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Abstract

This paper considers a mixed duopoly model where there are spillovers in environmental R&D. We adopt a three-stage game formulated by Haruna and Goel (2018) and investigate the impact of partial privatization on firm's investment in R&D and environmental taxes. We show that if the degree of privatization is relatively low and the spillover effect is significant, the private firm undertakes R&D and the government subsidizes emissions. Our model suggests that the government should never subsidize R&D when both firms invest in R&D. Furthermore, an increase in the degree of privatization is worse for the environment, but partial privatization increases social welfare.

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Pollution abatement and partial privatization

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Abstract

This paper studies the impact of partial privatization on firm's investment in R&D and environmental taxes. We consider a mixed duopoly model where there are spillovers in environmental R&D. We show that if the degree of privatization is relatively low and the spillover effect is significant, the private firm undertakes R&D and the government subsidizes emissions. Our model suggests that the government should never subsidize R&D when both firm invest in R&D. Furthermore, an increase in the degree of privatization is worse for the environment but partial privatization increases social welfare.

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1 Introduction

In recent years, environmental issues have increasingly become an important topic in public debates. Governments can usually promote green technology by imposing carbon taxes and providing research subsidies (Hsu et al., 2018).

In many countries (France, Italy, China...), private firms and the public firms coexist and compete in several highly R&D intensive industries such as gas, electricity, but also transport and telecommunications. For example, in Chinese telecommunication industry, the public firm Lenovo and the private firm Huawei have fierce R&D competition. In the academic literature, Poyago-Theotoky (1998) shows that the public firm is more innovative than the private firm while Nett (1994) shows the opposite.

In the last few decades, the privatization of public firms has spread in these R&D-intensive industries. Many papers have analyzed the impact of privatization on the environment in a mixed oligopoly industry. For example, Barcena-Ruiz and Garzon (2006) show that the environmental tax is lower in the mixed oligopoly than in the private oligopoly, but environmental damage is more important under nationalization. When firms supply differentiated goods, Wang and Wang (2009) show that the environment is more (less) damaged with privatization when the product is less (more) substitutable. In contrast, Naito and Ogawa (2009) argue that the optimal level of environmental regulation, critically depends on the degree of privatization, and its relationship is not monotonous.

The aim of this paper is to study the relationship between a public firm privatization and firm research and development (R&D) efforts in the presence of research spillovers. Following Poyago-Theotoky (2007) and Haruna and Goel (2018), we suppose that firms invest in R&D in order to develop new processes to reduce toxic emissions. Thus, in contrast to standard literature, firms choose output and emission levels at a different stage. Haruna and Goel (2018) examine and compare the equilibrium outcomes under full nationalization (mixed duopoly) and full privatization (private duopoly) and show that privatization leads to a reduction in R&D and tends to make the environment worse. However, this paper does not consider the possibility of the partial privatization of the public firm.

The introduction of partial privatization in the analysis is clearly relevant because in recent decades, many public firms have been partially privatized. Boubakri et al. (2008) show that between 1985 and 2005, partial privatization has been the most prevalent phenomenon in a sample of 120 developing countries (Pal and Saha, 2015). Bortolotti and Faccio (2009) show that in the OECD (Organization for Economic Co-operation and Development), at the end of 2000, governments retained control of 62.4% of privatized firms. Thus, the analysis of R&D activity in a market where a public firm is partially privatized have clear policy relevance.

In this context, we pose the following research questions: What is the impact of the degree of privatization on the firm's investment in R&D and environmental quality? What is the relationship between the emissions taxes and abatement technology?

We show that, irrespective of the degree of privatization and the spillover effects, the partially privatized firm invests more in R&D than the private firm. Moreover, the private firm's decision to invest in R&D depends on the degree of privatization. The private firm does not carry out R&D when the degree of privatization is relatively low. In addition, we show that the government never subsidies firms when both invest in R&D. In contrast, Haruna and Goel (2018) show that the emissions tax can be an emissions subsidy. Nevertheless, our model confirms that privatization makes the environment worse and social welfare can be enhanced by implemented partial privatization.

