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Research on Company Strategies Under Green Technology Investment in the 'Cap-and-Trade' System

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Abstract

In this paper, we will analyze the firm's strategies (production strategy, carbon trading strategy and green technology investment). In the 'cap-and-trade' system, we take green technology investment into account. We draw the conclusion that the firm may carry out the green technology investment in the 'cap-and-trade' system, and it has the optimal amount of green technology investment, as well as the maximum expected profit and it's carbon emissions. It proven that the 'cap-and-trade' system can encourage the firms to invest the green technology thus reducing carbon emissions. Additionally, the higher the carbon priceis, the higher the unit emission reduction rate is, and the higher the unit emission reduction rate is, the fewer the products are made. What's more, the total profit is proportional to the carbon emission caps. Finally, we do the sensitivity analysis, and discuss the impact of parameters' changes on production, green technology investment and carbon emissions.

Key words: Cap-and-trade; Emission cap; Green technology investment

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INTRODUCTION

In the "World Energy Outlook" released by the International Energy Agency（IEA）in November 2012, the demand of fossil fuel-based energy was expected to increase over 35% by 2035, which would increase the carbon emissions and cause to climate change directly or indirectly. The global warming caused by human activities had seriously threated global ecosystem and human existence.Under the existing level oftechnological level and production and consumption patterns, the economic development, urbanization, industrialization are closely related to energy consumption and carbon emissions. Therefore, as the inevitable product of socio-economic development, carbon emissions must be reasonably controlled. During the eighteenth National People's Congress and the First Session of the Twelfth CPPCC and NPC, our country proposed we should promote the construction of ecological civilization vigorously, control the total energy consumption, reduce energy consumption, material consumption and carbon dioxide emissions, and finally make a positive contribution to response to the global climate change.

The Congressional Budget Office（CBO, 2008）conducted a comprehensive study on the policy for reducing CO_2 emissions, they analyzed three different carbon policies: mandatory carbon emissions capacity, carbon emissions tax and cap-and-trade. As an important carrier of human activities, firms face multi-party challenges in commitment to climate change and energy conservation. The formulation of carbon restriction policy from government, the green consumption behavior of consumers and the green technology investment will have a huge impact on competition and cooperation among firm's pricing, production, and supply chains. Firms need to develop suitable strategies depending on the carbon emissions policy, in order to better meet the needs of green consumers and achieve their profit maximization (Chen, 2012).

In the period of the Twelfth Five-Year Plan, China will invest nearly 2.4 trillion Yuan for energy conservation projects. In addition to government-led public investment, the social venture capital and direct equity investments on clean technology accounted for the largest proportion of the global clean technology investments. As the microscopic body of implementing green technologies, firms will make decisions of production and green technology investment expecting from environmental protection, investment and efficiency, and choose projects with less energy consumption, less emissions and low cost to implement. In 2008, General Electric Company provided the ecomagination-certified Jenbacher gas engines for a chicken factory in Beijing, this use of green technology updates and transformation can generate electricity 14.6 million degree per year and reduce about 90,005 kilotons of carbon dioxide emissions .Therefore, the research on the impact of the emission cap and trade policy on the decision-making behavior of firms perspective to green technology investment has far-reaching significance.

2. LITERATURE REVIEW

The earliest studies of carbon emissions policy should be traced back to the 1970s, Weitzman (1974) proposed that environmental policy instruments can be divided into price-fixed policy and quantity-fixed policy. Montgomery (1972) was the earliest one began to study the emissions market design and emissions trading in licenses. Allen, et al. (2009) scientifically calculated the total global carbon emissions capacity under the control of temperature rise of 2 °C for the first time, thus laid a scientific foundation for the development of emission cap policy in other countries. Catherine and Danie (2011) researched the impact of carbon emissions capacity policy on the cost when applied to carbon emissions associated with electricity, natural gas and transportation services. Edward and Matthew (2010) used the externality theory of the space environment to study the optimal carbon tax in the case of individual utility and social welfare maximization. Zhang (2012) studied the investment and behavioral decision in enterprises with high and low carbon emissions under different carbon tax policies. Robert (2008) establish CO_2 cap-and-trade system which implements gradual trajectory of emissions reductions, and included mechanisms to reduce cost uncertainty, through coordinating distribution mechanism with other countries. But these documents didn't research the impact of carbon emissions policies on the firm's operating strategy from the microscopic perspective and optimization theory.

