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Carbon Regulation and Trading Supply Chain Factory Production and Emission Reduction Decision System

Gan Wan*and Jun Zhang**
*University of Electronic Science and Technology of China, School of Management and Economics, Chengdu, Sichuan, 611731, China
**Kunming Metallurgy College, Logistics Engineering and Management Faculty, Kunming, Yunnan, 650033, China

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ABSTRACT

In order to optimize the carbon tax constraints and consumer business strategy under the influence of the environmental protection consciousness, this article looks into the time factor, by means of differential game, based on supply chain upstream enterprise R & D subsidy object under long-term carbon tax policy. When there is a R & D subsidy with no cooperation between the manufacturers in emission reduction technology research and development, semi-cooperation and complete cooperation R & D, the three cases of decision making with respect to carbon tax, environmental effects, research and development effects and economic effects; R & D subsidy levels are discussed to provide advice to the manufacturers to choose a development strategy.

INTRODUCTION

Global warming is an important problem faced by all mankind today. The increasing greenhouse gases and their impacts on climate change have drawn the attention of world leaders and scientists. Issued by the state council in 2011 (The 12th five-year plan for controlling greenhouse gas emissions), it calls for a substantial reduction in carbon dioxide emissions per unit of gross domestic product by 17 percent from 2010 levels by 2015. The indicators of carbon tax collection, emission reduction and emission trading are finally decomposed and implemented to enterprises, so as to change the cost function of enterprises, change the decision-making behaviour of upstream and downstream enterprises and have an impact on the performance of supply chain (Balachandran & Nguyen 2017). At the same time, consumers' awareness of environmental protection is becoming stronger and stronger, and their consumption behaviour also changes due to their environmental orientation. In order to reduce the carbon label of products, enterprises should not only consider their own operation and emission decisions, but also consider the optimal allocation of resources and carbon emissions in each link from the whole supply chain (Yi et al. 2016). In this way, the behaviour decisions of the upstream and downstream parties of the supply chain should not only consider the constraints of national carbon emission policies and regulations, but also consider the pressure from market demand and competition, which will complicate the economic decisions of enterprises in emission level, pricing and even coordination (Yamazaki 2017).

To solve above problems, this article looks into the time factor, by means of differential game, based on supply chain upstream enterprise r & d subsidy object under long-term carbon tax policy. When there is a r & d subsidy with no cooperation between the manufacturers in emission reduction technology research and development, semi-cooperation and complete cooperation r & d; the three cases of decision making with respect to carbon tax, environmental effects, research and development effects and economic effects, r & d subsidy levels are discussed to provide advice to the manufacturers to choose a development strategy.

PAST STUDIES

A study analysed the low-carbon technology selection strategies of upstream and downstream enterprises in the supply chain under the carbon tax policy, and found that the optimal strategy of upstream enterprises is comprehensive research and development cooperation, while the optimal strategy of downstream enterprises is vertical cooperation or horizontal cooperation (Yang & Yu 2016). A research analysed the emission reduction effect of carbon subsidy policy in the case of cooperation and non-cooperation in the supply chain, and found that it could stimulate the members of the supply chain to reduce emission, and the higher the degree of integration, the stronger the emission reduction performance (Tsai et al. 2017). A study took product re-manufacturing into consideration, analysed the optimal production decision of each phase when the independent demand and alternative demand for new products and re-manufactured products under the monopoly manufacturing mechanism were analysed, and found that the carbon trading mechanism could not guide the company to adopt low-carbon re-manufacturing technology under the independent demand, but could when the alternative demand was (Ghosh et al. 2018). The above literatures are scarce in the supply chain research. Based on a study under the policy of carbon trading company under the random demand are analysed using the newsboy model of multiple product stage of the production planning, found that the carbon price will also affect the company investment in production capacity and output, the higher the carbon price, production capacity, the lower the marginal value, and output depends on carbon utility value and the size of the production of carbon in the utility cost (Saxena et al. 2018).