The paper is organized as follows. Section 2 sets up the model. In Section 3, we present the equilibriums. Sections 4 and 5 present respectively the impact of privatization and the welfare analysis. Finally, Section 6 offers some concluding remarks.

2 The model

We consider an economy where there exist one partially privatized firm (indexed by 0) and one private firm (indexed by 1) producing a homogeneous good. The firms engage in Cournot type quantity competition.

Let $q_i \geq 0$ denote the quantities produce by firm i $(i = 0, 1)$. Then, the inverse demand function is given by:

$$p = 1 - q_0 - q_1 \tag{1}$$

Marginal costs of production are identical for both firms, constant, and normalized to zero for simplicity.

Production processes in both firms pollute the environment; one unit of output emits one unit of pollutant. However, a firm can prevent pollution by undertaking abatement activities via environmental R&D. The cost of pollution abatement (R&D expenditure) of firm i is $a_i^2/2$, where a_i represents the abatement level of firm i. We assume that there are spillovers in R&D performance between firms. Thus net emissions from firm i are given by $e_i(q_i, a_i) = q_i - a_i - \gamma a_j$, where $0 \leq \gamma \leq 1$ represents the knowledge spillover from firm j to firm i.

The extent of environmental damage due to pollution by the industry is as follow: $ED = \frac{1}{2}(\sum e_i)^2$.

To correct pollution externality, the government imposes an environmental tax t on the emission level. The tax revenues collected by the government are $T = t \sum e_i$.

The profit function of firm i is given as:

$$\pi_i = pq_i - t(q_i - a_i - \gamma a_j) - \frac{a_i^2}{2} \qquad (i, j = 0, 1;\ i \neq j) \tag{2}$$

The social welfare function is the sum of consumer surplus CS, the producer surplus $\pi_0 + \pi_1$, and the tax revenues collected by the government T, less the environmental damage ED.

$$W = CS + \pi_0 + \pi_1 + T - ED \tag{3}$$

The private firm seeks profit maximization, whereas the partially privatized firm's objective function is the weight sum of consumer surplus and its profit (Beladi and Chao, 2006; Xu et al, 2016; Ouattara, 2018)[1]. Therefore the firm 0 objective function is given by

$$V = \alpha\pi_0 + (1-\alpha)(\pi_0 + CS) \tag{4}$$

where $\alpha \in [0,1]$ is the degree of private ownership (degree of privatization). When $\alpha = 1$, firm 0 is a fully privatized firm and maximizes profit, and when $\alpha = 0$, she is a completely consumer surplus-concerned public firm (Xu et al. 2016). The higher value of α denotes a higher level of privatization.

We propose a three-stage game. In the first stage, both the private firm and the partially privatized firm simultaneously and independently choose their environmental R&D effort. In the second stage, the government chooses the environmental tax rate to maximize social welfare. In the third stage, the two firms simultaneously and independently choose their outputs. To obtain a subgame perfect equilibrium, the game is solved by backwards induction.

3 Results

In the third stage of the game, the firm 0 and the firm 1 choose respectively q_0 and q_1 to maximize (4) and (2). Solving these problems, we obtain:

$$q_0 = \frac{(1-t)(2-\alpha)}{\alpha+2} \qquad q_1 = \frac{\alpha(1-t)}{\alpha+2} \tag{5}$$

A few remarks are in order. The output of both firms decreases with the environmental tax but does not depend directly on pollution abatement. This contrasts with the result of Haruna and Goel (2018), which shows that with higher emissions taxes the public firm increases its output, and pollution abatement has a direct impact on output. Moreover, our result shows that, with a higher degree of privatization, the private (partially privatized) firm increases (decreases) its output. However, the reduction in output is greater in the partially-privatized firm and privatization has a negative effect on total output.

