Impact of Stakeholder Behavior on the Carbon Emission Reduction in Supply Chain

Juning Su and Yang Pan
School of Economics and Management, Xi'an University of Technology, Xi'an, China

Keywords: Carbon emission reduction, Carbon cap-and-trade, Low-carbon-preference.

Abstract. In a two-echelon supply chain consisting of a manufacturer and a retailer, the carbon emission reduction model is established for the scenario where manufacturer invests R&D for carbon emission reduction, retailer shares R&D cost, government implements carbon cap-and-trade policy, and consumers have a low-carbon-preference. This research compares the optimal profits, the total carbon emission reduction level (TCRL) in supply chain and product sales volume, and discusses the impact of stakeholder behavior on carbon emission reduction in supply chain.

Introduction

In the 21st century, a series of environmental problems have become increasingly prominent. To control the negative impact of economic activity on the climate and environment, governments around the world are exploring effective scientific policies, regulations and measures. Among them, the carbon cap-and-trade policy, as a market-based policy, has the most significant effect[1]. Many scholars have studied supply chain operation under a carbon cap-and-trade policy. Drake et al. (2016) investigated the influence of government behavior on supply chain operation problems where the firm makes the decision regarding the technology and production capacity. They found that, under the cap-and-trade policy, the expected profits of enterprise are greater, and the expected emissions of product are lower[2]. On this basis, Lin et al. (2018) studied production and technology choices under government emission regulation. They found that firms may produce more even though they do not use more green technology under a more stringent regulation (fewer allowances)[3]. Kartick et al. (2018) discussed the joint impact of manufacturer's behavior and retailer's behavior in two-period supply chain frameworks. They found that procurement decision of retailer is a key factor in green supply chain[4]. Chen et al. (2017) used a random auction experiment and a questionnaire to examine consumers behavior. They found that how consumers' willingness to pay is influenced by carbon labels[5]. Going step further, Wang et al. (2016) focused on dyadic supply chain carbon emission reduction issues in an environment where consumers were assumed to be environmentally aware. They found that the cost-sharing contract can achieve the goal of reducing carbon emissions[6].

In the existing literature, the study of the carbon emission reduction decision in the supply chain often involves the behavior of two or three players. In reality, the enterprises in supply chain, as well as the external government and consumers, influence the carbon emission reduction decision. In this paper, we consider the behavior of four players at the same time, which makes the model more similar to the actual situation, and the conclusion is more valuable.

Model Description, Assumptions and Notations

The manufacturer sells products through an independent retailer in a 'low-carbon' sensitive market. The manufacturer is subjected to carbon cap-and-trade policy. The manufacturer should buy carbon allowances to offset the quota gap from the carbon market if their emission volume is larger than the allowance allocated by the government. In contrast, the manufacturer can sell its surplus quotas.

In supply chain, any player can influence the total carbon emission reduction level (TCRL) of the supply chain by affecting the level of carbon emission reduction of the unit product and product quantity. The manufacturer's low-carbon behavior is mainly reflected in investment in carbon R&D. The retailer's low-carbon behavior is mainly reflected in a promise to the manufacturer to share a part of carbon R&D cost. The government's low-carbon behavior is mainly reflected in a carbon allowance provided to the manufacturer that is based on historical data of carbon emissions and the trading price of each unit of carbon. The consumers' low-carbon behavior is mainly reflected in their low-carbon-preferences. To formulate analytical models, the following assumptions are made.

Assumption 1 Product quantity is measured as a linear decrease in the retail price and an increase in the carbon emission reduction level of the unit product. The functional form of product quantity is given as: $D=\alpha-\beta p+\gamma e$ where α represents the potential product quantity, β reflects consumers' sensitivity to retail price, γ characterizes the consumers' sensitivity to the level of carbon emission reduction of the unit product and e represents the carbon emission reduction level of unit product. The product quantity function of such a form appears in [7-8].

Assumption 2 The carbon R&D cost are measured as a quadratic increase in the level of carbon emission reduction of unit product. The functional form of carbon R&D cost is given as: ke^2, where k represents sensitivity to the carbon emission reduction investment. This form of the carbon R&D cost function appears in [9-10].