MATERIALS AND METHODS

Put Forward the Basic Model

Considering the supply chain composed of three enterprises, enterprise Mi(= 1,2) and Mj(= 1, 2) are manufacturers in the imperfect competitive market and take the leading position in the supply chain. The two manufacturers produce completely homogeneous products. In the wholesale market, guno competes with enterprise R, which is a retailer of two kinds of products. It purchases products from enterprise Mi and enterprise Mj and sells them to consumers via wholesale Wi and Wj (Li et al. 2017). In order to facilitate calculation, let the manufacturer's production cost be 0, and the market anti-demand function be Pi = 1 - 2qi + qj, j = 1, 2, and qi, qj are the enterprise output. The product will produce carbon emission in the production process, let unit product produce unit carbon emission. In order to reduce carbon emission, the enterprise decides to develop emission reduction technology, and its independent research and development effort level is xi (Guo & Liu 2016). The decision-making of enterprise I is carried out within the framework of d-j. In the R & D stage of emission reduction technology, two forms of technology R & D can be selected: independent R & D of low-carbon technology or cooperative R & D of low-carbon technology, and in the production stage, output competition or cooperation can be selected. The carbon emission stock of the enterprise is S(t), which meets the following dynamic equation

$$S(t) = q_i + q_j - (1+\beta)(x_i + x_j) - \delta S, S(0) = 0, I = 1,2, i \neq j \quad \ldots(1)$$

Environmental damage caused by carbon emission is D = S^2/2. In order to reduce the carbon emission of enterprises, they are encouraged to adopt low-carbon technology for production. For the research and development efforts of enterprises in emission reduction technology, the government provides the research and development subsidy of sharp unit rate, and at the same time imposes carbon tax on the environmental damage of enterprises. Thus, the profit function of manufacturer I is obtained

$$\pi_m^i = w_i q_i - x_i^2 / 2 + u x_i - \tau S^2 / 2, i, j = 1,2, i \neq j \quad \ldots(2)$$

The profit function of the retailer is

$$\pi_\tau = [1 - 2q_i - w_i] q_i + [1 - 2q_i - w_i] q_i, i, j = 1,2, i \neq j \quad \ldots(3)$$

The game between supply chain enterprises can be divided into three stages: two manufacturers decide the R & D level of different R & D forms at the same time according to the R & D subsidy u of the government xi, xj. Under the condition that the retailer knows the product demand of the manufacturer, the two manufacturers compete or cooperate in the output and determine the wholesale prices. The retailer determines the order quantity according to the market response curve of the two products (Zhou 2016, Wei et al. 2017).

Model Solution and Analysis

The retailer order quantity is solved by backward induction. Firstly, the retailer's order quantity is solved, and the retailer determines the order quantity qi and qj from the two manufacturers according to the profit maximization goal. The wholesale price that asks a manufacturer next level of research and development. The D-J analysis framework is adopted. The first stage is the r & d stage, the manufacturer determines the r & d level, the second stage is the production stage, and the manufacturer determines the wholesale price. The solution of the game model is discussed in three cases: first, the upstream of the supply chain is completely uncooperative, that is, both manufacturers compete in the research and development stage and the production stage; Case 2: the upstream of the supply chain is semi-cooperative, that is, the two manufacturers compete in the r & d stage and the production stage. Case 3 is the complete cooperation state of the upstream of the supply chain, that is, the two manufacturers cooperate in the research and development stage and the production stage.

According to qi and qj, equation (2) can be rearranged

$$\pi_m^i = \frac{w_i}{2} - \frac{w_i w_j + 2w_i^2}{6} - x_i^2/2 + ux_i - \tau S^2/2, i, j = 1,2, i \neq j \quad \ldots(4)$$

A manufacturer i, the value function of profit maximization is $V_i(S)$, the feedback strategy implemented by the government in the above three corresponding situations must satisfy the respective HJB(Hamilton-Jacobi-Bellman) equation.

