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The strategy choice of company in environmental research with government imposing carbon tax

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In order to find the optimal uniform carbon tax imposed by government to pursue social welfare maximization and how carbon tax would affect the stock price of Duopoly companies, this paper studies some scenarios where spillover effect is considered by utilizing game theory tool. Based on the complete information hypothesis, optimal quantity, emission reduction and carbon tax are solved. Further, it is found that, by numerical calculation and under same carbon tax, social welfare, company profit, emission reduction and stock price under scenario where companies adopt environmental research joint venture strategy are all higher than that of environmental cartel, that of scenario with competitive R&D activity and that of scenario without spillover effect considered, respectively. And, differences in terms of social welfare, profit and stock prices among these scenarios tend to widen with carbon tax increasing. In this sense, duopoly companies have the incentive to fully share information and cooperate in R&D activity (namely, they would adopt "environmental research joint venture" strategy) to benefit from the highest profit, highest stock price as well as emitting least pollution under the uniform carbon tax set by government.

Key words: environmental research joint venture, game analysis, welfare, stock, spillover

INTRODUCTION

In recent decades, climate change has caused adverse impacts on natural and human systems on all continents and across the oceans, and the cause of such unpleasant change is evidently due to anthropogenic greenhouse gas (GHG) emission [1]. With its overwhelming destruction power to the earth, greenhouse gas emission has gained considerable attention from both academic world and policymakers' offices. Compared with traditional method such as technology advancement and official mandate, market could also lower emission by price signal to accommodate behaviors and decisions of producer and consumer. And the market tool discussed here is carbon tax.

Carbon tax, one kind of environmental tax in essence, internalizes the loss caused by polluting companies into the cost function and manufacturing price, and is adopted by many countries such as Finland, Demark, Norway, Italy and Sweden [2]. Usually speaking, different scholars show quite opposite opinions about effect of carbon tax to the economy. Recently, game theory tool has become a powerful analytic tool for studying interactions between different parties emitting CO_2 to see their optimal choice. Many works with game theory about pollution or greenhouse gas emission have sprang up in terms of considering emission trading permits [3], non-cooperative or cooperative R&D [4], green supply chain scenario game model [5], choice and effects of imposing uniform or differential carbon tax [6].

It is not hard to conclude that carbon tax is widely discussed nowadays in many aspects, such as its socio-economic effects (such as welfare, Gini coefficient, income effect) at different regions, countries or sectors, effects with carbon emission trading combined [7] and game analysis. However, few people further study how the stockholder wealth would change due to carbon emission reduction R&D activity since some scholars started to pay attention to the environmental R&D cartel. Generally speaking, terminology "R&D" could be traced by Kamien et al. [8] who provided a classification of different R&D organizational forms to obtain cost-reducing R&D but he failed to consider the pollution aspect. Later, Poyago-Theotoky [4] took into account the pollution effects and developed it into "environmental R&D" or abatement activities where firms engages in R&D activity so as to develop new processes to reduce unneeded emissions. In his paper, Poyago-Theotoky [4] mainly discussed two kinds of environmental R&D activities: namely, (1) environmental competition R&D, (2) environmental cooperation R&D (hereinafter "environmental cartel" or "ERC") but only talked little and did none numerical experiment about the third environmental R&D activities: "environmental research joint venture" (hereinafter "ERJV"). In definition, it is quite easy to understand environmental competition

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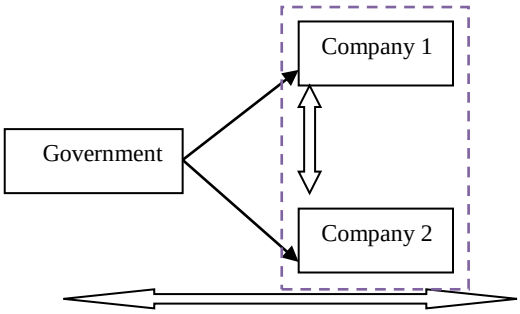
R&D as companies do not cooperate in emission reduction and they only care about their own profit function. Poyago-Theotoky [4] confirmed that ERC is an activity that "firms coordinate their R&D but do not share information fully" while ERJV refers to the situation where firms would share information completely (mathematically, the spillover effect parameter would be one).

