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# A Game Theoretic Model of Green Technology Rivalry

## *(Model Teori Permainan Bagi Persaingan Teknologi Hijau)*

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ABSTRACT

*The optimal research and development of green technology taxes (subsidies) is analyzed in a three-stage game model of an international Cournot duopoly. The governments simultaneously determine the environmental policies in the first stage. In the second stage, the firms simultaneously determine the green technology levels and set the output in the third stage. One firm exists in a home country and one firm exists in a foreign country that produce homogenous goods and export to the third-market country. By assuming that the green technology involves cost-increasing research and development (R&D), the present study finds that green technology is not overused to minimize the total production costs.*

*Keywords: Strategic trade policy; green technology; strategic environmental policy*

ABSTRAK

*Cukai(subsidi) optimal ke atas penyelidikan dan pembangunan teknologi hijau dianalisis dengan model permainan tiga-tingkat bagi persaingan duopoli antarabangsa Cournot. Kerajaan secara serentak menentukan polisi alam sekitar di tingkat pertama. Di tingkat kedua, firma secara serentak menentukan tahap teknologi dan seterusnya jumlah pengeluaran ditentukan pada tingkat ketiga. Sebuah firma di negara domestik dan sebuah lagi di negara luar mengeluar dan mengeksport barangan yang homogen ke negara pasaran ketiga. Dengan andaian teknologi hijau melibatkan penyelidikan dan pembangunan (P&P) dengan kos bertambah, kajian ini mendapati bahawa teknologi hijau tidak dieksploitasi bagi meminimakan kos pengeluaran.*

*Kata kunci: Polisi perdagangan strategik; teknologi hijau; polisi alam sekitar strategik*

## INTRODUCTION

A number of governments subsidize research and development (R&D) activities leading to the production of green technology[1] by domestic firms. Such subsidies are primarily given to industries in which firms compete in the international imperfect competition market. The present study presents a positive analysis to explain such trade strategy policies in the context of an imperfectly competitive world where green technology R&D (GT-R&D) rivalry between firms plays a significant role[2].

The present study focuses upon the possible subsidization of product R&D, such as subsidization of green technology in producing hybrid vehicles in the USA and Japan. In order to promote green technology, the U.S government has been supporting the consumer purchase of hybrid vehicles in the forms of the tax deduction and production subsidies (Beresteanu & Li 2011). In contrast to previous studies,[3] GT-R&D is assumed to be a cost-increasing R&D, which means that the total cost of production rises. Thus, the primary objective of the present study is to demonstrate how the strategies change when the costs of R&D differ from the previous framework. In particular, the rivalry in green technology development describes the game of R&D in product innovation.

An argument for strategic environmental policy has been developed by many analysts such as Barrett (1994), Markusen et al. (1995), Sturm (2001) and Yanase (2010). A strategic environmental policy considers the production activities of two firms that generate pollution emissions, which cause purely local damage. The models, based on imperfect competition market, are successful in explaining the tragedies of an 'ecological dumping' and 'race-to-bottom'. In contrast to Barrett (1994), the assumption is made in the present study, for simplicity, that the firms do not generate pollution emissions and, thus, no abatement costs are to be considered. However, instead of simply fulfilling the regulation, the GT-R&D is invented to fulfil green product demand or to create a green technology trend.[4]

The present study employs the strategic R&D policy framework of Spencer andBrander (1983), which includes an assumption that firms compete *a la Cournot*. Spencer and Brander (1983) find that if the export subsidy is applicable, a country will not choose to subsidize R&D. Their model is based on an assumption that the process R&D is assumed to be cost-decreasing R&D. In contrast, the present study examines product R&D and assumes that the GT-R&D increases production costs. In addition, export subsidies are not considered in the present study because World Trade Organization (WTO) codes restrict direct export subsidies. The present study finds that GT-R&D is not overused to minimize total costs and the optimal subsidy is positive. The findings also demonstrate that governmental subsidies encourage firms to invest in green technology.