The two manufacturers do not cooperate at all. The equation of HJB is

$$rV_i(S) = \left\{ \frac{w_i}{2} - \frac{w_i w_i + 2w_i^2}{6} - x_i^2/2 + ux_i - \tau S^2/2 \right. \\ \left. + V_i'(S)\left[1 - \frac{w_i + w_j}{2} - (1+\beta)(x_i + x_j) - \delta S\right], i, j = 1,2, i \neq j \right. \quad \ldots(5)$$

The two manufacturers are semi-cooperative, and the wholesale price is determined first, and then the research and development level is determined. At this stage, the joint profit of the two companies is $\hat{\pi} = \pi_m^1 + \pi_m^2$.

$$\hat{\pi} = \sum_{i=1}^{2}\left[\frac{w_i}{2} - \frac{w_i w_i + 2w_i^2}{6} - x_i^2/2 + ux_i - \tau S^2/2\right], \quad \ldots(6)$$
$$i, j = 1, 2, i \neq j$$

HJB equation is

$$rV_i(S) = \max_{wi,wj}\left\{\hat{\pi}\right\} + V_i'(S)[1 - \frac{w_i + w_j}{2} \\ - (1+\beta)(x_i + x_j) - \delta S], i, j = 1, 2, i \neq j \quad \ldots(7)$$

It's given by first order conditions $w_i = \frac{3[1 - V_i'(S)] - 2w_j}{4}$

by symmetry $w_j = \frac{3[1 - V_i'(S)] - 2w_i}{4}$

Equation (5) can be rewritten as

$$rV_i(S) = \max_{xi}\left\{\sum_{i=1}^{2}[w_i\, q_i - x_i^2/2 + ux_i - \tau S^2/2\right] \\ + V_i'(S)\left[\frac{2 + V_i'(S) + V_j'(S)}{4} - (1+\beta)(x_i + x_j) - \delta S\right], \\ i, j = 1,2, i \neq j \quad \ldots(8)$$

The two manufacturers fully cooperate with each other in these two stages for the joint profit of the two companies.

$$\hat{\pi} = \sum_{i=1}^{2}[w_i q_i - x_i^2/2 + ux_i - \tau S^2/2], i = 1, 2 \quad \ldots(9)$$

HJB equation is

$$rV_i(S) = \max_{wi,wj}\{\pi\} + V_i^{`}(S)[1 - \frac{w_i + w_j}{2} \\ -(1+\beta)(x_i + x_j) - \delta S], i, j = 1, 2, i \neq j \quad \ldots(10)$$

Research and development level, after finishing

$$rV_i(S) = \left\{[\frac{1}{4} + (1+\beta)^2]A^2 - \delta A - \tau\right\}S^2 \\ + \left\{\frac{1 + 4(1+\beta)^2}{2}AB - \delta B + \frac{1 - 4u(1+\beta)}{2}A\right\}S \\ + [\frac{1}{4} + (1+\beta)^2]B^2 + \left[\frac{1}{2} - 2u(1+\beta)\right]B \\ + \frac{1}{4} + u^2 \quad \ldots(11)$$

ANALYSIS OF EFFECT RESULTS

Economic Effects of Carbon Emission Reduction Technology Research and Development

The manufacturer's profit under the two kinds of technology is compared by numerical simulation. Take r = 0.05, β = 0, δ = 0.002, u = 0.007, τ = 0.005. Fig. 1 is obtained by using MATLAB2014a simulation. Fig. 1 shows that under the R & D cooperation of manufacturers on low-carbon emission reduction technology, their respective profits are higher than that under the R & D competition, and manufacturers are motivated to conduct R & D cooperation on emission reduction technology.

Take r = 0.05, β = 0, δ = 0.002, u = 0.007, τ = 0.005, β = {0,0.5,1}. It is found that manufacturers' profits increase with the increase of r &d spillover rate, as shown in Fig. 2 and Fig. 3.

R & D Level Effect of Carbon Tax Policy

The R & D level effect of manufacturer R & D competition is simulated and the carbon tax rate is calculated τ = 0, τ = 0.0025, τ = 0.005, u = 0.007. When calculating the corresponding R & D level, it is found that the R & D level of emission reduction technology of manufacturers increases with the increase of carbon tax rate, when the government