Assumption 3 The cost of the unit product is measured as a linear increase in the level of carbon emission reduction of the unit product. In addition to bulk investment in improving level of carbon emission reduction, during product packaging and handing, the manufacturer must pay additional costs to be compliant with environmental regulation. Therefore, the cost of the unit product is given as: $c+\lambda e$, where c is the fixed cost, λ is a positive parameter indicating the efficiency of carbon emission reduction technology. Such a form of the unit product's cost function is referenced in [4].

The meanings of the remaining parameters discussed in this chapter are shown in Table1.

Table 1. The Meanings of the Parameters Used In the Model

π_m	Profit of the manufacturer	δ	The proportion of carbon R&D cost shared by the retailer	E	The TCRL of the supply chain
π_r	Profit of the retailer	P_e	The trade price of unit carbon emission	K_g	The carbon allowance allocated by the government
π_{sc}	Profit of the supply chain				

Model Establishment and Solution

In a supply chain where manufacturer is dominant player, firstly the manufacturer makes it's optimal decisions regarding the level of carbon emission reduction of unit product e and wholesale price w. Then, based on the optimal decision of manufacturer, the retailer makes it's optimal decision regarding the retail price p. The objective function of manufacturer and retailer are expressed as follows.

$$\max \pi_m(w,e)=(w-c-\lambda e)D-P_e(e_0D-E-K_g)-(1-\delta)ke^2 \quad (1)$$

$$\max \pi_r(p)=(p-w)D-\delta ke^2 \quad (2)$$

Proposition1. The optimal level of carbon emission reduction e^*, wholesale price w^*, retail price p^* are: $e^*=\frac{(\alpha-\beta(c+P_ee_0))(\gamma-\beta(\lambda-P_e))}{8\beta k(1-\delta)-(\gamma-\beta(\lambda-P_e))^2}$ $w^*=\frac{(\alpha(\lambda-P_e)-\gamma(c+P_ee_0))(\gamma-\beta(\lambda-P_e))+4k(1-\delta)(\alpha+\beta(c+P_ee_0))}{8\beta k(1-\delta)-(\gamma-\beta(\lambda-P_e))^2}$

$p^*=\frac{(\alpha(\lambda-P_e)-\gamma(c+P_ee_0))(\gamma-\beta(\lambda-P_e))+2k(1-\delta)(3\alpha+\beta(c+P_ee_0))}{8\beta k(1-\delta)-(\gamma-\beta(\lambda-P_e))^2}$

Proof of Proposition1. Backward induction is used to find a perfect solution of the manufacturer-Stackelberg game. The first-order differential equation and the second-order differential equation of (2) with respect to p are $\frac{d\pi_r}{dp}=\alpha+\gamma e+\beta w-2\beta p$ and $\frac{d^2\pi_r}{dp^2}=-2\beta<0$. The existence of only the optimal retail price allows the retailer to maximize profit. The necessary condition $\frac{d\pi_r}{dp}=0$ yields:

$$p^* = \frac{\alpha+\gamma e+\beta w}{2\beta} \tag{3}$$

Then, the objective function faced by the manufacturer becomes as follows.

$$\max \pi_m(w,e) = \frac{1}{2}(w-c-\lambda e-P_e(e_0-e))(\alpha+\gamma e-\beta w)+P_eK_g-(1-\delta)ke^2 \tag{4}$$

By using the second-order differential equations of (4) with respect to the wholesale price w and level of carbon emission reduction e, we can obtain the Hessian matrix of the manufacturer as follows:

$$H=\begin{bmatrix}\frac{\partial^2\pi_m}{\partial w^2} & \frac{\partial^2\pi_m}{\partial w\partial e}\\ \frac{\partial^2\pi_m}{\partial e\partial w} & \frac{\partial^2\pi_m}{\partial e^2}\end{bmatrix}=\begin{bmatrix}-\beta & \frac{\gamma+\beta(\lambda-P_e)}{2}\\ \frac{\gamma+\beta(\lambda-P_e)}{2} & -\gamma(\lambda-P_e)-2(1-\delta)k\end{bmatrix}$$

We observed that the first-order main sub-formula of the Hessian matrix is $|H_1|=-\beta<0$, the second-order main sub-formula of the Hessian matrix is $|H_2|=2\beta k(1-\delta)-\frac{(\gamma-\beta(\lambda-P_e))^2}{4}$. In view of the existence of the optimal solution in actual production, this paper assumes that $8\beta k(1-\delta)>(\gamma-\beta(\lambda-P_e))^2$. The manufacturer's profit function is a joint concave function of the level of carbon emission reduction and wholesale price.