The strategic behaviour of agents in the present model are also similar to the Spence & Brender (1983), in which GT-R&D is assumed to be undertaken before the associated output is produced. The firms anticipate the effect of R&D on the resolution of output shares. The efficacy of government policy in the present study arises from the assumption that a government can credibly commit itself to R&D subsidies before R&D decisions are made by private firms. The motivation for governmental policy in the present study is similar to previous studies (e.g., Barrett 1994), which assume that a country attempts to capture a larger share of production or rent shifting. However, the difference in the present study is that the national incentive does not arise from damage costs because pollution is assumed to be consumption-pollution that occurs in a third country (e.g., Barrett 1994; Sturm 2001). The present study finds that a subsidy policy is optimal.

The remainder of the present study is organized as follows. Section 2 explains the basic setup of the model and the results in the quantity competition stage. Section 3 presents and discusses the results of subsidies of GT-R&D. Section 4 contains concluding remarks.

## MODEL

The basic setup of the model is based on a standard third-country model. Consider two symmetric countries, home and foreign, with one firm each. The model is analyzed on a three-stage game played by two competing firms and two competing governments. In the first stage, the governments choose GT-R&D subsidies. The governments know a game is being played by the firms. In the second stage, as the second player, the firms choose R&D levels and, in the third stage, choose output levels.

Firm $i$ produces output $x^i$ at variable cost $C^i$, which includes all costs except GT-R&D and earns revenue $R^i\ (x^1, x^2) = p(x^1, x^2)x^i$. The GT-R&D level of firm $i$ and cost per unit is denoted $g^i$ and $\alpha^i$, respectively. For simplicity, production externality is omitted. The profit function of firm $i$ is then denoted:

$$\pi^i(x^1, x^1; g^i) = R^i(x^1, x^1) - C^i(x^1, x^1; g^i) - \alpha g^i \qquad (1)$$

Output $x^1$ and $x^2$ are assumed homogenous. Therefore, using subscripts to denote derivatives, this implies:

$$R_j^{\,i} < 0 \text{ and } R_{ij}^{\,i} < 0 \qquad (2)$$

A rise in the cost-increasing GT-R&D increases $C^i$ given that $x^i$ and the rate of increase increases as $x^i$ rises. Therefore, firms must pay an additional cost of producing a green product (refer to the argument of Sallee (2011)). Marginal cost, $C_x^{\,i}$, is assumed to rise as $g^i$ increases. Thus:

$$C_g^{\,i} > \text{ and } C_{gg}^{\,i} < 0 \qquad (3)$$

The Cournot-Nash equilibrium in output is characterized by first order condition as follows:

$$\pi_{x^i}^{\,i} = R_{x^i}^{\,i}\,(x^1, x^2) = C_{x^i}^{\,i}\,(x^i; g^i) \qquad (4)$$

where $R_{x^i}^{\,i}(x^1, x^2) = p(x^1 + x^2) + p'(x^1 + x^2)\,x^i$. Second order conditions are characterized as follows:

$$\pi^i_{x^ix^i} = R^i_{x^ix^i} = C^i_{x^ix^i} = 0 \qquad (5)$$

The effect of output on marginal profit is also assumed to dominate cross effects, giving rise to the following condition:

$$D = \pi^1_{11}\pi^2_{22} - \pi^1_{12}\pi^2_{21} > 0 \qquad (6)$$

This condition holds globally and ensures the uniqueness and global stability of the equilibrium.

The solution $x^1$ and $x^2$ in (4) depend on $g^1$ and $g^2$, which can be written as:

$$x^1 = f^1(g^1, g^2) \text{ and } x^2 = f^2(g^1, g^2) \qquad (7)$$

Outputs depend on marginal cost, which depend on $g^i$. An increase in cost-increasing GT-R&D by firm 1 will increase marginal cost, shifting its reaction function inward and decreasing its output and market share, as illustrated in Figure 1, by the move from P to Q. The reaction functions in the diagram are downward sloping. This follows from the total differentiation of (4) with respect to $x^1$ and $x^2$, holding both $g^1$ and $g^2$ constant, which yields the slope of the reaction function, $\frac{dx^i}{dx^j} = -\frac{R^i_{x^ix^j}}{\pi^i_{x^ix^i}}$, which is negative from (2) and (5).

