emission tax is insufficient not only in green R&D investment but the output production: under-investment and under-production result in double welfare losses, i.e., cost inefficiency from the R&D investment and allocation inefficiency from output production.

- Lemma 1. $t^{\mathrm{TP}} \underset{>}{\overset{<}{=}} MD^{TP} \Leftrightarrow \gamma \underset{<}{\overset{>}{=}} 4(3\beta-1)$

In private market, the optimal emission tax with inefficient (efficient) R&D cost is lower (higher) than the marginal environmental damage: if spillover effect is high, the emission tax with a low (high) R&D cost can be higher (lower) than marginal environmental damage.

3. Private market

3.2. Green R&D Subsidy: performance subsidy (not cost reimbursement)

- Under the R&D subsidy, the objective function of private firm becomes as

$$T_i = \pi_i + sz_i$$

- Equilibrium outputs in the 3rd stage: $q_i = A/4$
- Equilibrium level of green R&D in the 2nd stage: $z_i = s/\gamma$

- The optimal emission tax can be derived from the F.O.C at the 1st stage:

$$\gamma \sum_{i=0}^{1} z_i(s) \frac{dz_i}{ds} - MED((1+\beta)\frac{dZ}{ds}) = 0$$

3. Private market

- The optimal R&D subsidy in private market (SP) is as follows:

$$s^{SP} = \frac{A(1+\beta)\gamma}{4(1+\beta)^2+\gamma}$$

- The comparison with the first-best outcomes:

$$Q^{\mathrm{FB}} \underset{<}{\geq} Q^{SP} \text{ and } \mathrm{Z}^{FB} \underset{<}{\geq} \mathrm{Z}^{SP} \text{ if } \gamma \underset{>}{\leq} \frac{4}{3}(1+\beta)^2 \text{ while } Q^{\mathrm{SP}} > \mathrm{Q}^{TP} \text{ and } \mathrm{Z}^{SP} > Z^{TP}$$

- The green R&D subsidy can increase not only cost efficiency from the R&D investments and allocation efficiency from output production.

- Lemma 2. $s^{\mathrm{SP}} > MD^{SP}$ for $\gamma > \underline{\gamma}$ and $\forall\beta$

In private market, government should subsidize more than marginal environmental damage in order to encourage more production.

3. Private market

- Proposition 1.

$$W^{SP} \underset{>}{\overset{<}{=}} W^{TP} \Leftrightarrow \gamma \underset{<}{\overset{>}{=}} \gamma^{P} \equiv \frac{2(1+\beta)}{9}\left(\sqrt{(313+\beta(98+361\beta))}-(5-19\beta)\right)$$

- Whether an emissions tax or a green R&D subsidy is better in a private market depends not only on the spillover rate but also on green R&D efficiency.

- Social welfare can be higher (lower) with an emissions tax than that with a green R&D subsidy with higher (lower) R&D cost.

4. Mixed market

4.1. Emission Tax

- With an emissions tax, a public firm maximizes social welfare whereas private firm maximizes its own objective function.

- Equilibrium outputs in the 3rd stage:

$$q_0 = \frac{3t + 6(1+\beta)(z_0 + z_1)}{9} \quad q_1 = \frac{3A - 4t - 2(1+\beta)(z_0 + z_1)}{9} \quad Q = \frac{3A - t + 4(1+\beta)(z_0 + z_1)}{9}$$

- The equilibrium output of a private (public) firm and total market output decreases (increases) as the emissions tax increases (decreases).

- The emissions tax encourages public firms to be more aggressive in terms of production output but, because the output is a strategic substitute, this makes private firms more passive in terms of its production output.