In the second stage of the game, the regulator sets the emissions tax, t, to maximize social welfare. We substitute q_i into (3), and thus social welfare is as follows:

$$W = \frac{(1-t)\left[4(2t+\alpha) + 4(\gamma+1)(\alpha+2)(a_0+a_1)\right] - (\alpha+2)^2\left[2a_0a_1(\gamma+1)^2 + (2\gamma+\gamma^2+2)(a_0^2+a_1^2)\right]}{2(\alpha+2)^2}$$

Differentiation it with respect to t, we obtain the optimal emissions fee,

[1]In this paper we assume that the public firm (or partially privatized firm) no longer internalizes environmental externalities in its objective function. This assumption allows us to clearly distinguish between the public firm and the regulator.

$$t = \frac{1}{2} - \frac{\alpha + (\gamma+1)(\alpha+2)(a_0+a_1)}{4} \tag{6}$$

The optimal emissions tax is decreasing in the degree of privatization. Furthermore, the emissions tax rate is decreasing in the total pollution abatement.

Substituting t into (5), we obtain:

$$q_0 = \frac{(2-\alpha)\left[(\gamma+1)(a_0+a_1)+1\right]}{4} \qquad q_1 = \frac{\alpha\left[(\gamma+1)(a_0+a_1)+1\right]}{4} \tag{7}$$

$$ED = \frac{\left[(\gamma+1)(a_0+a_1)-1\right]^2}{8} \tag{8}$$

The output of both firms and the environmental damage depend on total investment in R&D. The partially privatized firm has a higher output than the private firm (for $\alpha < 1$). This result, which is common in the literature, is different from that obtained by Haruna and Goel (2018), which shows that the two firms produce the same outputs. Note that the degree of privatization has no direct impact on the environmental damage.

In the first stage, the private firm and the partially privatized firm choose their pollution abatement levels to respectively maximize (2) and (4). Solving these problems, we obtain:

$$a_0 = \frac{1}{2}\frac{\alpha^3(\gamma+1)^3 + 2\alpha^2(\gamma+1)(5\gamma+\gamma^2+8) - 2\alpha(\gamma+3)(\gamma-1) - 4(8\gamma+\gamma^2+11)}{(\gamma+3)(\alpha+\gamma+\alpha\gamma+3)(-\alpha+2\gamma^2+\alpha\gamma^2-6)} \tag{9}$$

$$a_1 = -\frac{1}{2}\frac{\alpha^3(\gamma+1)^3 + 2\alpha^2(\gamma+6)(\gamma+1)^2 - 2\alpha(\gamma+2\gamma^2+\gamma^3+4) - 4(5\gamma+6\gamma^2+\gamma^3-4)}{(\gamma+3)(\alpha+\gamma+\alpha\gamma+3)(-\alpha+2\gamma^2+\alpha\gamma^2-6)} \tag{10}$$

Corollary 1 *The R&D effort of the partially privatized firm is always higher than that of the private firm*[2] *($a_0 - a_1 > 0$)*

This result shows that even if the partially privatized firm does not internalize the environmental damage, its invests more in R&D than the private firm. Indeed, Haruna and Goel (2018) show that the public firm undertakes more R&D than the private firm because the public firm has a strong incentive to reduce the extent of social damage. Here, we highlight the fact that this result holds even if the partially privatized firm does not internalize the social damage.

[2] $a_0 - a_1 = \frac{(\gamma+1)(1-\alpha)(\alpha+1)\left(\alpha+12\gamma+2\gamma^2+2\alpha\gamma+\alpha\gamma^2+14\right)}{(\gamma+3)(\alpha+\gamma+\alpha\gamma+3)(\alpha-2\gamma^2-\alpha\gamma^2+6)} > 0$

Proposition 1

- *The partially privatized firm always undertakes R&D to abate emissions ($a_0 > 0$)*
- *The private firm's decision to abate emissions depends on the degree of privatization*
  - *If the degree of privatization is relatively high ($\alpha > \alpha^{\pi}(\gamma)$), the private firm undertakes R&D ($a_1 > 0$)*
  - *If the degree of privatization is relatively low ($\alpha \leq \alpha^{\pi}(\gamma)$), the private firm does not conduct R&D ($a_1 \leq 0$).*

with α^{π}, the value of α such thaht $a_1 = 0$.

