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Trade, Transboundary Pollution and Strategic Environmental Policy

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ABSTRACT

To study the regional economic conditions on the strategic environmental policies under free trade agreement with transboundary pollution, we set up a model that specifies different types of transboundary pollution with a distinguishable factor denoted as abatement capability. We study the conditions for optimal cooperative and non-cooperative tax policy under symmetric oligopoly. We also examine the effect of different abatement capabilities under the cooperative and non-cooperative environmental policies.

Keywords: transboundary pollution, abatement capability, efficient emission tax, Nash equilibrium tax

INTRODUCTION

It is commonly believed that free trade might damage the environment, because government might relax their environmental policies in order to give their domestic producers a competitive edge in the world market. Such concerns usually lead to international conferences between trading partners to coordinate their environmental policies. Without such cooperation on environmental policies, countries with higher environmental standards tend to raise tariffs or using other non-trade barriers on imports from countries with lax environmental standards. Such policies have found favour with industries in the tradable sector, but it is also the source of contention between trading partners about covert protectionism, which is against the free-trade stipulation and would be weeded out or banned by trade agreement.

In a competitive market and free trade, countries which have no market power and no dispute over transboundary pollution would have no incentive to relax their environmental policies, because suppliers with no market power cannot alter market price to gain competitive edge. Conventional wisdom claims that, without trade barrier (i.e., tariffs), countries with high market power will have the incentive to relax their environmental regulation, thus extract rent from trade. Brander et al. [2, 21] showed that government tends to shift rent from foreign countries to home countries by using export subsidies or other government interventions. Rauscher [19], Kennedy [11] and Barrett [1] showed that government tends to use environmental policies to subsidize their exports in a free-trade environment. Such cases are usually characterized as "ecological dumping", i.e. a situation in which governments use low emission taxes and lax environmental standards for their domestic firms to dump their goods in the international market at relatively low prices. However, Krutilla [12] shows that a large net-exporting country will tighten its environmental regulation (i.e. set a tax rate above the standard Pigouvian level) and use the emission tax as an export tax to extract profits from importing countries, as long as the taxing country's net-exporter status is unchanged. And the net-importing countries will relax their environmental regulation. This effect is called the "term-of-trade effect". There is also the "pollution-shifting effect". Government may raise pollution taxes in order to shift the polluting factories to the other country. Pollution-shifting effect is exactly opposite to the "rent-shifting effect". However, there is no hard evidence to presume that all governments in the same trade situation will or will not engage in eco-dumping or pollution-shifting.

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In the literature concerning eco-dumping incentives under imperfectly competitive international market, Brander et al. [2, 21] showed that there is "rent shifting" incentive for some exporting governments to relax their environmental regulations. Kennedy [11] shows that the incentive for eco-dumping is intensified with transboundary pollution cases. However, Burguet et al. [3] study the effect of bilateral reduction in tariffs on the distortion of environmental policies, and show that trade liberalization actually reduces the incentive for a government to relax its environmental regulation. Duval et al. [7] shows that "burden shifting" (i.e. "pollution-shifting") effect might countervail "rent shifting" effect, regulators in net exporting countries might set a higher emission taxes. Hamilton et al. [8] shows that, with vertical contract in the international trade relationship, strategic distortion in environmental policies becomes unnecessary.

In the literature considering trade and incentive for innovation, Ulph [22] shows that governments might have incentive to relax regulation to encourage domestic producers to invest more on innovations. However, Michael Porter [16] argued that tougher regulation leads to improved industrial performance, thus, this would give that country a competitive advantage. Subsequently, Porter et al. [17, 18] argued that stringent environmental standard has dynamic benefits derived from its effect on promoting innovation. The dynamic benefits might be derived from the increased market share and innovation.

Simpson and Bradford [20] found only in very special cases, tougher regulation may induce the firm to innovate. But their result is not conclusive. Mohr [14] showed that the policy that conforms to the "Porter's hypothesis" is not necessarily optimal. However, they did not differentiate firm's ability to adapt under pressure. There is only a handful of studies on the innovation strategies for the small and medium corporations. (see Hoffmana et al. [9]). The innovation capability of small and medium firms is seldom studied. It is usually assumed that the innovation is too expensive for small and medium firms to undertake.