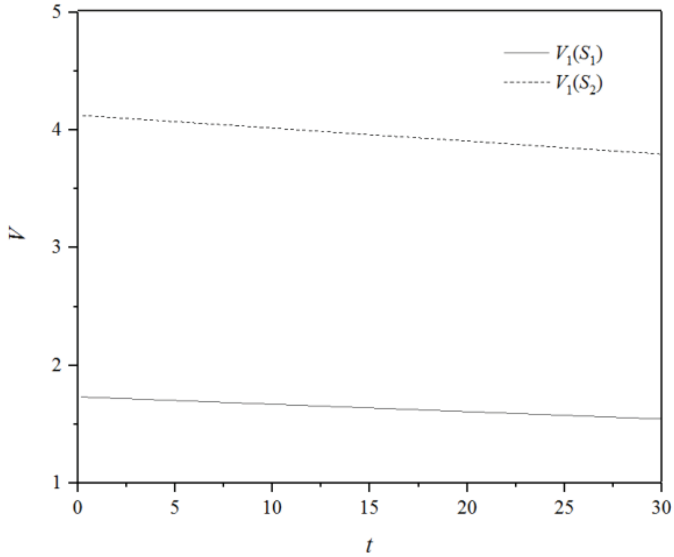

Fig. 1: Comparison of profits between R & D cooperation and competition.

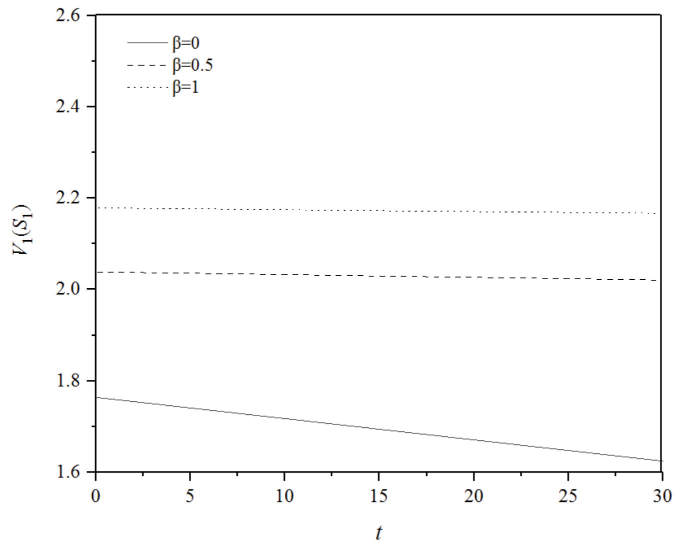

Fig. 2: Manufacturer's profit in r & d cooperation.

does not impose a carbon tax $\tau = 0$, the manufacturer's R & D level of emission reduction technology is 0, that is, there is no incentive for the manufacturer to reduce emission when there is no pressure to reduce emission. The greater the pressure to reduce emission, the greater the incentive to reduce emission, as shown in Fig. 4. Simulation of r & d level effect of manufacturer R & D cooperation can be found in $\tau = 0$, $\tau = 0.0025$, $\tau = 0.005$ when, the research and development level of corresponding emission reduction technology increases step by step, and $\tau > 0$is higher than the R & D level in the R & D competition, as shown in Fig. 5.

Then the R & D level effect under different r & d subsidy rates is simulated and the carbon tax rates are calculated respectively $\tau = 0$, $\tau = 0.0025$, $\tau = 0.005$ when calculating the corresponding r & d level. It is found that the r & d level of emission reduction technology with r & d subsidy under the same carbon tax rate is higher than that without r & d subsidy, as shown in Fig. 6. If there is no carbon tax, but give manufacturers r & d subsidies, even if there is no pressure to reduce emissions, as long as there is incentive to reduce emissions, manufacturers can also promote the research and development of emission reduction technology.