$$\alpha^{\pi} = \frac{1}{3(\gamma+1)}\left[\frac{2^{2/3}(5\gamma^3+32\gamma^2+99\gamma+84)}{F^{1/3}} + \frac{-2\gamma^2-14\gamma-12+F^{1/3}(2^{1/3})}{\gamma+1}\right] \text{ and}$$

$$F = (\gamma+1)^2\left(14\gamma^4+41\gamma^3-324\gamma^2-1359\gamma-1188+3\sqrt{\frac{3(8368+16632\gamma-16621\gamma^2 -72063\gamma^3-79754\gamma^4-43256\gamma^5 -12601\gamma^6-1919\gamma^7-128\gamma^8-2\gamma^9}{\gamma+1}}\right)$$

This proposition shows that there exists a critical level of α such that the R&D expenditure of the private firm is zero. If privatization is still below the critical level, the private firm does not conduct R&D ($a_1^* = 0$)[3], then only the partially privatized firm undertakes R&D. It is also clear from proposition 1 that if the degree of privatization is high enough, both firms undertake R&D ($a_1^* * > 0$ and $a_0^* * > 0$). This result is due to the fact that when the degree of privatization is low, the partially privatized firm's investment in R&D is high[4]. In this condition, the private firm has more incentive to free-ride on the partially privatized firm's investment in R&D.

Figure 1 illustrates the sign of a_1 for a different value of the spillover effect. When spillover effects are low ($\gamma = 0$; $\gamma = 1/3$), the private firm conducts R&D. However, as the spillovers increase, the critical value for the degree of privatization increases. For example, if $\gamma = 2/3$, the private firm undertakes R&D if $\alpha = 0.64$. For $\gamma = 1$, the private firm invests in R&D when $\alpha = 0.85$.

[3] The superscript $*$ stands for the case where only the partially privatized firm undertakes R&D and the superscript $**$ for the case where both firms undertake R&D.

[4] $\frac{\partial}{\partial\alpha}a_0 < 0$

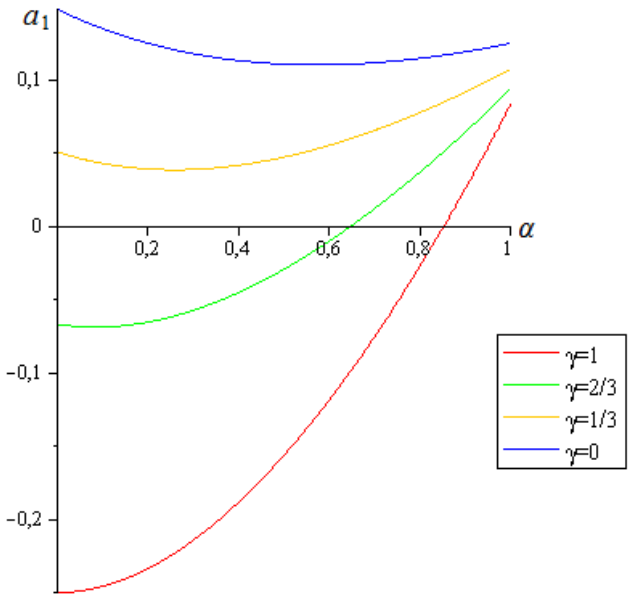

Fig.1: Private firm's investment in R&D as a function of privatization level

Substituting (9) – (10) back to (6), we get the optimal emission tax:

$$t^{**} = \frac{4\left(2-\alpha\right) - \alpha^2\left(\gamma+1\right)^2}{4\left(\gamma+3\right)\left(\alpha+\gamma+\alpha\gamma+3\right)}$$

$$t^{*} = \frac{\alpha^3(\gamma+1)^3(\alpha+6\gamma+\alpha\gamma+12)+2\alpha^2(\gamma+1)\left(23\gamma+16\gamma^2+3\gamma^3-2\right)-8\alpha\left(3\gamma+7\gamma^2+5\gamma^3+\gamma^4+4\right)-8\left(\gamma+15\gamma^2+7\gamma^3+\gamma^4-16\right)}{8(\gamma+3)(\alpha+\gamma+\alpha\gamma+3)(\alpha-2\gamma^2-\alpha\gamma^2+6)}$$

where t^{**} is the optimal tax when both firms undertake R&D and t^{*} the optimal tax when only the partially privatized firm undertakes R&D.