4. Mixed market

- Equilibrium level of green R&D in the 2nd stage:

$$z_0 = \frac{2(1+\beta)(22A(1+\beta)^2 + 90A\gamma - t(199 + \beta(239 + 40\beta) + 48\gamma))}{3\gamma(94(1+\beta)^2 + 81\gamma)}$$

$$z_1 = \frac{t(2(1+\beta)^2(199 + 40\beta) + 9(35 + 8\beta)\gamma) - A(44(1+\beta)^3 + 54(1+\beta)\gamma)}{3\gamma(94(1+\beta)^2 + 81\gamma)}$$

$$Z = \frac{t(73 - 8\beta) + 42A(1+\beta)}{94(1+\beta)^2 + 81\gamma}$$

- The public firm's R&D decreases as the emissions tax increases, whereas the private firm's R&D and total R&D increase.
- From the perspective of government policy, the emissions tax and the public firm's R&D investment are strategically substitutable policy instruments.

4. Mixed market

- The optimal emission tax in mixed market (TM) is as follows:

$$t^{TM} = \frac{2A(88(1+\beta)^5(199+40\beta)+6(1+\beta)^3(9883+1900\beta)\gamma+27(1+\beta)(1517+464\beta)\gamma^2+4374\gamma^3)}{8(1+\beta)^4(199+40\beta)^2+6(1+\beta)^2(77701+8\beta(5920+1037\beta))\gamma+9(21985+16\beta(1361+397\beta))\gamma^2+20412\gamma^3}$$

- The comparison with the first-best outcomes: $Q^{\mathrm{FB}} > \mathrm{Q}^{TM}$ and $\mathrm{Z}^{FB} > Z^{TM}$
- Even in the presence of public firm, the emission tax is insufficient not only in green R&D investment but the output production: both under-investment and under-production result in double welfare losses

- Lemma 3. $t^{\mathrm{TM}} \underset{>}{\overset{<}{=}} MD^{TM} \Leftrightarrow \gamma \underset{<}{\overset{>}{=}} \gamma^{TM}$ where γ^{TM} $(> \underline{\gamma})$ satisfies $t^{\mathrm{TM}} = MD^{TM}$

In mixed market, the optimal emission tax with inefficient (efficient) R&D cost is lower (higher) than the marginal environmental damage.

4. Mixed market

4.2. Green R&D Subsidy

- Equilibrium outputs in the 3rd stage:

$$q_0 = \frac{2(1+\beta)(z_0+z_1)}{3} \qquad q_1 = \frac{3A-2(1+\beta)(z_0+z_1)}{9} \qquad Q = \frac{3A+4(1+\beta)(z_0+z_1)}{9}$$

- The equilibrium output of a public (private) firm and total market output increases (decreases) as R&D increases.

- Due to the output substitution effect between public and private firms, a green R&D subsidy encourages output at the public firm, which in return reduces the private firm's output. The output substitution effect also increases as R&D increases.

4. Mixed market

- Equilibrium level of green R&D in the 2nd stage:

$$z_0 = \frac{2(1+\beta)(22A(1+\beta)^2+90A\gamma - 159s(1+\beta))}{3\gamma(94(1+\beta)^2+81\gamma)}$$

$$z_1 = \frac{s(318(1+\beta)^2+243\gamma) - (1+\beta)A(44(1+\beta)^2+54\gamma)}{3\gamma(94(1+\beta)^2+81\gamma)}$$

$$Z = \frac{81s + 42A(1+\beta)}{94(1+\beta)^2+81\gamma}$$

- The public firm's R&D decreases as the green R&D subsidy increases, whereas the private firm's R&D and total R&D increase.
- From the perspective of government policy, the green R&D subsidy and the public firm's R&D investment are also strategically substitutable policy instruments.

4. Mixed market

- The optimal level of R&D subsidy in mixed market (SM) is as follows:

$$s^{SM} = \frac{88A(1+\beta)^3 + 234A(1+\beta)\gamma}{636(1+\beta)^2 + 243\gamma}$$

- The comparison with the first-best outcomes:

$Q^{FB} \gtreqless Q^{SM} \gtreqless Q^{SP}$ and $Z^{FB} \gtreqless Z^{SM} \gtreqless Z^{SP}$ if $\gamma \lesseqgtr \frac{4}{3}(1+\beta)^2$ while $Q^{SP} > Q^{TP}$ and $Z^{SP} > Z^{TP}$

- The green R&D subsidy can increase not only cost efficiency from the R&D investments and allocation efficiency from output production.