We are interested in the policy implication for a small economy like Taiwan. Taiwanese economy is driven by numerous small exporting companies. Conventional wisdom and economic studies claimed that only larger corporations could adopt environmental R&D strategies successfully, while small firms suffer from a number of disadvantages (e.g. inability to spread risk over a portfolio of new products; difficulties in marketing a start-up branch abroad; and problems in funding longer-term R&D). Dean et al. [6] examined new business formations across 170 manufacturing industries over a 10 year span (from 1977 to 1987) and argued that stringent environmental regulation may discourage small business formations, because small and medium enterprises (SMEs) faced higher unit pollution abatement costs and unequal treatment from regulatory authorities. However, most Taiwanese companies are smaller than the firms in the SMEs categories, but they are diligent, creative, and very competitive in the world market. They might not be able to afford an overlarge R&D investment, but they have to comply with European regulation and standards if they want to sell their products in the European market. Nevertheless, Some Taiwanese companies have beaten their American and Japanese competitors in the European market. Some studies argued that SMEs have comparative advantage over larger firms because they are flexible in response to external threat or opportunity with efficient internal communication and interactive management style. The ability to adapt in response to a tougher standard is usually different across regions or across different groups of firm with different realized competitive strategies or positioning (see Keeble [10]; and L. A. Lefebvre et al. [13]). Some acquire the innovation knowledge because of the organizational or geographic proximity (see Davenport [5]), some by their government's interventions or other forces to promote collaboration amongst SMEs, some by increasing social capital or learning ability through networking or through local clusters (see Cooke et al. [4]; Hoffmana et al. [9]; and Mytelka [15]). It would be interesting to see how this capacity to adapt affect firm's output strategy and the relationship between environmental policy and the adapting capability. In this paper, we refer to such capability as the abatement capability.

To examine the effect of abatement capability and transboundary pollution on production and regulation, we incorporate these factors into the basic model. Our analysis focuses on the cooperative and non-cooperative environmental policy between trading partners in an oligopoly setting. We have characterized an abatement capability factor in the model. And we assume there's a regional free-trade-agreement between two trading partners under a two-stage Cournot-Nash game. We will present our model in the next section and then use the simulation result to examine the effects of abatement capability or the effect of transboundary pollution on regulation.

THE MODEL

Consider a model with two countries as trading partners, each producing a homogeneous and polluting product within a symmetric framework. There are n identical firms in each country. Consumers are also identical in both countries. And for each county firm emit e_i into the environment according to the chosen abatement technology, and the marginal cost of abatement also depends on the chosen technology, that is, marginal abatement cost θ_i is the proxy for the type of abatement technology adopted. When a firm adopts the clean abatement technology, marginal abatement cost θ_i is high. When the firm adopts the dirty abatement technology that emits more pollutants into the environment, its marginal abatement cost θ_i is low. Hence, emission level is the function of marginal abatement cost, that is, $e_i = e(\theta_i)$, and $e' < 0$, $e'' > 0$. Pollution generates environmental damages, and total damages are the sum of damages caused by local, global, and transboundary pollution. Damages for country i is denoted as $d_i = d(\sum_{j=1}^{N} \alpha_i^j n_j e_j y_j)$, where $\alpha_i^j \in [0,1]$ denotes the share of country i's total environmental damage caused by country j's production. Suppose $\partial d/\partial e > 0$, $\partial(\partial d/\partial e)/\partial e > 0$. If the externality is purely rival, it must satisfy $\sum_{i=1}^{N} \alpha_i^j = 1$, that is, the total pollution shares produced by country j's must equal to one. However, some pollution may be purely non-rival and some may be between purely rival and purely non-rival, e.g. the problem with green house gases is purely non-rival and the destruction of ozone layer is the case in between. Under purely non-rivalry condition, such as global warming, we have $\sum_{i=1}^{N} \alpha_i^j = N$. However, if $\alpha_i^j = 0$ for all $i \neq j$, then it means there is no transboundary externalities. In some cases, the pollution flow only uni-directional, that the damages may be shared mostly by the other country, such as jet stream or ocean current. The victim may suffer more damages than the culprit, depending on the factors that transfer the pollution over the border. In such case, both countries produce polluting goods, but country 1's pollution is blown away toward country 2, if the wind is uni-directional, then $\alpha_1^1 < 1$, $\alpha_1^2 = 0$, $\alpha_2^2 = 1$, $\alpha_2^1 = 1 - \alpha_1^1 > 0$.

In order to show the strategic behavior of the firms and the governments, our framework is a two-stage game. In the first stage, the regulator, i.e. the government in each country, sets an emission tax on the polluting production. In the second stage, the producers in each country take the emission tax as given, and choose their output level and play Cournot-Nash game.

