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Research on production decision-making mechanism of energy supply chain

ZHANG Yunlong[1], ZHAO Daozhi[1], XIE Xinpeng[2,3]

Abstract. This paper considers a supply chain system consisting of a product manufacturer that is regulated by the governmentand a supplier which provides the required electricity to the manufacturer. By establishing the Stackelberg game model for two main bodies, the influence of product power consumption and government energy constraint on optimal solution and optimal profit is discussed and analyzed. The results indicate that the government should prudently develop the upper limit of electricity, and the manufacturer should effectively manage the product's energy consumption, so that the utility of two main bodies can achieve the best.

Key words. government regulation; electric power supplier; electric energy price; Decision-making Mechanism.

1. Introduction

In order to achieve domestic and international commitments to control carbon emissions, placecountry-regionChina has piloted carbon trading in seven regions. Carbon assets have developed into a scarce resource that can be traded on international and domestic carbon trading markets. The power industry, as placecountry-regionChina's largest carbon sector, is an important market participant in existing carbon trading pilot and future national carbon markets. With the development of carbon emissions trading market at home and abroad, as well as the participation of placecountry-regionChina's power industry in the domestic carbon emissions trading market, this paper follows the latest developments from the power generation side and the grid side to the carbon market. The key influencing factors of the carbon

[1]Workshop 1 - Tianjin University, Management and Economics Department, Tianjin, China, 300027

[2]Workshop 2 - Military vehicle department of Miliitary Transport Insititute, Tianjin, China, 300161

[3]Corresponding author: XIE Xinpeng; e-mail: xiexinpeng2010@yeah.net

emission in placecountry-regionChina's power industry include the type of power generation, quota determination and distribution, and emission reduction methods.

2. Formulation of the problem

In the literature [1-5], initial allocation of carbon emissions quotas for the power sector has been studied. In the literature [1], the least squares method is used to study the initial distribution of carbon emission rights in the case of multi-criteria. Literature [2] shows five distribution modes, such as the average installed capacity allocation model, and compares their efficiency through analysis; literature [3] considered the actual situation of China's power industry development, proposed a two-level distribution mechanism based on regional comparison; In the literature [4], the fair distribution of the initial carbon emission rights of the unit is studied by using the rights-based distribution theory. Literature [5] compares the impact of the potential gains and compensation on the power generation enterprises based on the two distribution rules of historical emissions and historical production in the electricity market environment.

Literature [6] believes that the power supply chain is also a special supply chain, consisting of the power generation enterprises, power grid enterprises and power units.Literature [7] has discussed the construction of collaborative decision model of power supply chain alliance under the environment of BIC coal in power generation supply and procurement management.On the basis of the above literature, this study will investigate the enterprise's production decision and coordination mechanism of the electric supply chain, to achieve resources optimization allocation and enhance mutual cooperation.

3. Parameter Description

According to the above literature, based on the relevant results of the study, this paper will considere the coordination optimization problem with a newsboy model which is composed by a manufacturer under government regulation and an electric energy supplier in the supply chain system.

The cost c_m and the selling price of the production unit of the manufacturer p are constant. Manufacturer makes output quantity decision q based on the market demand in the sales season, and the demand D is random. The distribution function and probability density function of the random variable ε are defined as $\mathrm{F}(\cdot)$ and $\mathrm{f}(\cdot)$, respectively.To represent the loss rate of the demand distribution, we define the loss rate function of the demand distribution as follows.If $h'(x) > 0$, the loss rate function is increasing. Most forms of distribution meet the above characteristics, such as normal distribution, uniform distribution, Poisson distribution and Weibull distribution.

The electric energy consumption of the product of the manufacturer is $\mu \equiv \int_0^\infty x \cdot f\left(x\right)dx$, and it is assumed that the total electric energy consumption e_m is linearly related to the output, that is $E\left(q\right) = e_m \cdot q$. In addition, the government should restrict the manufacturer's electricity consumption, by setting the upper limit E_m. If the upper limit E_m cannot meet the current needs of the manufacturer, the manufacturer has to purchase the required electrical energy E_r with unit electrical energy price p_e from the supplier, i.e.,

$$E_r = (e_m \cdot q - E_m)^+ \tag{1}$$

Taking into account the actual situation of suppliers to supply the required power to the downstream manufacturers, the operation cost of the unit electric energy c_s including a series of procedures, including the application and approval of electrical energy. In this case, the supplier at first makes the price of electricity to the manufacturer p_e ($p_e > c_s$); and then the manufacturer determines the output quantity q of the product, according to the electricity price and government's upper limit of electric power.