- Lemma 4. $s^{SM} > MD^{SM}$ for $\gamma > \underline{\gamma}$ and $\forall\beta$

Even in the presence of a public firm, the optimal green R&D subsidy is always higher than marginal environmental damage, irrespective of the level of green R&D inefficiency and spillovers.

4. Mixed market

- Proposition 2.

  $W^{SM} \underset{>}{\overset{<}{=}} W^{TM} \Leftrightarrow \gamma \underset{<}{\overset{>}{=}} \gamma^{M}$ where γ^{M} satisfies $W^{SM} = W^{TM}$

- Whether an emissions tax or a green R&D subsidy is better in a mixed market depends not only on the spillover rate but also on green R&D cost efficiency.

- Social welfare can be higher (lower) with an emissions tax than with an R&D subsidy and higher (lower) green R&D cost.

5. Discussion on privatization

- Proposition 3. $t^{TM} > t^{TP}$ and $s^{SM} \underset{>}{\overset{<}{=}} s^{SP} \Leftrightarrow \gamma \underset{<}{\overset{>}{=}} 44(1+\beta)^2$
- Privatization policy reduces the emissions tax but can increase (decrease) the green R&D subsidy when green R&D cost is high (low).
- With an emissions tax, both output production and R&D investment are higher in a mixed market than in a private market:
  $Q^{\mathrm{FB}} > Q^{\mathrm{TM}} > Q^{\mathrm{TP}}$ and $Z^{\mathrm{FB}} > Z^{\mathrm{TM}} > Z^{\mathrm{TP}}$.
- With a green R&D subsidy, however, output production and R&D investment in mixed markets are higher (lower) than in a private market when green R&D cost is low (high):
  $Q^{\mathrm{FB}} \underset{<}{\overset{>}{=}} Q^{\mathrm{SM}} \underset{<}{\overset{>}{=}} Q^{\mathrm{SP}}$ and $Z^{\mathrm{FB}} \underset{<}{\overset{>}{=}} Z^{\mathrm{SM}} \underset{<}{\overset{>}{=}} Z^{\mathrm{SP}}$ if $\gamma \underset{>}{\overset{<}{=}} \frac{4}{3}(1+\beta)^2$.