Many scholars at home and abroad studied the decision behavior of enterprises under carbon constraints. On production decisions: Du, Ma, Fu, Zhu, and Zhang (2011) investigated the impact of emission 'cap-and-trade' mechanism in an emission-dependent supply chain with the emission permit supplier and the emission-dependent firm, and found the optimal permits pricing and production quantity respectively. Song and Leng (2012) found the firm's optimal production quantity and corresponding expected profit under carbon emissions policies including the mandatory carbon emissions capacity, the carbon emissions tax, and the cap-and-trade system. Jiang and Klabjan (2012) studied joint production capacity and investment decisions under carbon tax and cap-and-trade policy for an emissions intensive company that faces stochastic demand, and compared the impact of carbon emissions constraints on company's performance along four dimensions, including profit, total emissions, investment amount, and investment timing. On the investment in green technology: Yalabik and Fairchild (2011) analyzed the effects of consumer, regulatory, and competitive pressure on firm investments in environmentally friendly production, and showed that competition over environmentally sensitive customers can improve firms to bring about environmental investment to reduce carbon emissions. Sengupta (2012) found that when companies realized that consumers had a carbon-sensitive demand, companies wound actively signal their investment in clean technology and got better market response.

Based on the above basic researches, this paper studies firm's production strategy considering the green technology investment under the impact of the emission cap and trade, when the demand is random. We discuss the timing and the optimal amount of green technology investments, analyze the optimal production capacity of enterprises, the maximum expected profit, the optimal amount of carbon trading and optimal emission reduction. The conclusion laysa microscopic foundation to design and develop carbon emissions policies, verify the effectiveness and scientific of carbon emissions policy, thus has a strong practical significance.

3. MODEL DESCRIPTIONS AND ASSUMPTION

In this paper, we game-theoretically analyze the production strategy, carbon trading strategy and green technology investment strategy in the 'cap-and-trade' system, which takes green technology investment into account. Note that the carbon emissions are refers to the average emissions of greenhouse gases in the production. Model assumptions are as follows:

(1) The firm faces a stochastic demand, not considering the carbon emissions let out in transportation, storage and so on.

(2) Without green technology investment, the amount of carbon emissions of each unit product is a constant, so the total carbon emissions will add up with the increase of production.

(3) The cost of reducing carbon emissions will quickly be enhanced with the increase of reduction rate. On this occasion, the firm can decide the cost of green technology investment to control the carbon reduction rate.

(4) Reducing carbon emissions has no effect on the cost of production.

(5) The emission cap is an exogenous variable, which could not be moved to the next period.

(6) The price of carbon emission is also an exogenous variable, and it is depend on the carbon trade market.

(7) When it is needed to order, the firm can immediately acquire the inventory.

(8) The stock out is not allowed, and regardless of the salvage value, it means that in sales reason, products will always be sold out.

Parameters and variables used in this paper are as follows:

Table 1
Symbols and Definitions

Notation	Descriptions
x	Random variable of requirements, x>0
$f(\bullet)$	Probability density function of x, derivable, differentiable
$F(\bullet)$	Wrobability distribution function of x, derivable, reversible
P	The price of product
Q^*	Optimal production without carbon constraint policy
Q^*_i	Optimal production in the ‘cap-and-trade’ system
E_0	Total carbon emissions without carbon constraint policy
E_i	Total carbon emissions in the ‘cap-and-trade’ system
A	Carbon Emission cap
C_s	Cost of production
i	Price of each unit of carbon emission
e	Carbon emissions of each unit product without carbon constraint policy
ρ	Carbon reduction rate or cleanness coefficient,0≤ρ<1, ifρ=0, it means no green technology investment.
ρ^*	Optimal cleanness coefficient in the ‘cap-and-trade’ system.
$C(\rho)$	Cost of green technology investment, and $C'(\rho)>0, C''(\rho)>0, C'(\rho)\geq C'(0)$

4. MODEL FORMULATIONS

4.1 The Model Without Carbon Policy

Without Carbon Policy，The firm does not care how much carbon emissions produced by production, and will not invest in reducing emissions. The firm needs to make the optimal production , to maximize the expected profit.