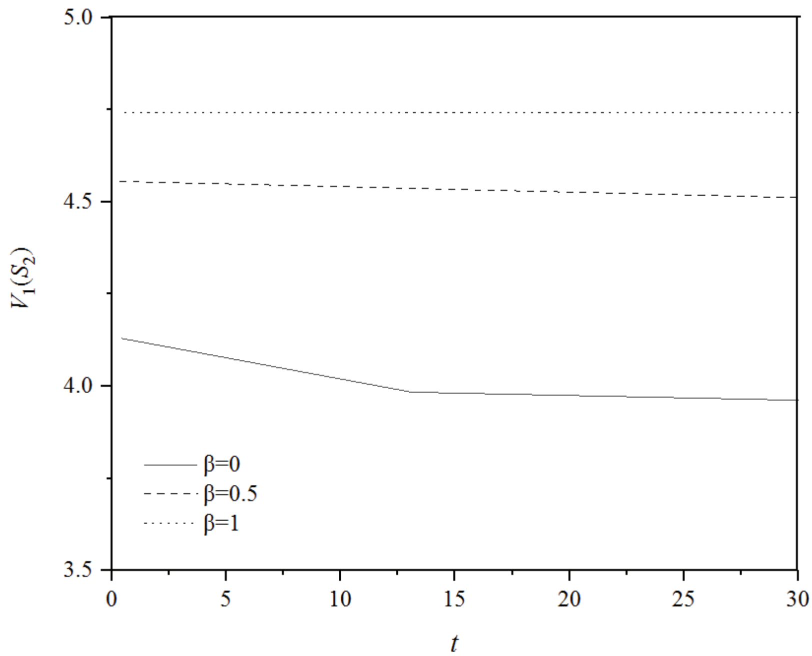

Fig. 3: Manufacturer's profit in R & D competition.

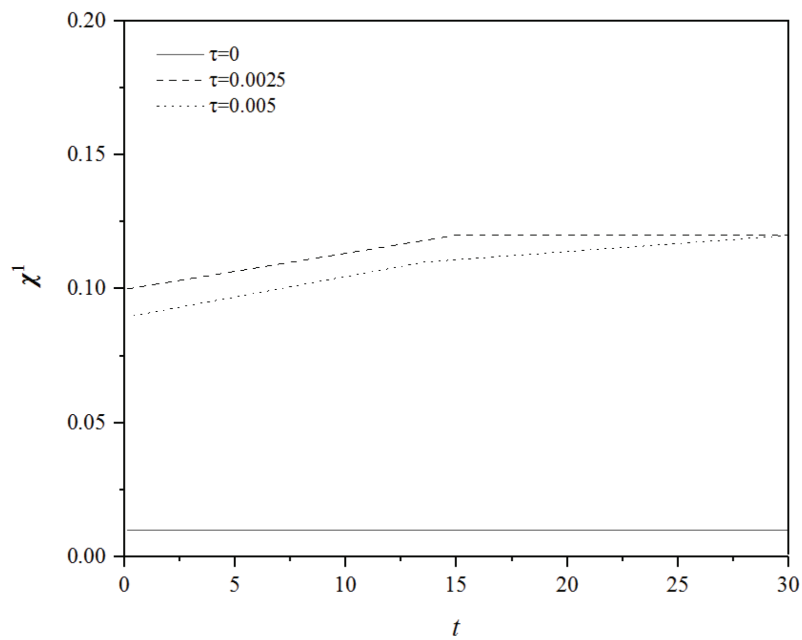

Fig. 4: R & D level under different r & d competition of carbon tax.