5. Discussion on privatization (Figure 1)

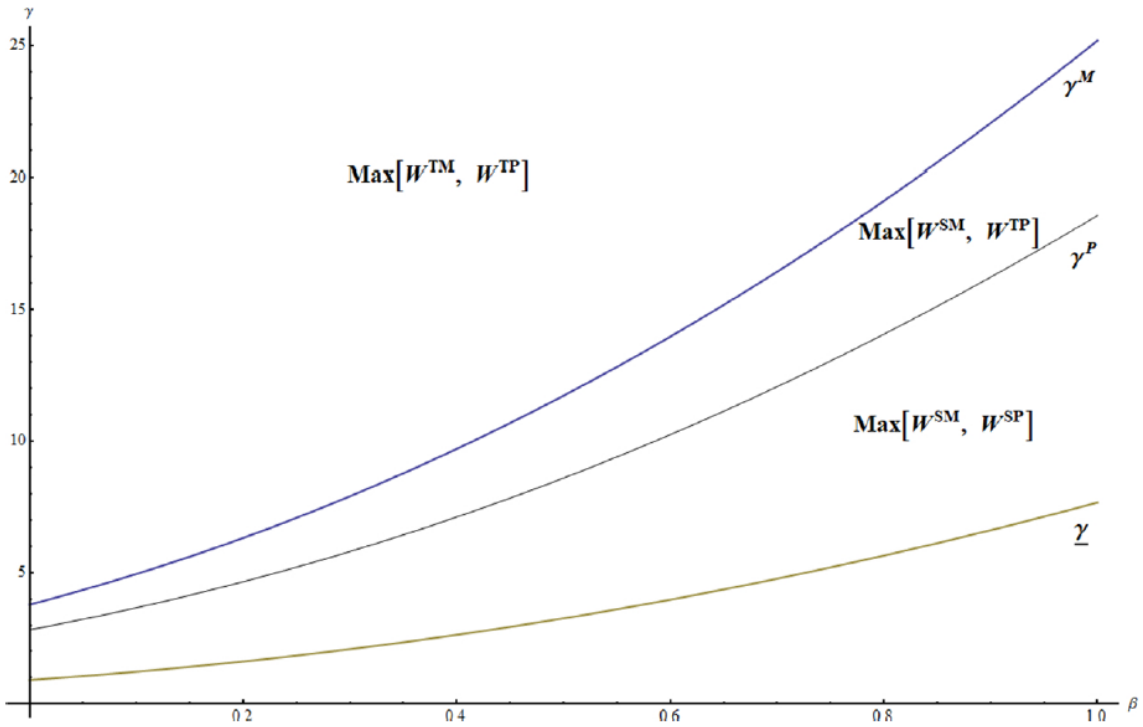

Figure 1. A comparison of γ^M and γ^P

5. Discussion on privatization

- Lemma 5. $\gamma^M > \gamma^P$ for $\gamma > \underline{\gamma}$ and $\forall\beta$

- If we compare the welfare threshold with an emissions tax and with a green R&D subsidy in both private and mixed markets, the government requires a lower threshold of green R&D inefficiency for privatization.

- This is because the government can use both public ownership and environmental policy, and thus the emergence of a public firm increases the welfare threshold.

- The government might prefer to adopt a green R&D subsidy in the presence of a public firm under certain condition in green R&D inefficiency.

5. Discussion on privatization (Figure 1)

- Proposition 4. With efficient R&D, $W^{\mathrm{SM}} > W^{\mathrm{SP}}$ for $\gamma > \underline{\gamma}$ and $\forall\beta$.
- When the government adopts a green R&D subsidy policy, mixed market always has higher welfare than the private market, and thus privatization lowers social welfare when green R&D inefficiency is lower.

- Proposition 5. With inefficient R&D, $W^{\mathrm{TM}} \gtreqless W^{\mathrm{TP}}$ for $\beta \gtreqless \beta^{T}$ where β^{T} satisfies $W^{\mathrm{TP}} = W^{\mathrm{TM}}$ and $\beta^{\mathrm{T}} > 0$ for $\gamma^{M} < \gamma$
- When the government adopts an emissions tax policy, the efficiency of the privatization policy depends on the effects of green R&D inefficiency and spillovers.

- Proposition 6. With moderate R&D, $W^{TP} \gtreqless W^{SM}$ for $\gamma \gtreqless \gamma^{TPSM}$ where γ^{TPSM} satisfies $W^{\mathrm{TP}} = W^{SM}$
- The government policies on environmental regulations and privatization depend on the relative R&D inefficiency and spillover effect in the region of $\gamma^{P} < \gamma < \gamma^{M}$.