When the market meets a stochastic demand, the firm’s expected profit is：

$$\pi(Q)=\begin{cases}Px-C_sQ, & x\leq Q\\ PQ-C_sQ, & x>Q\end{cases} \tag{1}$$

And the expected profit is：

$$\mathrm{E}[\pi(Q)]=P\left[Q-\int_0^Q F(x)dx\right]-C_sQ \tag{2}$$

From the formula, $S(Q)=Q-\int_0^Q F(x)dx$ welearn from Formula (1) and Formula (2) that, the firm can figure out the optimal production quantity Q^*, to maximize the profit. It can be calculated that：

$$\frac{\partial \mathrm{E}[\pi(Q)]}{\partial Q}=P\bar{F}(Q)-C_s \tag{3}$$

$$\frac{\partial^2 \mathrm{E}[\pi(Q)]}{(\partial Q)^2}=-Pf(Q) \tag{4}$$

Sincethat-$Pf(Q)<0$,E[π (Q)] is a strict concave function. Let $\frac{\partial \mathrm{E}[\pi(Q)]}{\partial Q}=0$, we can figure out the optimal production quantity Q^*：

$$Q^*=F^{-1}\left(\frac{P-C_s}{P}\right) \tag{5}$$

At the same time, the maximum expected profitE[π(Q^*)] can be figured out：

$$\mathrm{E}[\pi(Q^*)]=P\left[Q^*-\int_0^{Q^*} F(x)dx\right]-C_sQ^* \tag{6}$$

4.2 The Model Under Cap And Trade Policy

In the ‘cap-and-trade’ system, the firm needs to make out the optimal production , the optimal cleanness coefficient, as well as the carbon emissions trading to maximize the expected profit.

In the ‘cap-and-trade’system, the carbon price should not be too high, otherwise the manufacturers can’t profit for the high total cost of each product. So the carbon price should meet this formula: $P-C_s-C(\rho)-ei(1-\rho)>0$, that is:

$$i<\frac{P-C_s-C(\rho)}{e(1-\rho)}$$

The expect profit is：

$$\mathrm{E}[\pi(Q)]=P\left[Q-\int_0^Q F(x)dx\right]-[C_s+C(\rho)]Q$$
$$-[e(1-\rho)Q-\mathrm{A}]i\left(Q>0,\ \rho\geq 0\right) \tag{7}$$

Let $\Delta E=e(1-\rho)Q-A$, if $\Delta E>0$, the firm will buy extra carbon credit; Conversely, the firm may benefit from emitting less than the capacity by selling its unused carbon credits in the trading market. The parameter refers to the reduction rate. If the firm will not invest the green technology. It is easy to find that in the ‘cap-and-trade’ system, the decision variables are production Q^*_i and the optimal coefficient of clean production .

Proposition1: In the 'cap-and-trade' system, the firm can make out the optimal production quantity Q^*_i, the optimal carbon trade quantity ΔE^* and the optimal cleanness coefficientρ^*, to maximize the expected profit. The optimal decision is as follows:

$$\left(Q_i^*,\ \rho^*,\ \Delta E^*\right)=\begin{cases}\left(Q_1^*,\rho_1^*,e\left(1-\rho_1^*\right)Q_1^*-\mathrm{A}\right), & \dfrac{\mathrm{P}-C_s-C(\rho)}{e(1-\rho)}>i>\dfrac{C^{'}(0)}{e}\\ \left(F^{-1}\left[\dfrac{P-C_s-ei}{P}\right],0,eF^{-1}\left[\dfrac{P-C_s-ei}{P}\right]-\mathrm{A}\right), & i\le\dfrac{C^{'}(0)}{e}\end{cases} \tag{8}$$

In the formula above, $Q_1^*=F^{-1}\left[\dfrac{P-C_s-C\left(\rho_1^*\right)-ei\left(1-\rho_1^*\right)}{P}\right]$, $\rho_1^*=C^{'-1}(ei)$.

Proof: In the 'cap-and-trade'system, by considering the relations among the firm's parameters, it can be known that Q and are independent of each other, the function E[π(Q)] is a dual function, whose domain D is: Q>0, ρ≥0.