Using (4), the necessary conditions $\frac{\partial\pi_m}{\partial w}=0$ and $\frac{\partial\pi_m}{\partial e}=0$ yields:

$$\begin{cases}\frac{\partial\pi_m}{\partial w}=\frac{1}{2}(\alpha+\beta(c+P_ee_0)-2\beta w+(\gamma+\beta(\lambda-P_e))e)=0\\ \frac{\partial\pi_m}{\partial e}=\frac{1}{2}(-\alpha(\lambda-P_e)-\gamma(c+P_ee_0)+(\gamma+\beta(\lambda-P_e))w-2(\gamma(\lambda-P_e)e+2(1-\delta))ke)=0\end{cases}$$

The optimal level of carbon emission reduction e^* and wholesale price w^* are obtained as:

$$e^*=\frac{(\alpha-\beta(c+P_ee_0))(\gamma-\beta(\lambda-P_e))}{8\beta k(1-\delta)-(\gamma-\beta(\lambda-P_e))^2}\quad w^*=\frac{(\alpha(\lambda-P_e)-\gamma(c+P_ee_0))(\gamma-\beta(\lambda-P_e))+4k(1-\delta)(\alpha+\beta(c+P_ee_0))}{8\beta k(1-\delta)-(\gamma-\beta(\lambda-P_e))^2}$$

By substitute the optimal level of carbon emission reduction e^* and wholesale price w^* into (3), we can obtain the optimal retail price p^* as: $p^*=\frac{(\alpha(\lambda-P_e)-\gamma(c+P_ee_0))(\gamma-\beta(\lambda-P_e))+2k(1-\delta)(3\alpha+\beta(c+P_ee_0))}{8\beta k(1-\delta)-(\gamma-\beta(\lambda-P_e))^2}$.

Further, substituting the optimal outcomes into (1) and (2), we can obtain the following outcomes:

$$\pi_m^*=\frac{k(1-\delta)(\alpha-\beta(c+P_ee_0))^2}{8\beta k(1-\delta)-(\gamma-\beta(\lambda-P_e))^2}+P_eK_g\quad \pi_r^*=\frac{k(\alpha-\beta(c+P_ee_0))^2\left(4\beta k(1-\delta)^2-\delta(\gamma-\beta(\lambda-P_e))^2\right)}{\left(8\beta k(1-\delta)-(\gamma-\beta(\lambda-P_e))^2\right)^2}$$

$$\pi_{sc}^*=\frac{k(\alpha-\beta(c+P_ee_0))^2\left(12\beta k(1-\delta)^2-(\gamma-\beta(\lambda-P_e))^2\right)}{\left(8\beta k(1-\delta)-(\gamma-\beta(\lambda-P_e))^2\right)^2}+P_eK_g\quad E^*=\frac{2\beta k(1-\delta)(\gamma-\beta(\lambda-P_e))(\alpha-\beta(c+P_ee_0))^2}{\left(8\beta k(1-\delta)-(\gamma-\beta(\lambda-P_e))^2\right)^2}$$

Analysis of the Stakeholder Behavior Impact

Impact of Manufacturer's Behavior

To analysis the impact of manufacturer's behavior, we should derive the optimal results in the scenario that the manufacturer doesn't invest in carbon R&D. By substituting different conditions into (1) and (2), respectively. We can obtain the objective functions of retailer and manufacturer. Table 2provides the equilibrium outcomes. The detailed derivations are similar to those in previous section, and hence omitted. Where $A=\alpha-\beta\left(c+P_e e_0\right)$, $B=\gamma-\beta(\lambda-P_e)$, $M=8\beta k(1-\delta)$.