5. Discussion on privatization (Figure 2)

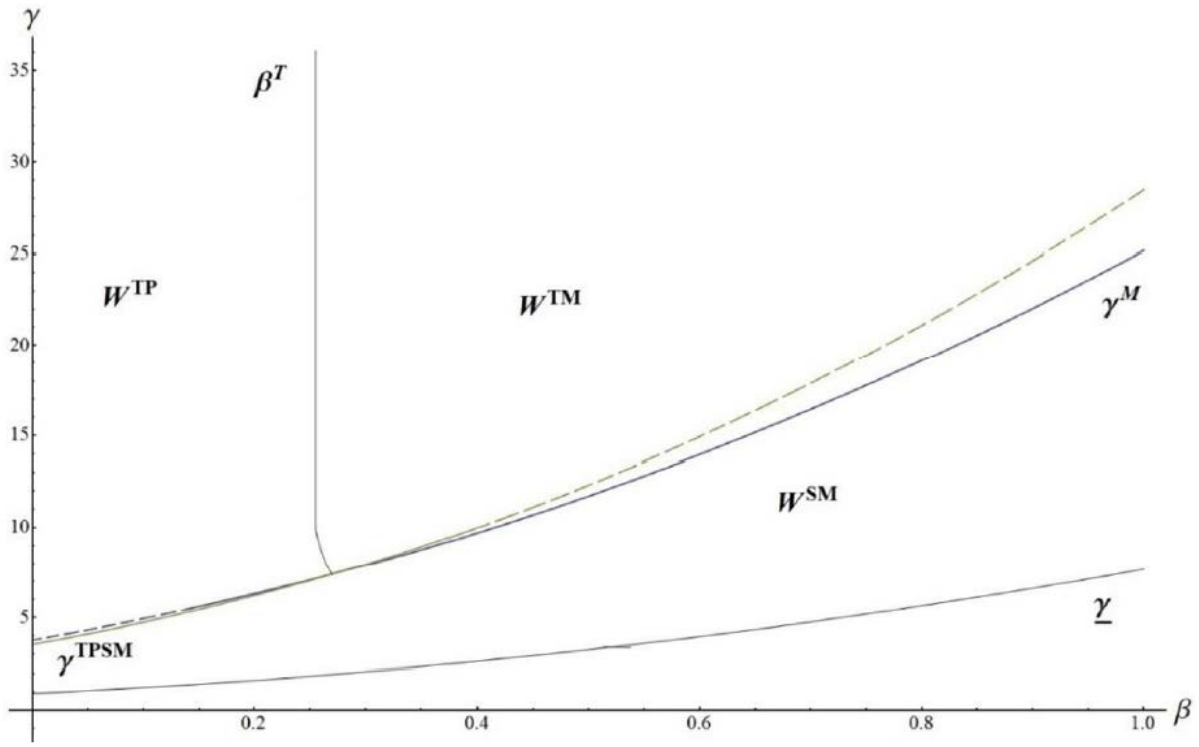

Figure 2. Optimal Policy Choices.

5. Discussion on privatization (Figure 2)

- Proposition 7. The optimal policy choices:

(1) If $\underline{\gamma} < \gamma < \text{Min}[\gamma^{TPSM}, \gamma^{M}]$, W^{SM} is the highest welfare.

(2) If $\gamma > \text{Min}[\gamma^{TPSM}, \gamma^{M}]$, W^{TM} is the highest when $\beta > \beta^{T}$, otherwise, W^{TP}.

- The government should provide the green R&D subsidy and keep the public firm with an efficient R&D.
- The government should impose the emission tax with an inefficient R&D and determine privatization policy depending on the R&D spillovers.
- The government should retain the public firm with a higher rate of spillovers while privatize the public firm with a lower rate of spillovers.

5. Discussion on privatization (Figure 2)

- Policy suggestions:

(1) When the green R&D is efficient, the R&D subsidy policy is more effective in the presence of the public firm.

(2) When the green R&D is inefficient, emission tax policy is superior, but the welfare effect of privatization depends on the R&D spillovers.

- When spillover effect is weak, the government should privatize the public firm in order to reduce large R&D investment by the public firm.
- As the spillover effect increases, the government should maintain the public firm to encourage the output productions and R&D investments.

5. Discussion on time-consistent emission tax

- We can extend the analysis to a time-consistent policy framework in which the government can strategically choose an optimal environmental policy after observing firms' R&D investment.

- Poyago-Theotoky (2007, 2010), Ouchida and Goto (2014, 2016), Garcia et al. (2018), Goel and Haruna (2019)

- The timing of the scenario changes as follows.

1st stage: Both firms determine their R&D simultaneously.

2nd stage: The government chooses the optimal tax level.

3rd stage: Both firms compete in output simultaneously.

5. Discussion on time-consistent emission tax

- In a private duopoly a time-consistent tax policy is better than a committed one because the government decreases the tax level for increasing production output, but welfare can be higher (lower) with an emissions tax than with an R&D subsidy under a higher (lower) R&D cost.

- In a mixed duopoly a time-consistent tax policy is better than a committed one because the government decreases the tax level to achieve higher production output, but welfare can be higher (lower) with an emissions tax than with an R&D subsidy under a higher (lower) R&D cost.