Equilibrium Strategies for Polluting Firms

In the second stage, given t_i, the optimal problem of a representative firm of country i is

$$\max_{y_i^H, y_i^F, \theta_i} p(X_i) y_i^H + p(X_{-i}) y_i^F - \theta_i y_i - t_i e_i y_i \tag{1}$$

where y_i is the production level of the i^{th} firm, and the superscript H denotes production for home consumption, and the superscript F denotes production for exports, so $y_i = y_i^H + y_i^F$. X_i denotes total consumption in country i, and $X_i = n_i y_i^H + n_{-i} y_{-i}^F$. The first-order conditions for the representative firm are

$$p + \frac{p' y_i}{2} = \theta_i + t_i e_i \tag{2}$$

$$t_i e' = -1 \tag{3}$$

Equation (2) implies that marginal revenue of production equals marginal cost of production under emission tax system. Set $k = -e'$. Equation (3) can be rewritten as $t = 1/k$. Note that k can be interpreted as the technical capability of adopting a cleaner abatement technology, we denote it as the abatement capability, and $k = -e' = k(\theta_i) > 0$ while $k' < 0$, which means marginal level of k decreases when θ increases. Under this condition, the firm's marginal emission level is decreasing when the firm shifts from a low abatement cost (i.e., dirtier technology) to a high abatement cost (i.e. cleaner technology). In other words, with one more dollar invested in a cleaner abatement technology, the country with higher k can reduce more emission. Hence, k can be characterized as the "abatement capability" factor, and emission tax is inversely related to the abatement capability. First order condition can be rearranged as the following Nash equilibrium condition:

$$p = \theta_i + \frac{e_i}{k_i} - \frac{p' y_i}{2} \tag{4}$$

And the second-order condition is 3p'+p"y < 0. Considering a symmetric equilibrium, that is, $Y_i = Y_i = X_i = X_{-i} = X$ and $t_i = t_j = t$, equilibrium condition of equation (2) can be rearranged as the following:

$$y = \frac{2(\theta + te - p)}{p'} \tag{5}$$

Assume that the polluting product is a normal good, by definition, we have p′ < 0. Equation (5) shows that the equilibrium output is negatively related to θ, t, and e in the symmetric case. The equilibrium output level cannot be negative, i.e. y ≥ 0, hence, θ, t, and e should satisfy $p - t\,e - \theta \geq 0$, i.e. market price exceeds the after-tax marginal costs. Differentiate (4) with respect to y and k yields

$$\frac{dy_i}{dk} = \frac{2(d\theta/dk - e_i/k_i^2 + \frac{e'}{k_i}\frac{d\theta}{dk})}{(3p' + p''y)} > 0 \tag{6}$$

Recall that $e' = -k$ and based on the second order condition from firms' optimal strategy. Output is positively related to the abatement capability, i.e. $dy_i/dk > 0$ (which implies $dy_i/dt_i < 0$, because in equilibrium, $t = 1/k$). This is quite interesting, because this comparative static result shows that when the environmental tax increases, firm may reduce its output in order to gain more profit. Nonetheless, equation (6) states that if abatement capability is higher, the firm will produce more. On the other hand, equation (6) also shows that a firm may choose to innovate and improve its abatement capability, and if its abatement capability do increase, its output level will also increase. Differentiate equation (3) with respect to θ_i and t_i yields the following:

$$\frac{d\theta_i}{dt_i} = \frac{-e'}{te''} = \frac{1}{t^2 e''} = \frac{(e')^2}{e''} = \frac{k^2}{e''} > 0 \tag{7}$$

Equation (7) shows that if a regulator set a higher emission tax, in equilibrium, firm's abatement cost may increase.

We will discuss the first stage's optimal strategy for both governments in the next section. In the first stage, given the equilibrium behaviour of firms and the tax rates of the other country, regulator chooses its emission tax rate to maximize the domestic welfare. We will also discuss two different optimal strategies which are the cooperative and non-cooperative strategies.

Efficient Emission Tax (Cooperative Outcome)

Let us consider the efficient tax rate under free trade agreement. In equilibrium, firm will maximize $\pi_i = py_i - \theta_i y_i - t_i e_i y_i$, and first order condition would yield the following conditions: $p + p'y_i = \theta_i + t_i e_i$, and $te' = -1$.

The efficient emission tax rate is chosen to maximize the joint welfare of both countries. Each country's welfare is total surplus plus tax revenue, then subtract the damages from it.

Let $2X = X_i + X_{-i} = Y_i + Y_{-i}$. The joint welfare function is the following:

$$W = [\int_0^{2X} p(u)du - 2pX] + \sum[pY_i - \theta_i Y_i - t_i e_i Y_i] + \sum te_i Y_i - D \tag{8}$$

given Y_i, Y_{-i}, θ_i, θ_{-i} from firm's equilibrium choices, and $D = \sum d_i$. Joint welfare function can be rewritten as

$$W = \int_0^{2X} p(u)du - \sum \theta_i Y_i - \sum d_i \tag{9}$$

First order condition of (9) with respect to t_i is

$$2p\frac{dX}{dt_i} - \sum_i \theta_i \frac{dY_i}{dt_i} - Y_i \frac{d\theta_i}{dt_i} = (d_i'\alpha_i^i + d_j'\alpha_j^i)e_i \frac{dY_i}{dt_i} + (d_i'\alpha_i^j + d_j'\alpha_j^j)e_j \frac{dY_j}{dt_i} + (d_i'\alpha_i^i + d_j'\alpha_j^i)Y_i e_i' \frac{d\theta_i}{dt_i} \tag{10}$$

This means marginal social cost equals marginal social benefit. Marginal social cost reflects the welfare loss by the reduced output and the reduced consumption. Marginal social benefit reflects the reduced damages.