① When there is analytical solution of the equation that $C'(\rho)=ei$, (ρ>0), or $C'(0)<ei$, within the domain D there is the only stationary point P_1, at this time this point is also the most value.To figure out the pointP_1: (Q^*_1, ρ^*_1), and $Q_1^*=F^{-1}\left[\frac{P-C_s-C(\rho_1^*)-ei(1-\rho_1^*)}{P}\right]$, $\rho_1^*=C^{'-1}(ei)$;

$$\frac{\partial^2\mathrm{E}[\pi(Q)]}{(\partial Q)^2}=-Pf(Q)<0,\frac{\partial^2\mathrm{E}[\pi(Q)]}{(\partial\rho)^2}=-C^{''}(\rho)Q<0,\frac{\partial^2\mathrm{E}[\pi(Q)]}{\partial Q\partial\rho}=0$$

So in the stable point P_1 (Q^*_1, ρ^*_1), the Hesse matrix is:

$$\begin{vmatrix}\dfrac{\partial^2\mathrm{E}[\pi(Q)]}{(\partial Q_1^*)^2} & \dfrac{\partial^2\mathrm{E}[\pi(Q)]}{\partial Q_1^*\partial\rho_1^*}\\ \dfrac{\partial^2\mathrm{E}[\pi(Q)]}{\partial\rho_1^*\partial Q_1^*} & \dfrac{\partial^2\mathrm{E}[\pi(Q)]}{\left(\partial\rho_1^*\right)^2}\end{vmatrix}=\begin{vmatrix}-Pf(Q_1^*) & 0\\ 0 & -C^{''}(\rho^*)Q_1^*\end{vmatrix}=f(Q_1^*)C^{''}(\rho^*)PQ_1^*>0$$

It can be known that the Hesse matrix is a negative definite matrix, so the stable point P_1 (Q^*_1, ρ^*_1) is a maxima of function E[π(Q)].

② When the function $C'(\rho)=ei$, (ρ≥0) has no solution ($C'(0)\geq ei$), the maxima or minimum must be on the edge of domain D.

Then it is not hard to know that the maxima or minimum is just the point P_2 (Q^*_2, ρ^*_2), and that:

$$Q_2^*=F^{-1}\left[\frac{P-C_s-ei}{P}\right],\ \ \rho_2^*=0$$

It can be seem that, in the 'cap-and-trade' system, although the firm can make out the optimal strategy, it will not sure to invest green technologies. Whether to invest, still need to consider the carbon emission price and the marginal cost of reducing carbon emissions $\frac{C^{'}(0)}{e}$.If $i>\frac{C^{'}(0)}{e}$, the firm will invest green technologies first.

Proposition 2: In the 'cap-and-trade'system, the firm's production and carbon emissions are both less than those without carbon policy. The critical value of the firm's emission cap $\mathrm{A}_0=\frac{[C_s+C(\rho)]Q_i^*+e(1-\rho)Q_i^*i+P\left[Q-\int_0^Q F(x)dx\right]-P\left[Q_i^*-\int_0^{Q_i^*}F(x)dx\right]-C_sQ}{i}$.
If the emission cap is higher than , the firm's profit will be higher than that without carbon constraint.

Proof: Comparing between formula (5) and formula (8), it can be known that $Q^*_r>Q^*_{ct}$;

Comparing the total carbon emissions:

$$\mathrm{E}_i=eQ^*_i(1-\rho^*)<eQ^*=\mathrm{E}_0$$

Comparing the firm's profit between formula (2) and formula (7):

$$\Delta\mathrm{E}(\pi)=\mathrm{E}[\pi(Q_i^*)]-\mathrm{E}[\pi(Q^*)]$$

$$=P\left[Q_i^*-\int_0^{Q_i^*}F(x)dx\right]-[C_s+C(\rho)]Q_i^*-e(1-\rho)Q_i^*i$$

$$-P\left[Q-\int_0^{Q}F(x)dx\right]+C_sQ+\mathrm{A}i$$

Let $\Delta\mathrm{E}(\pi)=0$, it can be known that $\mathrm{A}_0=\frac{[C_s+C(\rho)]Q_i^*+e(1-\rho)Q_i^*i+P\left[Q-\int_0^Q F(x)dx\right]-P\left[Q_i^*-\int_0^{Q_i^*}F(x)dx\right]-C_sQ}{i}$.

If A>A_0, $\Delta E(\pi)>0$, the expected profit is higher than that without carbon profit.

In the 'cap-and-trade'system, the carbon emission and production has been suppressed, while the firm's profit will not sure to subject to negative impacts. When the firm has extra carbon credit, the firm can sell the rest of the carbon credit to promote the profit.