Proposition 2 Due to investment in carbon R&D, the optimal equilibrium satisfy:

1) $\pi_m^*(\delta=0,e\neq0)-\pi_m^*(\delta=0,e=0)>0$ 2) $\pi_r^*(\delta=0,e\neq0)-\pi_r^*(\delta=0,e=0)>0$ 3) $\pi_{sc}^*(\delta=0,e\neq0)-\pi_{sc}^*(\delta=0,e=0)>0$

4) $E^*(\delta=0,e\neq0)-E^*(\delta=0,e=0)>0$ 5) $D^*(\delta=0,e\neq0)-D^*(\delta=0,e=0)>0$

Proof of Proposition 2. In the absence of manufacturer investment, the difference between the profit of manufacturer is $\pi_m^*(\delta=0,e\neq0)-\pi_m^*(\delta=0,e=0)=\dfrac{A^2B^2}{8\beta k\left(8\beta k-B^2\right)}>0$. Similarly, the difference between the profit of the retailer is $\pi_r^*(\delta=0,e\neq0)-\pi_r^*(\delta=0,e=0)=\dfrac{A^2B^2\left(16\beta k-B^2\right)}{16\beta\left(8\beta k-B^2\right)^2}>0$. The difference between the profit of the supply chain is $\pi_{sc}^*(\delta=0,e\neq0)-\pi_{sc}^*(\delta=0,e=0)=\dfrac{A^2B^2\left(32\beta k-3B^2\right)}{16\beta\left(8\beta k-B^2\right)}>0$. The difference between TCRL of the supply chain is $E^*(\delta=0,e\neq0)-E^*(\delta=0,e=0)=\dfrac{2\beta kBA^2}{\left(8\beta k-B^2\right)^2}>0$. The difference between sales volumes of products is $D^*(\delta=0,e\neq0)-D^*(\delta=0,e=0)=\dfrac{8\beta k\delta A+AB^2}{4\left(8\beta k-B^2\right)}>0$.

Proposition 2 implies that manufacturer's behavior is always beneficial for carbon emission reduction in supply chain. Investing in carbon R&D can increase profits of supply chain and players. At the same time, investing in carbon R&D can also increase the TCRL of supply chain and sales volume. That is, investing in carbon R&D can provide more low-carbon products to the market. Therefore, the manufacturer plays a key role in carbon emission reduction decisions, and it's low-carbon behavior is always beneficial for reducing the TCRL of the supply chain.

Table 2. Equilibrium solutions without the manufacturer's behavior

	π_m^*	π_r^*	π_{sc}^*	E^*	D^*
$\delta=0$, $e\neq0$	$\frac{kA^2}{8\beta k-B^2}+P_eK_g$	$\frac{4\beta k^2A^2}{\left(8\beta k-B^2\right)^2}$	$\frac{kA^2\left(12\beta k-B^2\right)}{\left(8\beta k-B^2\right)^2}+P_eK_g$	$\frac{2\beta kBA^2}{\left(8\beta k-B^2\right)^2}$	$\frac{2\beta kA}{8\beta k-B^2}$
$\delta=0$, $e=0$	$\frac{A^2}{8\beta}+P_eK_g$	$\frac{A^2}{16\beta}$	$\frac{3A^2}{16\beta}+P_eK_g$	0	$\frac{A}{4}$
$\delta=0$	$\frac{kA^2}{8\beta k-B^2}+P_eK_g$	$\frac{4\beta k^2A^2}{\left(8\beta k-B^2\right)^2}$	$\frac{kA^2\left(4\beta k-B^2\right)}{\left(8\beta k-B^2\right)^2}+P_eK_g$	$\frac{2\beta kBA^2}{\left(8\beta k-B^2\right)^2}$	$\frac{2\beta kA}{8\beta k-B^2}$
$\gamma=0$	$\frac{k(1-\delta)A^2}{M-C^2}+P_eK_g$	$\frac{kA^2\left(4\beta k(1-\delta)^2-\delta B^2\right)}{\left(M-B^2\right)^2}$	$\frac{kA^2\left(12\beta k(1-\delta)^2-C^2\right)}{\left(M-C^2\right)^2}+P_eK_g$	$-\frac{2\beta k(1-\delta)CA^2}{\left(M-C^2\right)^2}$	$\frac{2\beta k(1-\delta)A}{M-C^2}$
$K_g=0$, $P_e\neq0$	$\frac{k(1-\delta)A^2}{M-B^2}$	$\frac{kA^2\left(4\beta k(1-\delta)^2-\delta B^2\right)}{\left(M-B^2\right)^2}$	$\frac{kA^2\left(12\beta k(1-\delta)^2-B^2\right)}{\left(M-B^2\right)^2}$	$\frac{2\beta k(1-\delta)BA^2}{\left(M-B^2\right)^2}$	$\frac{2\beta k(1-\delta)A}{M-B^2}$
$K_g=0$, $P_e=0$	$\frac{k(1-\delta)E^2}{M-F^2}$	$\frac{kE^2\left(4\beta k(1-\delta)^2-\delta F^2\right)}{\left(M-F^2\right)^2}$	$\frac{kE^2\left(4\beta k(1-\delta)^2-F^2\right)}{\left(M-F^2\right)^2}$	$\frac{2\beta k(1-\delta)FE^2}{\left(M-F^2\right)^2}$	$\frac{2\beta k(1-\delta)E}{M-F^2}$