Note that $t^{**} \geq 0$. This implies that the government never subsidies firms when both invest in R&D. This result is in contrast to that obtained when the public firm internalizes pollution emissions, where the emissions tax can be an emissions subsidy (Haruna and Goel, 2018).

Proposition 2 *In equilibrium:*

- *both firms invest in R&D and the government chooses a positive emissions tax, if* $\alpha > \alpha^{\pi}$;
- *only the partially privatized firm invests in R&D and the government chooses a positive emissions tax, if* $\alpha^{t} < \alpha \leq \alpha^{\pi}$;
- *only the partially privatized firm invests in R&D and the government chooses an emissions subsidy, if* $\alpha < \alpha^{t}$

with α^{t}, the value of α such that $t^{*} = 0$. Since the expression of α^{t} is rather complicated, we abstain from presenting it here and use a figure.

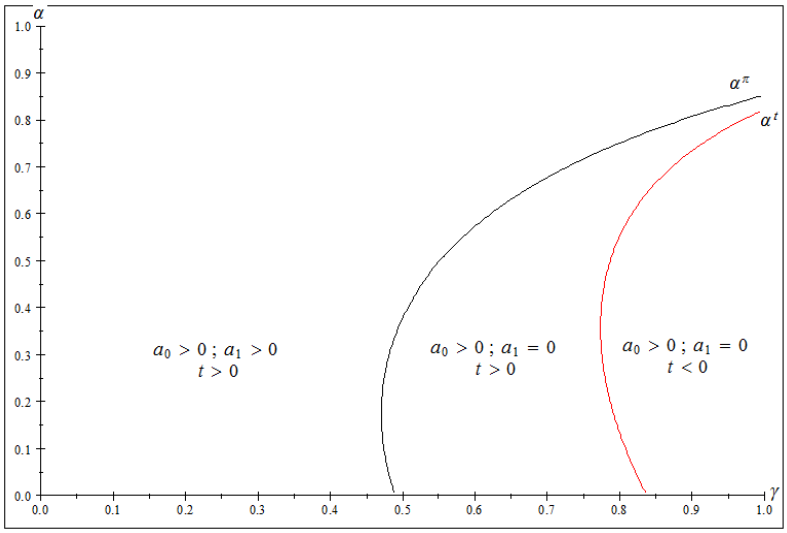

Fig 2: R&D and emissions taxes

As illustrated by Figure 2, this proposition points out the relation between emissions taxes and R&D efforts. We show that the government always sets a positive emissions tax when both private and partially privatized firms invest in R&D. Furthermore, when both α and γ take intermediate values, the tax remains positive even if only firm 0 invests in R&D. Finally, if the degree of privatization is relatively low and a spillover effect is significant, the private firm undertakes R&D and the government subsidizes emissions to encourage the partially privatized firm to produce more.

4 Impact of privatization

Now we can study the effects of the increase of the degree of privatization on relevant variables. We analyze only the case where both firms invest in R&D.

Substituting $(9)-(10)$ back to $(7)-(8)$, we get the SPNE equilibrium:

$$q_0^{**} = \frac{(2-\alpha)\left(\alpha(\gamma+1)^2+2\gamma(\gamma+6)+14\right)}{4(\gamma+3)(\alpha+\gamma+\alpha\gamma+3)} \qquad q_1^{**} = \frac{\alpha\left(\alpha(\gamma+1)^2+2\gamma(\gamma+6)+14\right)}{4(\gamma+3)(\alpha+\gamma+\alpha\gamma+3)}$$

$$ED^{**} = \frac{\left(\alpha(\gamma+5)(\gamma+1)+4\right)^2}{8(\gamma+3)^2(\alpha+\gamma+\alpha\gamma+3)^2}$$

$$CS^{**} = \frac{\left(\alpha(\gamma+1)^2+2\gamma(\gamma+6)+14\right)^2}{8(\gamma+3)^2(\alpha+\gamma+\alpha\gamma+3)^2}$$