This paper aims to study scenarios where both Duopoly companies are dedicated to reducing their carbon emissions, so uniform carbon tax makes sense for analysis that follows. Based on pioneering works of Poyago-Theotoky [4] and Sun [9], effect of uniform carbon tax under framework of welfare by adopting game theory analytic tool is tested with further research on "environmental research joint venture" which is neglected by Poyago-Theotoky [4]. Specifically, this paper, combining with the total social utility which contains the carbon tax revenue to return, constructs a three-stage Duopoly model: the first stage shows the optimal uniform carbon tax set by administrative institution on the corporations in order to get maximum social utility, followed by the second stage demonstrating how hard these two companies would be dedicated to reducing carbon emission and the third stage presenting the optimal quantity decision made by these two participants to chase maximum profit in goods market. In essence, the first stage is a Stackelberg model, the second one is a cooperative or non-cooperative game and the third stage is a typical Duopoly model. Overall, the technological route for this three-stage game model for duopoly market under government's regulation is showed below:



First stage, Stackelberg model: government sets carbon tax and companies decide how to react to it, such as adopting cleaner production process
Second stage: emission reduction activity
Third stage, Cournot model: how companies compete in the goods market to get maximum profit with full knowledge of carbon tax

Fig. 1. Technology route of duopoly model

MODELING

Assumptions

Assumption 1: There are only two companies in the market and these two companies produce homogeneous goods to satisfy market need. Market quantity shares linear relationship with market price: $P = \alpha - \beta Q$. For convenience, let beta be one. And each company owns same unit cost c, releasing one unit emission per product [4].

Assumption 2: Spillover effect is considered here. That is, companies influence each other in terms of reduction technologies to some degree: u ranges from 0 to 1. In detail, if u equals 0, then no spillover effect exists, otherwise, companies would reduce emissions by just using the other company's existing green technology. Specifically, if company 1 releases total emission e_j, then company 2 could reduce pollution by amount of $u_j e_j$ without any investment in R&D, therefore, actually total emission is $w_i = q_i - e_i - u_j e_j$, i,j=1,2 and $i \neq j$. (see J.A. Poyago, 2007[4]; Sun, 2014[9]). Moreover, as J.A. Poyago-Theotoky (2007) suggested, when u equals 1, then it means two Duopoly companies adopt environmental research joint venture strategy.

Assumption 3: carbon emission reduction cost (R&D cost function) is a convex function, appearing in the form of quadratic function $\frac{re_i^2}{2}$: and r>0. Here, r refers to the cost parameter of R&D and larger r means lower research efficiency or higher investment in reduction technology.

Assumption 4: complete information hypothesis holds and government levies uniform carbon tax on these two companies to pursue the harmonization of economy, society and environment. Here, society aspect contains collected carbon emission transferred to the consumer as well as consumer surplus.

Social welfare functions building

Concerning utility, this paper follows logic of Wang [10] that government considers harmonization of economy, society and environment. In detail, the total social utility function would contain profits of companies, consumer surplus and tax revenue, and pollution caused. In quantitative terms and for convenience, pollution part is captured via a linear function with pollution damage parameter d (d>0) from Poyago-Theotoky [4]:

$$U_{pollution} = d(w_1 + w_2)$$

Therefore, total utility function appears in the following form:

$$U_{total} = \Phi_1 + \Phi_2 + U_{comsumer} + U_{tax} - U_{pollution}$$

Where sum of Φ1 and Φ2 denotes economic part, sum of $U_{consumer}$ and U_{tax} donates society part, and $U_{pollution}$ denotes environment part.

Table 1. optimal result of carbon tax, reduction and quantity

Item	Spillover effect exists			No spillover effect $u_1 = u_2 = 0$
	Competitive strategy	Cooperative strategy		
	$0 < u_1, u_2 < 1$	$0 < u_1, u_2 < 1$ Environment R&D cartel (ERC)	$u_1 = u_2 = 1$ Environment research joint venture (ERJV)	
Carbon tax	$t^* = \frac{6dr + 9d(u_1}{4r}$	$t^{**} = \frac{9d(2+2u_1+2u_2)+9d(u_i}{4r+9(1+u_1)^2+}$	$t^{***} = \frac{3dr+36d-Ar}{2r+36}$	$t^{****} = \frac{3dr+9d-Ar}{2r+9}$
Reduction	t^*/r	$t^{**}(1+u_i)/r$	$2t^{***}/r$	t^{****}/r
Quantity	$(A-t^*)/3$	$(A-t^{**})/3$	$(A-t^{***})/3$	$(A-t^{****})/3$