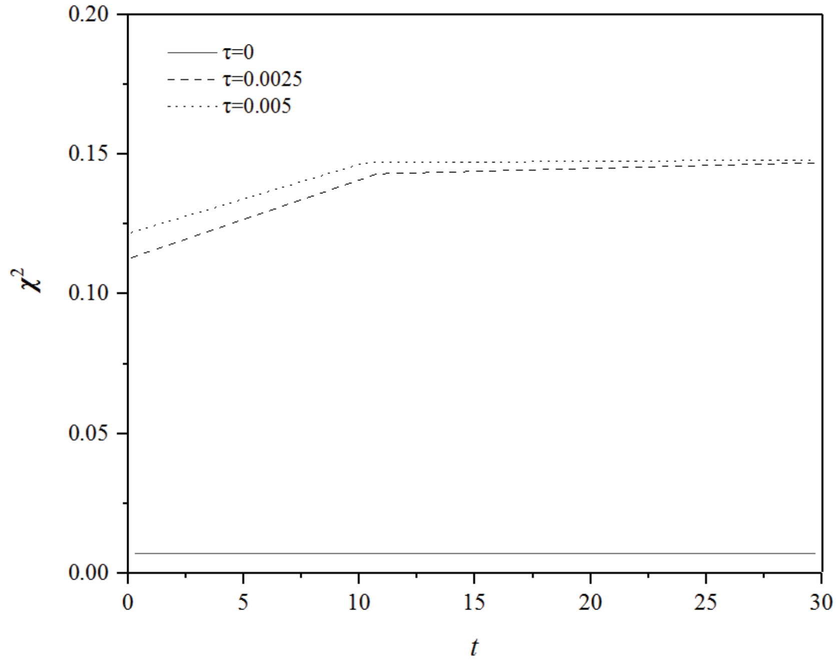

Fig. 5: R & d level under different r & d cooperation of carbon tax.

Influence of Carbon Tax Policy on Retailer's Ordering Decision

Newsboy model with the needs of normal distribution function, due to the particularity of normal distribution function and solving, result and solving process is expressed by the mathematical formula. This paper adopts the method of case analysis to verify proposition conclusion, analysis of carbon tax policy on the retailer's order decision and supplier lead time strategy impact on emissions.

By calculation, it can be seen from Table 1 and Table 2 that with the gradual increase of carbon tax, the corresponding situation is that under the carbon tax policy, the retailer's ordering time is more and more advanced, the order quantity under the carbon tax policy is $\lambda\tau < 1/2$, the monotone gets smaller, gets bigger and bigger and then gets smaller. When there is carbon tax, the length of lead time is proportional to the carbon tax rate. When tighter carbon policies are put in place (raising the carbon tax rate), retailers order at the earliest possible moment. When the carbon tax rate is 0, the $t\tau$ in Table 1 is 7.17, and the $t\tau$ in Table 2 is 0, which is the same as the lead time when there is no carbon emission reduction policy, but still earlier than the latest ordering time. The supplier's lead time strategy is effective, and the effect of lead time strategy is further improved with the increasingly stringent carbon tax policy. It can also be seen from Table 1 and Table 2 that under the carbon tax policy, the retailer's optimal order decision is to increase the lead time, and the order quantity is determined according to the product profit attribute. For high-profit products, the order quantity is first increased and then decreased, while for low-profit products, the order quantity is monotonously reduced. From a policy maker's point of view, as long as the carbon price is positive, retailers will always be able to bring forward the ordering time.

RESULT ANALYSIS

Found through the analysis that the effect of competition is located in the upstream of the manufacturer's optimal decision for cooperative research and development of low carbon technology, cooperative production. But when the supply chain upstream manufacturers choose the optimal technology research and development form, does not necessarily for the reduced carbon emissions of the whole society, in the long term cooperation r & d environmental effect is better than that of independent research and development, cooperative research and development of the environment in the short term effect to independent research and development of the situation. The r & d level effect of the optimal technology r & d form depends on the size of the r & d spillover level of emission reduction and the level of subsidy rate. The higher the spillover level is, the lower the enterprise's r & d