Proposition 3 *If both firms invest in R&D, an increase in the degree of privatization:*

- *Decreases the aggregate investment in R&D.*
- *Decreases the environmental tax rate.*
- *Decreases the total output.*

- *Damages the environment.*

Proof. $\frac{\partial}{\partial\alpha}(a_0^{**}+a_1^{**})=\frac{-8\gamma-\gamma^2-11}{(\gamma+3)(\alpha+\gamma+\alpha\gamma+3)^2}<0$

$\frac{\partial}{\partial\alpha}(q_0^{**}+q_1^{**})=\frac{-(\gamma+1)\left(8\gamma+\gamma^2+11\right)}{2(\gamma+3)(\alpha+\gamma+\alpha\gamma+3)^2}<0;$

$\frac{\partial}{\partial\alpha}ED^{**}=\frac{(\gamma+1)\left(8\gamma+\gamma^2+11\right)\left(5\alpha+6\alpha\gamma+\alpha\gamma^2+4\right)}{4(\gamma+3)^2(\alpha+\gamma+\alpha\gamma+3)^3}>0;$

$\frac{\partial}{\partial\alpha}t^{**}=\frac{-\alpha(\gamma+1)^2(\alpha+2\gamma+\alpha\gamma+6)-4(3\gamma+5)}{4(\gamma+3)(\alpha+\gamma+\alpha\gamma+3)^2}<0$ ■

This proposition shows that privatization makes the environment worse. In fact, privatization has two effects on environmental damage. First, privatization reduces environmental damage by limiting the total output of the industry. Second, privatization increases environmental damage by restricting the aggregate investment in R&D. Since the second effect dominates the first, environmental damage is more important when the degree of privatization increases. This result is similar to that of Haruna and Goel (2018). Thus, whether or not firm 0 internalizes environmental damage, privatization makes the environment worse. However, our result is in contrast to that obtained when both firms choose output and emissions (abatement) levels at the same stage (Ouattara, 2018).

5 Welfare analysis

We now discuss the welfare implication of partial privatization. Figure 3 illustrates the sign of $\frac{\partial W^{**}}{\partial\alpha}$ for a different value of spillover effect. Since $\frac{\partial W^{**}}{\partial\alpha}\mid_{\alpha=0}>0$, therefore social welfare increases when firm 0 is at least partially privatized[5]. We also show that full privatization is never desirable since $\frac{\partial W^{**}}{\partial\alpha}\mid_{\alpha=1}<0$. Furthermore, for given γ, there exists a critical value of α such that $\frac{\partial W^{**}}{\partial\alpha}=0$. For example, when knowledge spillovers are absent ($\gamma=0$) the optimal degree of privatization is $\alpha=0.34$. When spillovers are present, the critical value of α increases (for full spillovers ($\gamma=1$), the optimal degree of privatization is $\alpha=0.89$). Thus, partial privatization is the best choice.

Corollary 2 *The optimal degree of privatization increases with the knowledge spillovers.*

[5] We show that $\frac{\partial W^{**}}{\partial\alpha}\mid_{\alpha=0}=\frac{76\gamma+228\gamma^2+765\gamma^3+326\gamma^4-337\gamma^5-288\gamma^6-57\gamma^7+3\gamma^8+\gamma^9+243}{-(\gamma+3)^5(-3+\gamma^2)^3}>0$