Proposition 3: In the 'cap-and-trade'system, the more the carbon price is, the striking the firm's green technologies will be promoted, the lower the production quantity is, and the lower the carbon emissions quantity is; The high the firm's quota is, the more the profit is.

Proof: Considering formula (8), if $\frac{P-C_s-C(\rho)}{e(1-\rho)} > i > \frac{C'(0)}{e}$,$\rho^* = C'^{-1}$ (ei).

And it can be proved that:

$$\frac{\partial \rho^*}{\partial i} > 0 \tag{9}$$

If $i \le \frac{C'(0)}{e}$, $Q_i^* = F^{-1}\left[\frac{P-C_s-ei}{P}\right]$, then:

$$\frac{\partial Q_i^*}{\partial i} < 0 \tag{10}$$

If

$$\frac{P-C_s-C(\rho)}{e(1-\rho)} > i > \frac{C'(0)}{e}, Q_i^* = F^{-1}\left[\frac{P-C_s-c(\rho_1^*)-ei(1-\rho_1^*)}{P}\right]$$

$$= F^{-1}\left[\frac{P-C_s-g(\rho_1^*)-g'(\rho_1^*)(1-\rho_1^*)}{P}\right]$$

And it can be known that $\frac{\partial Q_i^*}{\partial \rho_1^*} < 0$, $\frac{\partial Q_i^*}{\partial i} < 0$.

Considering formula (7):

$$\frac{\partial E[\pi(Q)]}{\partial A} > 0 \tag{11}$$

Proposition 3 show that, in the 'cap-and-trade'system, what affect the enterprise production and green technology factors of investment strategy is not the carbon quota, but the market trading price of carbon. Carbon quota only affects the expected profit. The higher the carbon quota is, the higher the expected profit will be. So if the carbon quota is high enough, the profit will be higher than that without carbon constraint.

5. NUMERICAL ANALYSIS AND SENSITIVITY ANALYSIS

For some products in the market, the decision variables can be known through the historical data or some products questionnaire survey. So in this section, we will use a set of data to verify and supplement the previous developments. Assuming that the market demand for the product follows a left-truncated normal distribution, which is assumed as a mean of 150 and standard deviation of 10, that is $f(x) \sim N(150, 10^2)$. The selling price of the products (P) is 150, the unit production cost (C_s) is 15, the supply cost per unit permit (i) is 5, the emissions per unit product (e) is 1.5, and the emission cap (A) which is allocated by the government is 250. What's more, the cost of green technology investment meets the function $C(\rho) = \frac{5}{1-\rho}$, $C'(\rho) = \frac{5}{(1-\rho)^2} > 0, C''(\rho) = \frac{10}{(1-\rho)^3} > 0$, $C'(0)=5$.

In above settings, without carbon policy, the firm has an optimal production, that is $Q^*=192$ and the profit $E[\pi(Q^*)]$ is 25920.

However, in the 'cap-and-trade' system, the optimal cleanness coefficient $\rho^*=C'^{-1}(ei)=0.18$, the cost of green technology investment $C(\rho)=6.1$, the optimal production quantity $Q_i^* = F^{-1}\left[\frac{P - C_s - C(\rho^*) - ei(1-\rho^*)}{P}\right]$ $=138$, $\Delta E^*=e(1-\rho)\,Q_i^*-A=-80.3$. The formula $\Delta E^*<0$ means that the firm will benefit from emitting less than the capacity by selling its unused carbon credits in the trading market, and the final profit $E[\pi(Q_i^*)]$ is 18190.

If the emission cap is higher than the critical value $A_0 = \frac{[C_s + C(\rho)]Q_i^* + e(1-\rho)Q_i^* i + P\left[Q - \int_0^Q F(x)dx\right] - P\left[Q_i^* - \int_0^{Q_i^*} F(x)dx\right] - C_s Q}{i}$ $=1796$, the firm's profit $E[\pi(Q_i^*)]$ will be higher than that without carbon constraint $E[\pi(Q^*)]$.

In order to further study the influence of emission cap and carbon price, on the profits, carbon emissions and production, we make sensitivity analysis and come to several valuable managerial insights into the environmental policy.