- A green R&D subsidy is desirable with inefficient R&D whereas a time-consistent tax policy is desirable with efficient R&D only when public firms exist.

- In mixed market, a privatization policy in a time-consistent framework does not improve welfare.

6. Time-consistent emission tax and privatization (Figure 3)

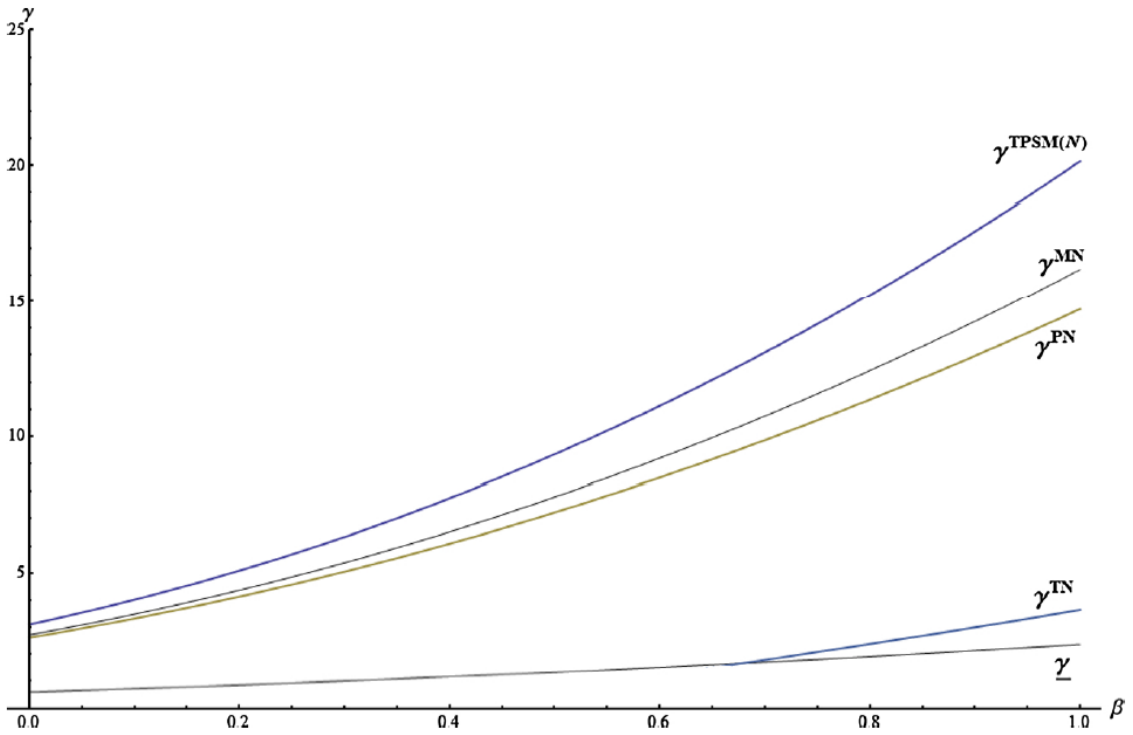

Figure A4. Optimal policy choices with a time-consistent emission tax.

7. Conclusion

- Our findings highlight the importance of government policy mix in upgrading toward a system of sustainable green growth.
  - a green R&D subsidy is better (worse) than an emissions tax when green R&D is efficient (inefficient), irrespective of R&D spillovers.
  - the existence of public firms encourages the government to adopt the subsidy policy.
  - when R&D is inefficient, the government should choose an emissions tax and (not) privatize public firms if the spillover rate is (not) low.
  - when R&D is efficient, a privatization policy is not desirable irrespective of spillovers.

8. Future Works

- Different market structures: Stackelberg and Bertrand competition in markets with differentiated products.
- Heterogenous objectives: environmental awareness or environmental corporate social responsibility.
- Heterogenous green R&D subsidies: green manufacturing versus green consumption.
- Heterogenous emission technologies: end-of-pipe versus integrated.
- Financial burdens under taxes versus green funds