In the symmetric case the efficient tax is the following:

$$t^* = \frac{[1-(\alpha_i^i+\alpha_j^i)d'k]}{2[p-\theta-(\alpha_i^i+\alpha_j^i)d'e]\cdot\varepsilon\cdot e''} \tag{11}$$

where ε = (dX/dt)(t/X) is the elasticity of equilibrium output with respect to t. Equation (11) shows that efficient tax is lower if k is higher. The following conditions is derived from (11):

$$if \quad \left[(p-\theta-(\alpha_i^i+\alpha_j^i)d'e)\varepsilon\right]\cdot\left[1-(\alpha_i^i+\alpha_j^i)d'k\right]>0 \quad then \quad t^*>0 \tag{12}$$

This condition states that government should levy pollution tax if the conditions $[p-\theta-(\alpha_i^i+\alpha_j^i)d'e]\varepsilon$ < 0 and $(\alpha_i^i+\alpha_j^i)d'k=(\alpha_i^i+\alpha_i^j)d'k>1$ are satisfied. Notice that ε < 0, thus $[p-\theta-(\alpha_i^i+\alpha_j^i)d'e]$ > 0. It states that the profit gained from producing polluting product (i.e., $p-\theta$) is larger than the emission damages caused by production in both countries (i.e., $(\alpha_i^i+\alpha_i^j)d'e$). In other words, it is beneficial for firms to produce polluting goods. But the additional damage caused by spending $1 in producing the polluting goods (i.e. $(\alpha_i^i+\alpha_i^j)d'k$) is larger than its cost, Under this circumstance, there are unrealized external costs, so the government should levy emission taxes to internalize the externality.

Nash Equilibrium Tax (Non-cooperative Outcome)

Given the equilibrium behavior of firms and given the tax rates of the other country, each country chooses its emission tax rate to maximize its own welfare. In an open economy, the home government chooses t_i to maximize

$$W_i=[\int_0^{X_i}p(u)du-pX_i]+[pY_i-\theta_iY_i-t_ie_iY_i]+t_ie_iY_i-d_i \tag{13}$$

given t_j, Y_i, Y_j, θ_i, θ_j. Equation (12) can be rewritten as

$$W_i=[\int_0^{X_i}p(u)du-\theta_iX_i]+(p-\theta_i)(Y_i-X_i)-d_i \tag{14}$$

The first order condition of equation (13) with respect to t_i is

$$\begin{aligned}&(p-\theta_i)\tfrac{dX_i}{dt_i}-X_i\tfrac{d\theta_i}{dt_i}+(p-\theta_i)(\tfrac{dY_i}{dt_i}-\tfrac{dX_i}{dt_i})+(Y_i-X_i)(p'\tfrac{dX_i}{dt_i}-\tfrac{d\theta_i}{dt_i})\\&-\textstyle\sum_s d_i'\alpha_i^se_s\tfrac{dY_s}{dt_i}-d_i'\alpha_i^iY_ie'\tfrac{d\theta_i}{dt_i}=0\end{aligned} \tag{15}$$

This condition can be rewritten as

$$(p-\theta_i)\tfrac{dY_i}{dt_i}+(Y_i-X_i)p'\tfrac{dX_i}{dt_i}-Y_i\tfrac{1}{t_i^2e''}-\textstyle\sum_s d_i'\alpha_i^se_s\tfrac{dY_s}{dt_i}+d_i'\alpha_i^iY_i\tfrac{k}{t_i^2e''}=0 \tag{16}$$

or

$$\begin{aligned}&(p-\theta_i)(\tfrac{dY_i}{dt_i}-\tfrac{dX_i}{dt_i})+[(p-\theta_i)+(Y_i-X_i)p']\tfrac{dX_i}{dt_i}-\textstyle\sum_s d_i'\alpha_i^se_s\tfrac{dY_s}{dt_i}\\&-(1-d_i'\alpha_i^ik_i)Y_i\tfrac{1}{t_i^2e''}=0\end{aligned} \tag{17}$$

Notice that from equation (15) to (17), *s* denotes foreign country, i.e. *s* = -*i*. The first two terms of the Nash condition reflects the net effect on welfare cost associated with the tax, and the last two terms reflects the marginal effect on internal (i.e. domestic) and transboundary pollution damages.