Impact of Retailer's Behavior

Proposition 3 Comparing the scenario where the retailer shares the carbon emission reduction R&D cost and doesn't share, the optimal equilibrium satisfies:

1) $\pi_m^*-\pi_m^*(\delta=0)>0$ 2) $\pi_r^*-\pi_r^*(\delta=0)\geq0,\ \forall\delta\leq\dfrac{B^2\left(8\beta k-B^2\right)}{4\beta k\left(16\beta k-B^2\right)}$ 3) $\pi_{sc}^*-\pi_{sc}^*(\delta=0)\geq0$ $,\forall\delta\leq\dfrac{2\left(8\beta k-B^2\right)}{32\beta k-3B^2}$

4) $E^*-E^*(\delta=0)>0$ 5) $D^*-D^*(\delta=0)>0$

Proof of Proposition 3. When the retailer doesn't share the carbon emission reduction R&D cost, the difference between the manufacturer's profit is $\pi_m^* - \pi_m^*(\delta=0)\frac{k\delta A^2B^2}{(M-B^2)(8\beta k-B^2)}>0$. Similarly, the difference between retailer's profit is $\pi_r^* - \pi_r^*(\delta=0)=\frac{k\delta A^2B^2\left(B^2(8\beta k-B^2)-4\beta k\delta(16\beta k-B^2)\right)}{(M-B^2)^2(8\beta k-B^2)^2}$, and when $\delta\le\frac{B^2(8\beta k-B^2)}{4\beta k(16\beta k-B^2)}$, $\pi_r^*-\pi_r^*(\delta=0)\ge0$. The difference between the supply-chain's profit is $\pi_{sc}^*-\pi_{sc}^*(\delta=0)=\frac{k\delta A^2B^2\left(B^2(8\beta k-B^2)-4\beta k\delta(16\beta k-B^2)\right)}{(M-B^2)^2(8\beta k-B^2)^2}$, and when $\delta\le\frac{2(8\beta k-B^2)}{32\beta k-3B^2}$, $\pi_{sc}^*-\pi_{sc}^*(\delta=0)\ge0$. The difference between the TCRL of supply chain is $E^*-E^*(\delta=0)=\frac{2\beta k\delta BA^2(64\beta^2k^2-B^4)}{(M-B^2)^2(8\beta k-B^2)}>0$. The difference between sales volume is $D^*-D^*(\delta=0)=\frac{8\beta k\delta AB^2}{(M-B^2)(8\beta k-B^2)}>0$.

Proposition 3 implies that the retailer's behavior is not always beneficial for the carbon emission reduction decision. The TCRL of supply chain and product sales volume are affected when manufacturer and retailer are willing to share the carbon emission reduction R&D costs. That is, the retailer's low-carbon behavior can lead to more low-carbon products. When the manufacturer and retailer are willing to share the carbon emission reduction R&D costs, the profit of the manufacturer can increase, but it does not necessarily increase the retailer's profit and supply chain's profit. Therefore, the retailer should formulate a reasonable carbon emission reduction R&D cost share ratio.

Impact of Consumers' Behavior

Proposition 4 Comparing the equilibrium solution of the scenario where the consumers are low-carbon-preference and that of the scenario where the consumers are absence of low-carbon-preference, we can obtain:

1) $\pi_m^*-\pi_m^*(\gamma=0)\ge0, \forall\gamma\ge2C$ 2) $\pi_r^*-\pi_r^*(\gamma=0)\ge0, \forall\gamma\ge2C$ and $\forall\delta\le1/2$ 3) $\pi_{sc}^*-\pi_{sc}^*(\gamma=0)\ge0$, $\forall\gamma\ge2C$ and $\forall\delta\le2/3$