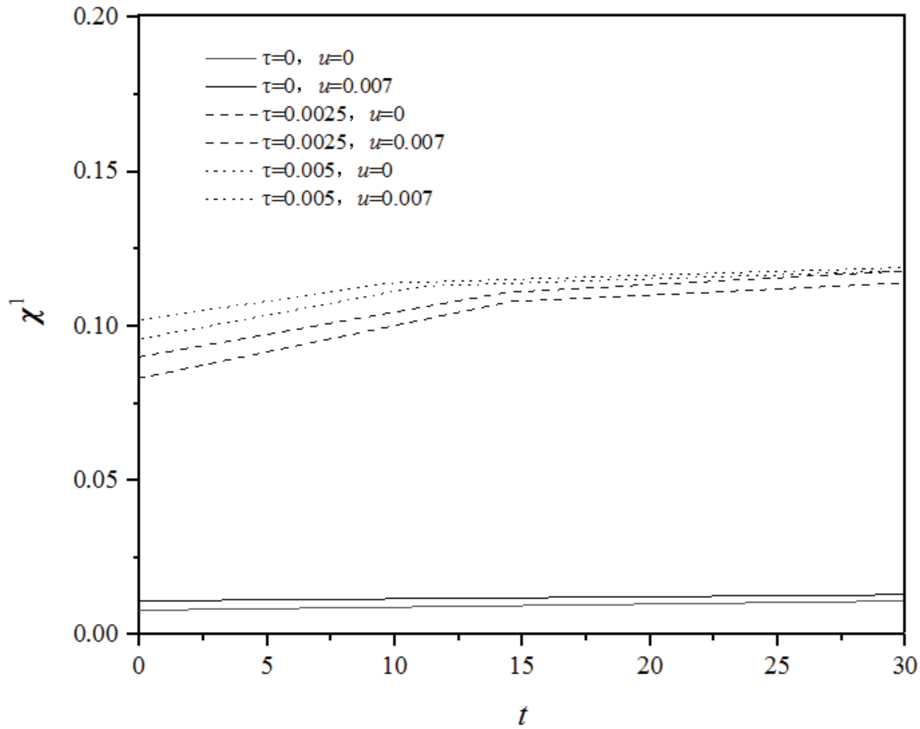

Fig. 6: R & D level under different carbon tax subsidy rates.

Table 1: Influence of carbon tax policy on lead time and order quantity of low-profit products.

T	qτ	tτ
0.0000	889.9541	7.1671
0.5172	863.0614	4.0809
0.8621	845.0788	2.2381
1.2069	827.0904	0.5403
3.4482	711.00446	0.0000

Table 2: Influence of carbon tax policy on lead time and order quantity of high-profit products.

T	qτ	tτ
0.0000	0.0000	1439.3759
0.5172	0.0000	1441.3071
0.8621	0.0000	1442.0986
1.2069	0.0000	1442.4982
3.4483	0.0000	1435.8205

willingness and level will be; the higher the subsidy rate is, the higher the enterprise's r & d willingness and level will be. For upstream of the supply chain enterprise, based on the consideration of profit, there is always a motivation for emission reduction technology research and development cooperation. For considering the effect of the environment, government tax policy and emission reduction technology r & d subsidy can effectively improve the level of research and development efforts to stimulate the supply chain enterprises, reduce the carbon footprint of supply chain, but if the government only choose one of the strategies, obviously the pressure to reduce emissions of carbon tax policy reduction technology research and development effect is better than that of emission reduction technology r & d subsidy of emission reduction technology research and development results. If the implementation of carbon tax policy aims at reducing carbon emissions in the long run, enterprises should be encouraged to carry out r & d cooperation according to the overflow level of r & d. If the implementation of carbon tax policy aims to achieve the target emission reduction task in the short term, enterprises should be encouraged to carry out research and development competition according to the overflow level of research and development.

The impact of the increase of carbon tax on the output decision of the manufacturer is related to the initial carbon footprint of the product and the channel structure. When the initial carbon footprint of the product is high, the manufacturer's output decision under the carbon tax policy is always to reduce production. When the initial carbon footprint of products is low, under the carbon tax policy, when the retailer dominates the channel structure, the manufacturer's output decision is to reduce production; under other structures, when the carbon tax does not exceed the threshold, the manufacturer's output decision is to reduce production; when the carbon tax exceeds the threshold, the manufacturer's output decision is to increase production. If the upstream and downstream of the supply chain can reach a cooperative emission reduction agreement in the form of bargaining, the manufacturer's optimal decision is always to increase the output in the dominant position. When the retailer is dominant, the manufacturer's optimal decision is always to reduce the output. Under the leaderless structure, the manufacturer's optimal output decision depends on the tax rate.

The carbon tax policy itself does not affect the cooperative emission reduction strategy of supply chain members, but the channel structure does. When manufacturers dominate the channel structure, both sides have cooperation motivation, and the optimal decision of supply chain is cooperation. When retailers dominate the channel structure, the emission reduction under the cooperative strategy is lower than that under the decentralized emission reduction strategy, and both parties have no cooperation motivation. The optimal emission reduction strategy for the supply chain is decentralized emission reduction. In the leaderless channel structure, different from carbon tax, one party is willing to cooperate in emission reduction while the other party is not willing, and there is no consistent emission reduction strategy. For the clean industry with low initial carbon footprint of products, it can reduce emissions with high carbon tax. For the polluting industry with high initial carbon footprint of products, the threshold of tax rate should be considered when carbon tax policy is used to reduce emissions, and the effect of emission reduction will be counterproductive if the tax rate exceeds the threshold.