Let $\tau_i = t_i^2$. Rearranging the Nash equilibrium condition yields the implicit tax rule

$$\tau_i=\left(1-d_i'\alpha_i^ik_i\right)\cdot Y_i\Big/e''\left[(p-\theta_i)\tfrac{dY_i}{dt_i}+(Y_i-X_i)p'\tfrac{dX_i}{dt_i}-\textstyle\sum_s d_i'\alpha_i^se_s\tfrac{dY_s}{dt_i}\right] \tag{18}$$

This implicit tax rule shows that Nash equilibrium tax depends more on internal externality (i.e. domestic pollution) rather than the transboundary externality.

In the symmetric case, i.e. $Y_i=Y_j=X_i=X_j$, equation (16) can be rewritten as

$$(p-\theta_i)\varepsilon_i - \frac{1}{te''} - \sum_s d_i'\alpha_i^s e_s\varepsilon_s + d_i'\alpha_i^i k_i\frac{1}{te''} = 0 \quad (19)$$

where $\varepsilon_s = (\partial Y_s/\partial t_i)t_i/Y_s$.

The symmetric Nash equilibrium tax is

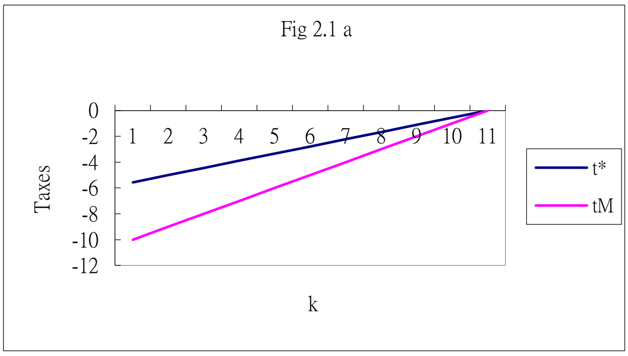
$$t^M = \frac{1-d'\alpha_i^i k_i}{e''[(p-\theta_i)\varepsilon_i - \sum_s d'\alpha_i^s e_s\varepsilon_s]} \quad (20)$$

Equation (20) suggests that non-cooperative government only consider its home profits and costs. Home government only levy emission taxes, i.e. $t^M > 0$, if $p-\theta-\sum_s \alpha_i^s e_s d' > 0$ and $d'\alpha_i^i k_i > 1$. This is quite intuitive. The first condition captures net rent-shifting effect (i.e. profit from trade exceeds the externality cost from trade). The second condition reveals the externality from trade. Net rent-shifting effect is positive, which suggests that non-cooperative government would encourage trade by lowering taxes, and emission tax can only be positive if the domestic social cost is greater than domestic private cost. That is, if the additional damages caused by spending $1 in producing the polluting goods (i.e. $\alpha_i^i d' k_i$) is larger than its cost, then the regulator should internalize the domestic externality by taxing emission.

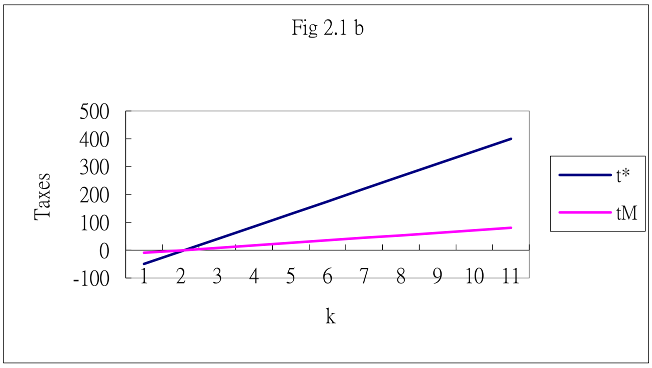
Simulation Result

Using the equilibrium result developed in the previous section, we can examine the effect of k on the efficient tax and Nash tax under three transboundary pollution scenarios: non-transboundary pollution, transboundary pollution, and global pollution. First, in the non-transboundary pollution cases, we set two different market schemes, i.e. low rent ($p-\theta=1$) and high rent ($p-\theta=10$), and two different damage scheme, i.e. low marginal damage (d'=0.1) and high marginal damages (d'=0.9). We will show some interesting result concerning the effect of k in this section.

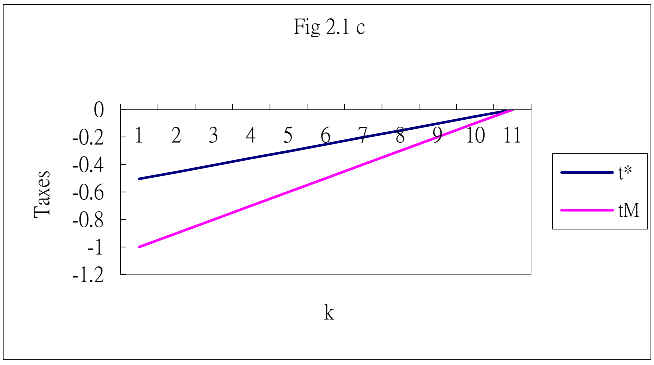
The simulation result for non-transboundary pollution is shown in Fig. 2.1a through 2.1d. The parameter set for the simulation is shown underneath the graph.