The total differentiation of (4) with respect to $x^1$ and $g^1$ yields:

$$f^{\,i}_{g^i} = \frac{dx^i}{dg^j} = \frac{C^i_{x^ig^i}\pi^2_{x^2x^2}}{D} < 0 \text{ and}$$

$$f^{\,j}_{g^i} = \frac{dx^i}{dg^j} = -\frac{C^i_{x^ig^i}\pi^2_{x^2x^1}}{D} > 0 \qquad (8)$$

Based upon equations (4), (5) and (6), equation (8) shows that a firm's output decreases a firm's own GT-R&D and increases the rival firm's GT-R&D. To sum up, the following proposition is obtained:

Proposition 1 *The GT-R&D lowers own output and increases the rival output.*

Intuitively, given that the product innovation is cost-increasing, the GT-R&D causes the firms to pay innovation costs. In contrast to process R&D, which

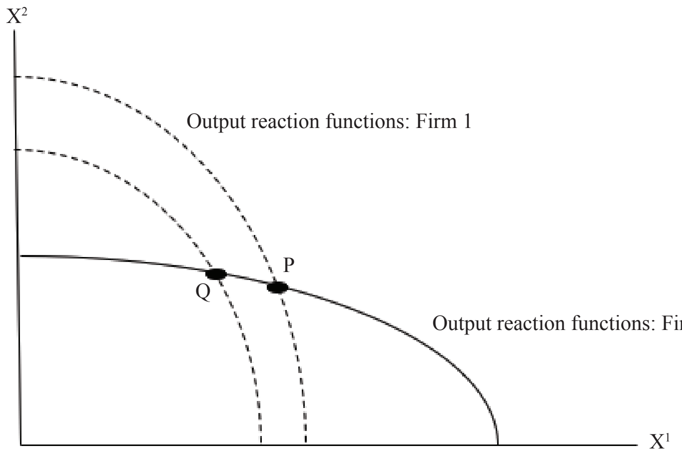


FIGURE 1. Reaction Function

lowers the production costs, hence GT-R&D increases a firm's output and lowers the rival firm's output.

Rewriting the profit function as functions of $g^i$, the GT-R&D levels that the firms choose in the preceding stage are analyzed. The profit function for firm *i* is rewritten as follows:

$$\theta^i = \pi^i\,(f^1(g^1, g^2), f^2(g^1, g^2); g^i) \tag{9}$$

Based upon equations (1), (4) and (8), the Nash equilibrium in R&D level is characterized by the first order conditions of equation (9), as follows:

$$\theta^i_{g^i} = \pi^i_{x^i} f^i_{g^i} + \pi^i_{x^j} f^i_{g^i} - C^i_{g^i} - \alpha = 0 \tag{10}$$

$$= R^i_{x^j} f^i_{g^i} - C^i_{g^i} - \alpha = 0 \tag{11}$$

since $\pi^i_i = 0$ and $\pi^i_j = R^i_j$. The second order condition is as follows:

$$\theta^i_{g^i g^i} = R^i_{x^j} f^j_{g^i g^i} + f^j_{g^i}\left(\frac{dR^i_{x^j}}{dg^i}\right) - C^i_{xg} f^i_{g^i} - C^i_{gg} < 0 \tag{12}$$

And assuming the condition is analogous to equation (6), which ensures the uniqueness and global stability of the equilibrium, yields the following equation:

$$D = \theta^1_{g^1g^1}\theta^2_{g^2g^2} - \theta^1_{g^1g^2}\theta^2_{g^2g^1} > 0 \tag{13}$$

Based upon equations (2), (8) and (10), equation (11) yields the following equation:

$$R^i_{x^j} f^j_{g^j} = C^i_g + \alpha < 0 \tag{14}$$

Hence, equation (14) yields the following proposition:

Proposition 2 *GT-R&D is not overused to minimize the production costs*

This result, equation (14), differs from the Spencer and Brander (1983), given that domestic GT-R&D causes the increase of rival outputs. In particular, Spencer and Brander (1983) show that a firm may over invest in R&D during the R&D process. Intuitively, R&D is not overused since GT-R&D cannot be used to minimize total costs for the output chosen.