4) $E^*-E^*(\gamma=0)>0$ 5) $D^*-D^*(\gamma=0)\ge0, \forall\gamma\ge2C$

Proof of Proposition4. When the consumers do not have a low-carbon-preference, the difference between the manufacturer's profit is $\pi_m^*-\pi_m^*(\gamma=0)=\frac{k\gamma(1-\delta)A^2(\gamma-2C)}{(M-B^2)(M-C^2)}$. When $\gamma\ge2C$, $\pi_m^*-\pi_m^*(\gamma=0)\ge0$. Similarly, the difference between the retailer's profit is $\pi_r^*-\pi_r^*(\gamma=0)=\frac{kA^2B\left((M-C^2)(M(1-2\delta)-\delta C^2)+B(4\beta k(1-\delta)^2-\delta C^2)\right)}{(M-B^2)^2(M-C^2)^2}$. When $\gamma\ge2C$ and $\delta\le1/2$, $\pi_r^*-\pi_r^*(\gamma=0)\ge0$. The difference between the supply-chain's profit is $\pi_{sc}^*-\pi_{sc}^*(\gamma=0)=\frac{kA^2B\left(M(M-C^2)(2-3\delta)+\gamma B(12\beta k(1-\delta)^2-C^2)\right)}{(M-B^2)(M-C^2)}$. When $\gamma\ge2C$ and $\delta\le2/3$, $\pi_{sc}^*-\pi_{sc}^*(\gamma=0)\ge0$. The difference between the TCRL of the supply chain is $E^*-E^*(\gamma=0)=\frac{2\beta k(1-\delta)A^2\left(B(M-C^2)^2+C(M-B^2)^2\right)}{(M-B^2)^2(M-C^2)^2}>0$. The difference between the sales volume is $D^*-D^*(\gamma=0)=\frac{2\beta k\gamma A(1-\delta)(\gamma-2C)}{(M-B^2)(M-C^2)}$. When $\gamma\ge2C$, $D^*-D^*(\gamma=0)\ge0$.

Proposition 4 shows that the impact of consumers' behavior on the carbon emission reduction decisions in supply chain is influenced by retailer's behavior. Consumers with low-carbon-preference are always beneficial for the TCRL of supply chain. When the consumers' preferences regarding the level of carbon emission reduction are greater than a certain threshold, the profit of the manufacturer and the sales volume are increasing with respect to the consumers' low-carbon-preference. The impact of consumer behavior on the supply-chain's profit and retailer's profit is affected by consumers' behavior and retailer's behavior.

Impact of Government's Behavior

Proposition 5 Comparing the impact of the government's carbon cap-and-trade policy, the optimal equilibrium satisfies:

1) $\pi_m^*\left(K_g=0\right)-\pi_m^*\left(P_e=0,K_g=0\right)\geq 0$, $\forall P_e \geq \frac{2E\left(e_0\left(M-F^2\right)-EF\right)}{\beta\left(E^2+e_0^2\left(M-F^2\right)\right)}$ 2) $\pi_{sc}^*\left(K_g=0\right)-\pi_{sc}^*\left(P_e=0,K_g=0\right)\geq 0$, $\forall P_e \geq \frac{2N\left(e_0^2\left(M-F^2\right)-\left(E-\gamma e_0\right)F\right)}{\beta\left(N^2+e_0^2\left(M-F^2\right)\right)}$

Proof of Proposition 5. In the absence of government policy, the difference between the manufacturer's profit is $\pi_m^*\left(K_g=0\right)-\pi_m^*\left(P_e=0,K_g=0\right)=\frac{k(1-\delta)\beta P_e\begin{pmatrix}\left(E^2+e_0^2\left(M-F^2\right)\right)\beta P_e\\-2E\left(e_0\left(M-F^2\right)-EF\right)\end{pmatrix}}{\left(M-B^2\right)\left(M-F^2\right)}$. When $P_e \geq \frac{2E\left(e_0\left(M-F^2\right)-EF\right)}{\beta\left(E^2+e_0^2\left(M-F^2\right)\right)}$, $\pi_m^*\left(K_g=0\right)-\pi_m^*\left(P_e=0,K_g=0\right)\geq 0$. Similarly, the difference between the supply-chain's profit is $\pi_{sc}^*\left(K_g=0\right)-\pi_{sc}^*\left(P_e=0,K_g=0\right)=\frac{k(1-\delta)\beta P_e\begin{pmatrix}\left(N^2+e_0^2\left(M-F^2\right)\right)\beta P_e\\-2N\left(e_0^2\left(M-F^2\right)-NF\right)\end{pmatrix}}{\left(M-B^2\right)\left(M-F^2\right)}$. When $P_e \geq \frac{2N\left(e_0^2\left(M-F^2\right)-NF\right)}{\beta\left(N^2+e_0^2\left(M-F^2\right)\right)}$, $\pi_{sc}^*\left(K_g=0\right)-\pi_{sc}^*\left(P_e=0,K_g=0\right)\geq 0$.