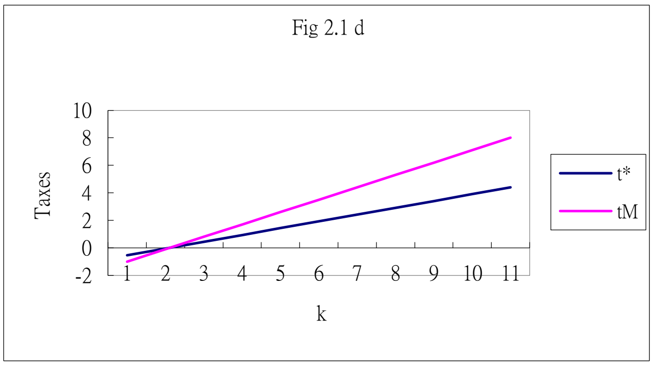
$\alpha_i^i=\alpha_j^j=1$, $\alpha_j^i=\alpha_i^j=0$, ε= -1, e″=0.1, e_i=1, e_j=1, $p-\theta=1$, d'=0.1, $(p-\theta)-(\alpha_i^i+\alpha_i^j)d'e=0.9$



$\alpha_i^i=\alpha_j^j=1$, $\alpha_j^i=\alpha_i^j=0$, ε= -1, e″=0.1, e_i=1, e_j=1, $p-\theta=1$, d'=0.9, $(p-\theta)-(\alpha_i^i+\alpha_i^j)d'e=0.1$



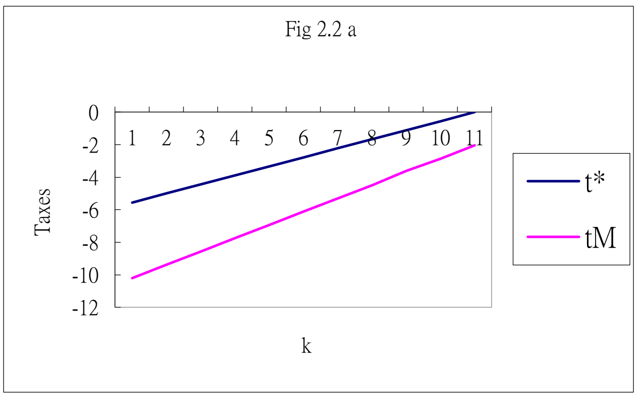
$\alpha_i^i = \alpha_j^j = 1$, $\alpha_j^i = \alpha_i^j = 0$, ε= -1, e″=0.1, e_i=1, e_j=1, $p-\theta = 10$, d'=0.1, $(p-\theta)-(\alpha_i^i+\alpha_i^j)d'e = 9.9$



$\alpha_i^i = \alpha_j^j = 1$, $\alpha_j^i = \alpha_i^j = 0$, ε= -1, e″=0.1, e_i=1, e_j=1, $p-\theta = 10$, d'=0.9, $(p-\theta)-(\alpha_i^i+\alpha_i^j)d'e = 9.1$

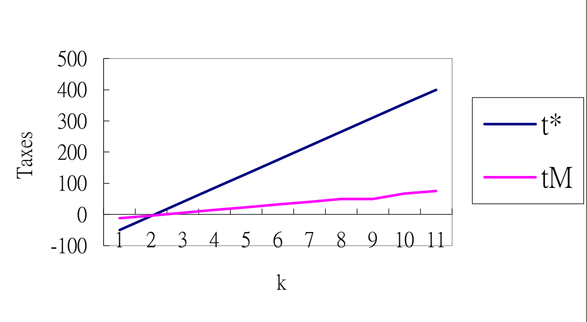
From Figure 2.1a through 2.1c, Nash tax is lower than efficient taxes. It is interesting to show that government would subsidize firm’s production when marginal damage is low in both cooperative and non-cooperative cases, but the subsidy decreases when k increases. Government would levy environmental tax when marginal damage is high in both cooperative and non-cooperative cases. Nash tax is lower than efficient taxes in most cases except when profit and marginal damages are both high (in Fig. 2.1d). It is also interesting to know that when k increases, government tends to increase environmental taxes.

Next, let us consider the transboundary pollution cases, we set internal pollution share to be 0.8 and external pollution share as 0.2 which is fairly common in the real world. The simulation results for low damage case (*d′*=0.1) are similar to the case of non-transboundary pollution under different degree of transboundary share and different profit schemes. They are also similar to the graph shown in Figure 2.2a. So when damage is low, Nash taxes is lower than efficient taxes and government subsidizes firms under both strategies, in other words, emission tax is negative in the case of low damages with or without transboundary pollution.