CONCLUSION

There exists in emission reduction technology research and development of the supply chain link, the emission reduction technology research and development subsidies carbon tax competition policy under the manufacturer's optimal decision for the low carbon technology research and development, cooperative production cooperation, cooperation mode of research and development level and profits were higher than competition mode. But when selecting supply chain cooperative r & d not necessarily conducive to the environmental improvement of the whole society, in the long-term cooperation r & d environment effect is better than that of independent research and development, cooperative research and development of the environment in the short-term effect to independent research and development of the situation. The r & d level effect of the optimal technology r & d form depends on the size of the r & d spillover level of emission reduction and the level of subsidy rate. The higher the spillover level is, the lower the enterprise's r & d willingness and level will be; the higher the subsidy rate is, the higher the enterprise's r & d willingness and level will be.

In the production link of the supply chain, the impact of the carbon tax increase on the output decision of the manufacturer is related to the initial carbon footprint of the product and the channel structure. When the initial carbon footprint of the product is high, the manufacturer always decides to reduce the output. When the initial carbon footprint of products is low, under the carbon tax policy, when the retailer dominates the channel structure, the manufacturer's output decision is to reduce production; under other structures, when the carbon tax does not exceed the threshold, the manufacturer's output decision is to reduce production; when the carbon tax exceeds the threshold, the manufacturer's output decision is to increase production. If the upstream and downstream of the supply chain can reach a cooperative emission reduction agreement in the form of bargaining, the manufacturer's optimal decision is always to increase the output in the dominant position. When the retailer is dominant, the manufacturer's optimal decision is always to reduce the output. Under the leaderless structure, the manufacturer's optimal output decision depends on the tax rate.

REFERENCES

Balachandran, B. and Nguyen, J.H. 2017. Carbon risk and dividend policy in an imputation tax regime. Social Science Electronic Publishing.

Ghosh, A., Sarmah, S.P. and Jha, J.K. 2018. Collaborative model for a two-echelon supply chain with uncertain demand under carbon tax policy. Sādhanā, 43(9): 144.

Guo, Z.Q. and Liu, H.B. 2016. The impact of carbon tax policy on energy consumption and CO2 emission in China. Energy Sources Part B Economics Planning and Policy, 11(8): 7.

Li, X., Peng, Y. and Zhang, J. 2017. A mathematical/physics carbon emission reduction strategy for building supply chain network based on carbon tax policy. Open Physics, 15(1): 97-107.

Saxena, L.K., Jain, P.K. and Sharma, A.K. 2018. Tactical supply chain planning for tyre remanufacturing considering carbon tax policy. International Journal of Advanced Manufacturing Technology, 97(1-4): 1505-1528.

Tsai, W.H., Yang, C.H., Huang, C.T. and Wu, Y.Y. 2017. The impact of the carbon tax policy on green building strategy. Journal of Environmental Planning and Management, 60(8): 1-27.

Wei, L. and Jia, Z. 2017. Carbon tax, emission trading, or the mixed policy: which is the most effective strategy for climate change mitigation in China? Mitigation and Adaptation Strategies for Global Change, 22(6): 1-20.

Yamazaki, A. 2017. Jobs and climate policy: evidence from British Columbia's revenue-neutral carbon tax. Journal of Environmental Economics and Management, 83: 197-216.

Yang, S. and Yu, J. 2016. Low-carbonization game analysis and optimization in a two-echelon supply chain under the carbon-tax policy. Journal of Chinese Economic and Foreign Trade Studies, 9(2): 113-130.

Yi, J., Zhao, D., Hu, X. and Cai, G. 2016. An integrated CO2 tax and subsidy policy for low carbon electricity in Guangdong, China. Energy Sources Part B Economics Planning and Policy, 11(1): 44-50.

Zhou, X. 2016. Assessment of carbon tax policy and border carbon adjustment: implications for industrial competitiveness, carbon leakage and trade. Plastic and Reconstructive Surgery, 137(4): 690e-699e.