As retailer's profit and the TCRL of supply chain are complex, this paper provides numerical illustrations for discussions. The results are shown in Table 3.

Table 3. Equilibrium solutions without the government's behavior

$\alpha=400$, $\beta=1$, $\gamma=3$, $c=2$, $\lambda=0.1$, $e_0=10$, $\delta=0.2$, $k=200$, $K_g=0$						
P_e	0	6	12	18	24	30
D	100.38	92.10	90.41	100.00	120.41	160.14
E	90.91	295.65	329.20	447.05	694.16	2589.81
π_r	9998.68	7862.29	6496.98	5676.90	5923.53	14539.05

The model analysis and numerical illustration imply that initiating a carbon cap-and-trade policy can increase the TCRL of supply chain, but it doesn't necessarily increase the sales volume and the manufacturer's profit, retailer's profit and supply-chain's profit. When the carbon trade price is more than a certain threshold, the manufacturer's profit, retailer's profit and supply-chain's profit are increasing with respect to the carbon trade price. Therefore, a reasonable carbon trading price is critical. It can improve the enthusiasm of enterprises in supply chain, provide more low-carbon products to the market, reduce the total carbon emission level in supply chain.

Conclusions

This paper discusses the impact of the internal and external stakeholders on the carbon emission reduction in a two-echelon supply chain. Through the calculation of the model and the analysis of the examples, we find the following conclusions. The manufacturer's low-carbon behaviors always beneficial for carbon emission reduction, while the retailer's low-carbon behavior, the consumers' low-carbon behavior, and the government's low-carbon behavior are not always beneficial for carbon emission reduction. Through the calculations, this paper finds the favorable boundary conditions. The impact of the consumers' behavior on carbon emission reduction decisions is influenced by the retailer's behavior. When the retailer is willing to share a portion of carbon emission reduction R&D cost, the retailer's profit and supply-chain's profit would decrease with respect to retailer's behavior and consumers' behavior.

Acknowledgment

This paper is supported by the Project of Shaanxi Provincial Natural Science Foundation Research Project (2017JM7013), Shaanxi Provincial Social Science Foundation Research Project (2017S010).

References

[1] J. Kroes, R. Subramanian, Operational Compliance Levers, Environmental Performance, and Firm Performance under Cap-and-trade Regulation, J. Manufacturing and Service Operations Management.14(2012) 186-201.

[2] F. Drake, R. Kleindorfer, L Van, Technology Choice and Capacity Portfolios under Emission Regulation, J. Production and operations management. 6(2016)1006-1025.

[3] L. Jenyen, X. Sean, G. Fei, Production and Technology Choice under Emissions Regulation: Centralized vs Decentralized Supply Chains, J. unpublished.

[4] D. Kartick, S. Subrata, Influence of Procurement Decisions in Two-period Green Supply Chain, J. Journal of Cleaner Production. 190(2018) 388-402.

[5] N. Chen, H. Zhang, S Huang, L. Zheng, Chinese Consumer Response to Carbon Labeling: Evidence from Experimental Auctions, J. Journal of Environmental Planning and Management. 4(2017)1-19.

[6] W. Qinpeng, Z. daozhi, H. Longfeng, Contracting Emission Reduction for Supply Chains Considering Market Low-carbon-preference, J. Journal of Cleaner Production.120(2016)72-84.

[7] D. Ghosh, J. Shah, "Supply Chain Analysis Under Green Sensitive Consumer Demand and Cost Sharing Contract," International Journal of Production Economics. vol. 164,pp.319-329, 2015.

[8] H. Song, X. Gao, Green Supply Chain Game Model and Analysis under Revenue Sharing Contract, J. Journal of Cleaner Production. 170(2017) 183-192.

[9] X. Chen, S. Benjaafar, A.Elomri, The Carbon-constrained EOQ,J. Operations Research Letters.2 (2013) 172-179.