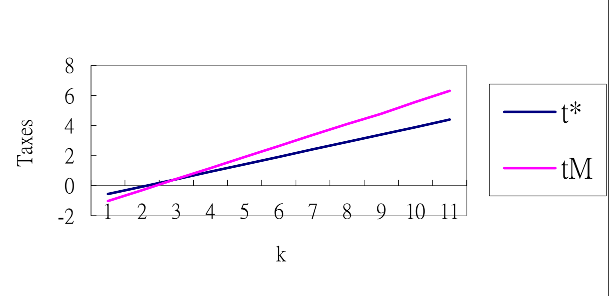
$\alpha_i^i = \alpha_j^j = 0.8$, $\alpha_j^i = \alpha_i^j = 0.2$, ε= -1, e″=0.1, e_i=1, e_j=1, $p-\theta = 1$, d'=0.1, $(p-\theta)-(\alpha_i^i+\alpha_i^j)d'e = 0.9$

Fig 2.2 b



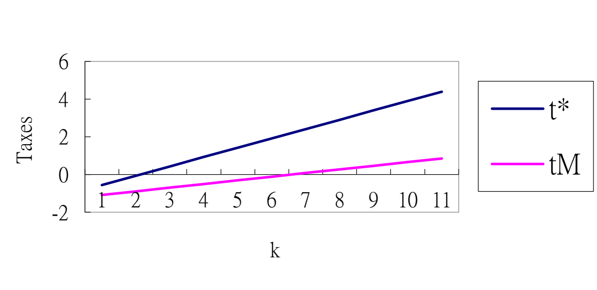
$\alpha_i^i = \alpha_j^j = 0.8$, $\alpha_j^i = \alpha_i^j = 0.2$, ε= -1, e″=0.1, e_i=1, e_j=1, $p-\theta = 1$, d'=0.9, $(p-\theta)-(\alpha_i^i+\alpha_i^j)d'e = 0.1$

Fig 2.2 c



$\alpha_i^i = \alpha_j^j = 0.8$, $\alpha_j^i = \alpha_i^j = 0.2$, ε= -1, e″=0.1, e_i=1, e_j=1, $p-\theta = 10$, d'=0.9, $(p-\theta)-(\alpha_i^i+\alpha_i^j)d'e = 9.1$

Fig 2.2 d

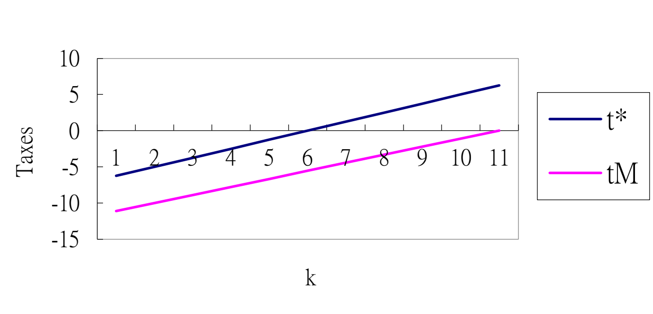


$\alpha_i^i = \alpha_j^j = 0.2$, $\alpha_j^i = \alpha_i^j = 0.8$, ε= -1, e″=0.1, e_i=1, e_j=1, $p-\theta = 10$, d'=0.9, $(p-\theta)-(\alpha_i^i+\alpha_i^j)d'e = 9.1$

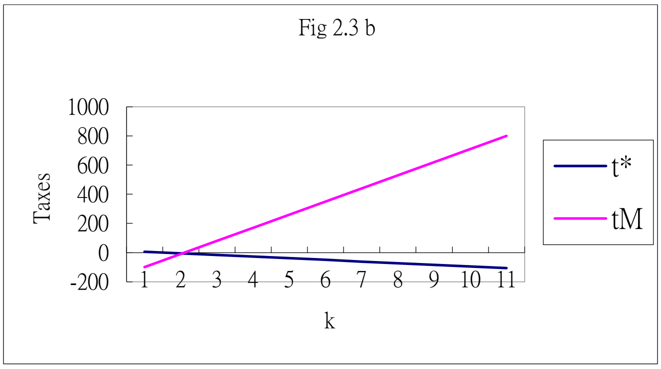
Again, if damages are high, emission tax is positive, as shown in Figure 2.2b through 2.2d. By comparing Figure 2.2c and 2.2d, it is interesting to learn that if internal pollution share is higher than external share, Nash tax will be higher than the efficient one, otherwise, non-cooperative Nash government will tax less than cooperative government.