Functions solving

Under complete information hypothesis, use reverse calculation methodology to solve the third stage:

max

$$\prod_i = (\alpha - (q_i + q_j))q_i - cq_i - t(q_i - e_i - u_j e_j) - re_i^2/2$$

Companies with carbon tax constraints compete in the goods market and decide the optimal output to chase the maximum profit, therefore, take the partial derivatives of profit function to the independent variable "quantity" and set them to zero. Solve simultaneous equations about quantities to obtain:

$$q_1 = q_2 = (A-t)/3, \text{ where } A = \alpha - c$$

Then, companies plan carbon emission reduction strategy and during the second stage, still calculate the partial derivatives of profit function to emission reduction amount. Note that, cooperative R&D situations ("ERC" where $0 < u_1, u_2 < 1$ and "ERJV" where $u_1 = u_2 = 1$) ask that total profit of two companies reaches the top while competitive R&D situation (where $0 < u_1, u_2 < 1$) means that each company cares only about its profit maximum. Final results are displayed in table 1. Note that, in the no spillover effect scenario, profit would not be influenced by the spillover effect parameters (as $u_1 = u_2 = 0$), so the results for competitive strategy and cooperative strategy are the same.

When it comes to the first stage, take results containing key variables "carbon tax" from stage 3 and stage 2 into the total social utility functions and get the partial derivatives of social functions to the carbon tax to get the optimal uniform carbon tax rate as showed in table 1.

Judging from table 1, under same tax scenarios and regardless of government optimizing total utility, environment research joint venture ($u_1 = u_2 = 1$) reduces more than any other strategy, even all of these scenarios would produce same quantities.

Further, it can be proved that $t^{***} > t^{**} > t^{*} > t^{****}$ with respect to d given other parameters in optimal carbon tax formula remain unchanged. That is to say, optimal carbon tax under environment research joint venture is higher than that of environment R&D cartel, that of competitive strategy with spillover effect considered and that of no spillover effect scenario, respectively. And again, it could be confirmed that environment research joint venture would reduce much more pollution than any other three strategy.

CONCLUSIONS

This paper studies the optimal uniform carbon tax imposed by government in Duopoly companies in order to pursue total social utility under four scenarios, namely, scenario where duopoly companies compete in both product market and emission reduction R&D, scenarios where duopoly companies only compete in product market and collaborate in emission reduction (if they do not fully share information, then it is "environmental cartel"; otherwise, it is "environmental research joint venture") and scenario where no spillover effect exists. Observing the quantity, emission reduction and total social welfare, it is concluded that environmental research joint venture dominates the other three under same carbon tax. Furthermore, this paper studies the stock price of duopoly companies and finds a negative relationship between carbon tax and stock price. Compared with other three scenarios, companies adopt environmental research joint venture strategy enjoys the highest stock price (i.e. the highest personal wealth for stockholders), and the stock prices of other two scenarios, scenario where companies competes in R&D with spillover effect considered and scenario with no spillover effect, are somewhat identical.

However, some questions should also be paid attention when carbon tax is imposed in reality. First, as discussed above, China has a strong wish to impose carbon tax but now has not yet conducted such action, so the inverse demand presented

function and other parameters here are just used to analyze, true parameters should be studied in careful manner to get satisfactory result to make government policy more powerful and useful. Also, note that collaboration in R&D (environmental research joint venture then environmental cartel) is always good for duopoly companies to conduct; however, companies would more likely tend to take part in seeking rent rather than collaboration in R&D (see Fig 2, take environmental cartel scenario for example).

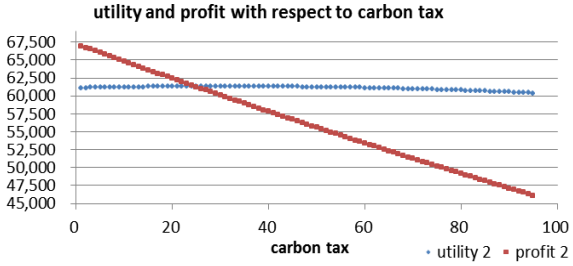


Fig. 2. Rent-seeking problems

As discussed above, quantity and profit would decrease with increased carbon tax and the highest quantity and corresponding profit lie in the point that no carbon tax is imposed, so the duopoly companies may use their market power or other means to persuade, bribe or even threaten the government to set lower carbon tax far from the optimal one. Therefore, even the collaboration strategy (that is "environmental research joint venture") dominates other strategies, how to make sure such strategy to come into reality or conduct effectively really matters.

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