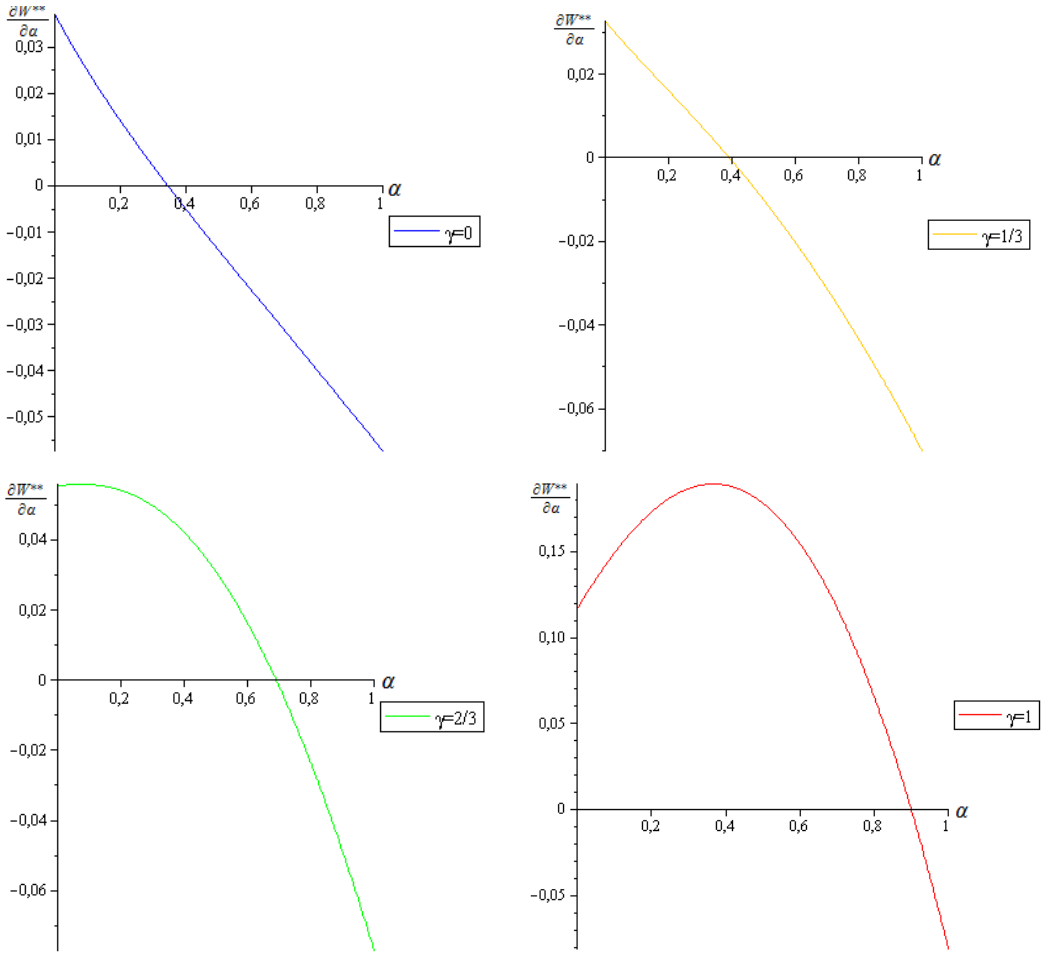

Fig 3: Privatization effect on social welfare

6 Conclusion

Our model serves to illustrate the sensitivity of environmental policy and a firm's investment in R&D to the degree of partial privatization of the public firm. Some of our findings are summarized below:

First, the partially privatized firm undertakes more R&D than the private firm and always invests in R&D. However, the private firm does not conduct R&D when the degree of privatization is relatively low. This finding highlights that when the private firm determines its R&D investments, it should consider the degree of public firm's privatization.

Second, when both firms invest in R&D, the government should never subsidize R&D. In other words, pollution tax is the optimal policy to curb emissions when the level of privatization is high enough. This result is fairly remarkable in that it is different to that obtained by Haruna and Goel (2018), who show that the emissions tax can be an emissions subsidy.

Finally, an increase in the degree of privatization makes the environment worse, since the total pollution level increases with privatization. Furthermore, partial privatization increases social welfare. For the social planner, this finding implies that full privatization cannot be recommended, since the partial privatization of the public firm is socially desirable and

reduces the level of pollution.

We conclude this paper by providing an avenue for future work. We supposed that the owners and managers of both firms have the same goals. However, in many companies, ownership and management are separated. The introduction of managerial delegation would have an impact on a firm's investment in R&D and the emissions tax.

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