Finally, in the global pollution cases, the pollution is purely non-rivalry, i.e. $\alpha_i^i = \alpha_j^j = 1$, $\alpha_j^i = \alpha_i^j = 1$, once again, non-cooperative Nash government tends to subsidize firms when marginal damage is low (see Fig 2.3a and 2.3c), but the subsidy decreases when k increases. Cooperative government will subsidize firm's production as long as k≦5, however, if k>5, efficient tax rate starts to rise with k.

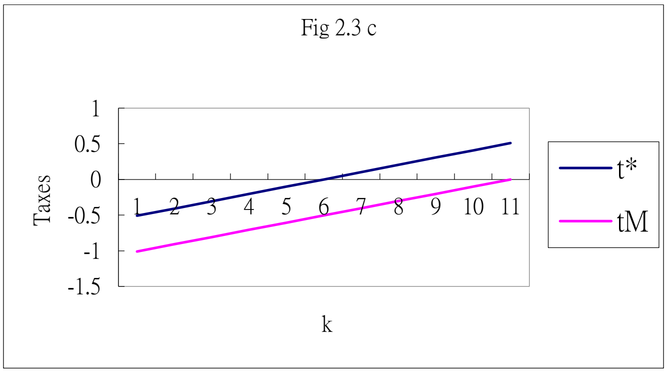
Fig 2.3 a



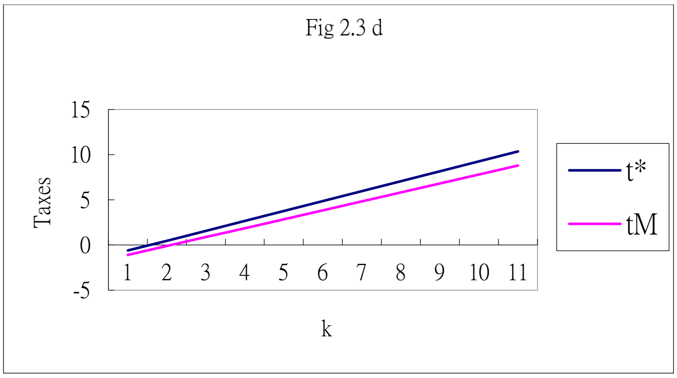
$\alpha_i^i = \alpha_j^j = 1$, $\alpha_j^i = \alpha_i^j = 1$, ε= -1, e″=0.1, e_i=1, e_j=1, $p-\theta = 1$, d'=0.1, $(p-\theta)-(\alpha_i^i+\alpha_i^j)d'e = 0.8$



$\alpha_i^i = \alpha_j^j = 1$, $\alpha_j^i = \alpha_i^j = 1$, $\varepsilon = -1$, $e'' = 0.1$, $e_i = 1$, $e_j = 1$, $p - \theta = 1$, $d' = 0.9$, $(p-\theta) - (\alpha_i^i + \alpha_i^j) d' e = -0.8$



$\alpha_i^i = \alpha_j^j = 1$, $\alpha_j^i = \alpha_i^j = 1$, $\varepsilon = -1$, $e'' = 0.1$, $e_i = 1$, $e_j = 1$, $p - \theta = 10$, $d' = 0.1$, $(p-\theta) - (\alpha_i^i + \alpha_i^j) d' e = 9.8$



$\alpha_i^i = \alpha_j^j = 1$, $\alpha_j^i = \alpha_i^j = 1$, $\varepsilon = -1$, $e'' = 0.1$, $e_i = 1$, $e_j = 1$, $p - \theta = 10$, $d' = 0.9$, $(p-\theta) - (\alpha_i^i + \alpha_i^j) d' e = 0.1$

Note that in the global pollution cases, only Fig 2.3b shows $t^M > t^*$ when marginal damage is high and profit is very low. Under such condition, marginal profit is not enough to compensate marginal damage. In Fig 2.3b, Nash tax increases speedily with k, but efficient tax decreases with k. In most of our simulation results, Nash taxes are lower than efficient taxes, which might suggest non-cooperative government tends to shift rent from foreign firms to domestic firms, which also shows the tendency of eco-dumping.

CONCLUSION

This paper investigates the effect of abatement capability on output and the relationship between abatement capability and emission taxes. We find that higher technological capability on abatement induces higher equilibrium output. This is quite intuitive in the sense that with lower transitional cost (i.e. higher abatement capability), the firm can easily comply with tougher regulation, thus produces more. We also investigate the different trends between efficient tax policy and Nash equilibrium tax strategy. From the Simulation results, we can see some hint of rent-shifting effect, and non-cooperative emission tax is lower than efficient tax in most cases. But it is unclear of what exactly is at work. We also check the simulation results on the effect of k on taxes, it is not clear why government would subsidize heavily when k is low or levy good amount of taxes when k is high. This might be viewed as "punishing the good guys." Or it might just be the "term of trade" effect.

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