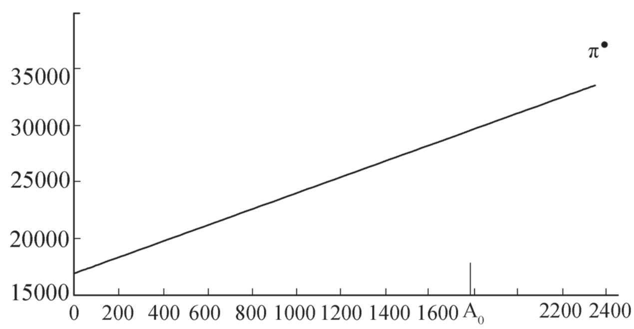

Figure 1
Sensitivity Of Final Profit To Emission Cap

As can be seen from Figure 1, the final profit is a direct proportion of emission cap.

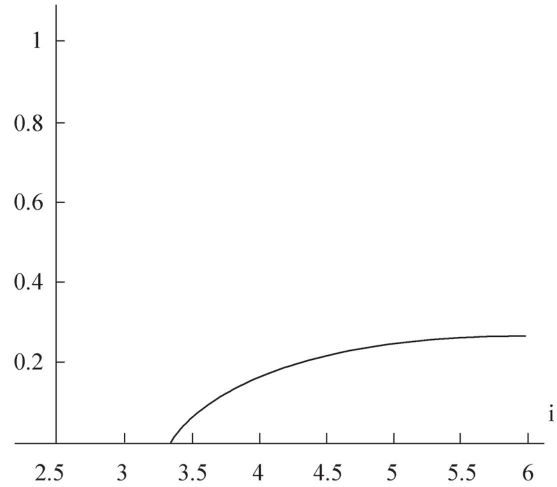

Figure 2
Sensitivity of Cleanness Coefficient to Carbon Price

Figure 2 means that the cleanness coefficient will increase gradually with carbon price, however, the growth rate decreases when the carbon price increases. What's more, if the carbon price is less than 3.33, the firm will not invest green technologies.

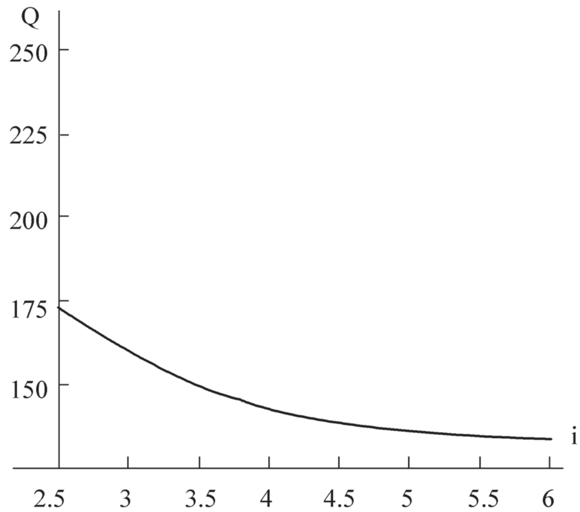

Figure 3
Sensitivity of Production to Carbon Price

Figure 3 proves that in the 'cap-and-trade' system, thee policy of carbon price restrains the firm's production. The more the carbon price is, the lower the production quantity will be.

6. CONCLUSIONS AND FUTURE RESEARCH

In this paper, we discussed the firm's strategies (that is production strategy, carbon trading strategy and green technology investment strategy) in a 'cap-and-trade' system, which takes green technology investment into account. We draw the conclusion that the firm may carry out the green technology investment, and it has the optimal amount of green technology investment, as well as the maximum expected profit and it's carbon emissions. It is proved that the 'cap-and-trade' system can promote the firm to invest the green technology investment to reduce carbon emissions. In addition, the higher the carbon price is, the higher the unit emission reduction rate is, and the fewer products are made. What's more, the total profit is proportional to the emission cap. Finally, we analyzed the parameters' sensitivity, and discussed the impact of parameters' changes on production, profit, and green technology investment and carbon emissions. This paper lays a micro base for the government to make carbon constraint policy, and for the firms to reduce carbon emissions.

There is still much room for further extensions and improvement, such as considering multiply kinds of products with different amount of carbon emissions, where the firm needs to consider products' different demands, different carbon emissions per unit product and different costs of production. Additionally, company strategies under green technology investment in the 'carbon emissions tax' system or in the 'mandatory carbon emissions capacity' system are worth investigating as well. When the government adopts different emissions policies, the firm's strategies will also make corresponding changes.

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