## TRADE POLICY

In this section, trade (industrial) policy, in the form of GT-R&D subsidies, is demonstrated to enable a domestic firm to capture a larger share of the world market so as to increase profits and rent.

The government is assumed to be an agent that can set subsidy rates on GT-R&D expenditure in a period before the firms spend on GT-R&D. The assumption is that a government can pre-commit itself to such subsidies is similar to the previous studies (e.g., Barrett 1994; Spencer &Brander 1983; Sturm 2001).

The profit function of a firm with a subsidy, per unit of GT-R&D, is redefined as follows:

$$\theta^i(g^1, g^2; s) = R^1(x^1, x^2) - C^1(x^1, g^2) - (\alpha - s)g^i \tag{15}$$

The point of interest concerns the effects of subsidies on GT-R&D levels. The subsidy shifts out the R&D reaction function of the domestic firm, increasing its equilibrium GT-R&D and reducing the GT-R&D undertaken by the foreign firm, provided reaction functions are downward sloping. The results are obtained by the total differentiation of the first order conditions of (15) as follows:

$$\frac{dg^1}{ds} = -\frac{\theta^2_{x^2x^2}}{D} > 0 \text{ and } \frac{dg^2}{ds} = \frac{\theta^2_{x^2x^1}}{D} < 0 \tag{16}$$

As a result, the following proposition is put forward:

Proposition 3 *A domestic GT-R&D subsidy increases domestic GT-R&D and reduces foreign GT-R&D given* $\theta^2_{x2x1} < 0$. *If* $\theta^2_{x2x1} > 0$*, foreign GT-R&D rises.*

### THE OPTIMAL DOMESTIC GT=R&D SUBSIDY

The optimal subsidy is found by maximizing net domestic welfare. For simplicity, environmental damages are omitted. To sum up, welfare is defined as follows:

$$\omega^1(s) = \theta^1(g^1, g^2; s) - sg^1 \tag{17}$$

Based upon equation (1), equation (17) represents domestic welfare with subsidy.

The level of GT-R&D chosen by the domestic firm is the level that maximizes its profit within the confines of the behavior that characterizes the two-stage Nash Equilibrium. If a firm violates this equilibrium, it risks the possibility of earning lower profit during the unstable situation that follows. By providing a subsidy to firms, a government alters the perceived cost structure and changes the set of actions that are compatible with the two-stage Nash equilibrium. This allows a domestic firm to earn a higher profit net of the subsidy.

However, the present study examines the incentives facing a single government. Additionally, the use of the benefit function, equation (17), involves the usual assumptions necessary for partial equilibrium surplus analysis. In particular, the private cost of R&D reflects its full social opportunity cost if GT-R&D is not subsidized. Based upon equation (17), the first order condition for the welfare maximizing subsidy is as follows:

$$\frac{d\omega^1}{ds} = \theta_1^{\,1} f_s^{\,1} + \theta_2^{\,1} f_s^{\,2} + \theta_s^{\,1} - g^1 - s g_s^{\,1} \tag{18}$$

Based upon the sign of equations (15), (10) and (16), the subsidy is calculated as follows:

$$s = \theta_2^1 \left( \frac{dg^2}{dg^1} \right) > 0 \tag{19}$$

The optimal GT-R&D subsidy is equal to the increase in a firm's own profit from a reduction in the foreign firm's GT-R&D brought about by an increase in a firm's own GT-R&D. This leads to the following proposition:

Proposition 4 *The optimal subsidy is positive.*

### NON COOPERATIVE INTERNATIONAL EQUILIBRIUM

Such GT-R&D rivalry does have a beggar-thy-neighbour aspect. By imposing a subsidy, country 1 gains at the expense of country 2. In one regard, a government considers an environmental effect of the subsidy. However, who bears the costs of subsidizing R&D is another aspect that should be considered by a government. The welfare function is rewritten as follows:

$$\Omega^i(s^1, s^2) = g^i(g^1, g^2; s^i) - s^i g^i \tag{20}$$

Equation (20) demonstrates that domestic welfare contains producer surplus, which depends on the subsidization of GT-R&D. This welfare function, equation (20), has the same form as equation (17) since the subsidy of country 2, $s^2$, affects the profits of firm 1 only indirectly through its impact on GT-R&D levels. The non-cooperative equilibrium occurs where $\frac{\partial \omega^1}{\partial s^1} = 0$, $\frac{\partial \omega^2}{\partial s^2} = 0$ and implies positive subsidies.

$$s = n_j^i f_{g^i}^j \left( \frac{dg^j}{dg^i} \right) \tag{21}$$

The sign of equation (21) is similar to equation (19). Therefore, if both firms are similar, the total rent is lower and both countries earn less rent at the non-cooperative equilibrium than they would if they had been able to come to an agreement not to subsidize GT-R&D. Both producing countries are then worse off due to their subsidization of GT-R&D. Intuitively, consuming countries gain from the fall in prices resulting from greater production.

## CONCLUDING REMARKS

National governments play a significant role in certain international markets, particularly newly emerging green technologies. In this emerging industry, a small number of firms exist that compete for market shares. Therefore, governments and firms have a clear understanding that they are involved in a strategic game involving foreign counterparts.

The present study examines a market in which domestic firms and foreign firms compete for market shares in a third market. The approach is similar to a volume of previous papers concerning R&D rivalry. However, the present study shows that the strategic game played by firms leads them to not overuse GT-R&D in the absence of government policy. On the other hand, governments have an incentive to subsidize GT-R&D to enable domestic firms to capture a larger share of the market.[5] Furthermore, government subsidies encourage firms to do more 'green R&D' in the place of tough environmental regulations proposed by the 'Porter hypothesis'.[6]

It should be emphasized that the analysis presented in the present study is not in any sense a recommendation that environmental policies should be strategically used. The present study could be expanded in a number of ways. For instance, an empirical analysis can be conducted to prove the above results.

### NOTES

1 The definition of 'green technology' or 'green product' is as follows: "At its most basic level, the green economy is the clean energy economy, consisting primarily of four sectors: renewable energy (e.g. solar, wind, geothermal); green building and energy efficiency technology; energy-efficient infrastructure and transportation; and recycling and waste-to-energy. The green economy is not just about the ability to produce clean energy, but also technologies

that allow cleaner production processes, as well as the growing market for products which consume less energy, from fluorescent light bulbs to organic and locally produced food" (Chapple 2008: 1).

2 A number of studies incorporate environmental issues into the strategic trade model, such as surveys concerning international trade and environmental policy (Sturm 2001; Sturm & Ulph 2002; Ulph 2002; Sturm 2003). Furthermore, Yanase (2010), among others, extansively develops a study of domestic pollution or production pollution.

3 Previous studies assume that R&D is a cost-decreasing R&D, including the study of international R&D rivalry pioneered by Spencer and Brander (1983) and subsequently extended by DeCourcy (2005), amongst others.

4 For example, Toyota kept the price of the Prius low because, in the long run, the firm wanted the hybrid drivetrain to be viewed as mainstream technology (Sallee 2011).

5 A government should help domestic firms to invest in environmentally friendly technology. For instance, Juan (2011) argues that the subsidy policy of a government can encourage firms to engage in technological innovation

6 The 'Porter hypothesis' argues that tough environmental regulations are a means of encouraging firms to invest in the green technology (Xepapadeas & de Zeeuw 1999).

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