4. Mathematical model

Firstly we established the game models with two main bodies, and then we derive the manufacturer's optimal production quantity and the supplier's optimal electricity price according to each body's pursuit of profit maximization. Specifically, the supplier at first makes the electric energy price decision p_e, and then the manufacturer determines the product yield quantity q based on the electricity price and government's upper electric power limit E_m.Under stochastic demand conditions, the product expected to sell is $S\left(q\right)$. That is

$$S\left(q\right) = E\left[\min\left(q, D\right)\right] = \begin{cases} D, D \le q \\ q, D > q \end{cases} \tag{2}$$

So the manufacturer's profit function can be expressed as:

$$\Pi_M\left(q\right) = p \cdot E\left[\min\left(q, D\right)\right] - c_m \cdot q - p_e \cdot E_r \tag{3}$$

Take the equation (2) into the equation (3), the manufacturer's profit function eventually available:

$$\Pi_M\left(q\right) = \begin{cases} p \cdot \left[q - \int_0^q F(x)dx\right] - c_m \cdot q, & q \le E_m/e_m \\ p \cdot \left[q - \int_0^q F(x)dx\right] - c_m \cdot q - p_e \cdot \left(e_m \cdot q - E_m\right), & q \ge E_m/e_m \end{cases} \tag{4}$$

From the piecewise function (4) can be seen that$\partial^2\Pi_M\left(q\right)/\partial q^2 = -p \cdot f\left(q\right) < 0$are both satisfied, there are only the optimal output t q^* of the manufacturer's profit Π_M reaches maximum value.

Through the above equation, we can easily get the formula (5):

$$q^{*}=\begin{cases} F^{-1}\left(\frac{p-c_m-e_m\cdot p_e}{p}\right), & E_m<e_m\cdot F^{-1}\left(\frac{p-c_m-e_m\cdot p_e}{p}\right)\\ \frac{E_m}{e_m}, & e\cdot F^{-1}\left(\frac{p-c_m-e_m\cdot p_e}{p}\right)<E_m<e_m\cdot F^{-1}\left(\frac{p-c_m}{p}\right)\\ F^{-1}\left(\frac{p-c_m}{p}\right), & E_m>e_m\cdot F^{-1}\left(\frac{p-c_m}{p}\right)\end{cases}\tag{5}$$

For the electric power suppliers, it is necessary to meet the manufacturer's production of electrical energy, so its profit function can be expressed as:

$$\Pi_S\left(p_e\right)=\left(p_e-c_s\right)\cdot E_r=\left(p_e-c_s\right)\cdot\left(e_m\cdot q-E_m\right)\tag{6}$$

4.1. Optimal Value of the Solution

From the manufacturer's optimal output $F\left(q^{*}\right)=\frac{p-c_m-e_m\cdot p_e}{p}$, it can be seen that as a result of monotonically increasing function $F\left(\cdot\right)$, the optimal output and power price is negatively correlated, that is $\frac{\partial q^{*}}{\partial p_e}=\frac{\partial q^{*}}{\partial F(q^{*})}\cdot\frac{\partial F(q^{*})}{\partial p_e}=-\frac{e_m}{p\cdot f(q^{*})}<0$. Then put optimal yield q^{*} substitution to the supplier's profit function, and the electricity price p_e of the first derivative is $\frac{\partial\Pi_S(p_e)}{\partial p_e}=\left[e_m\cdot q^{*}\left(p_e\right)-E_m\right]+\left(p_e-c_s\right)\cdot e_m\cdot\frac{\partial q^{*}(p_e)}{\partial p_e}$, due to the second derivative:

$\frac{\partial^2\Pi_S(p_e)}{\partial p_e^2}=2e_m\cdot\frac{\partial q^{*}(p_e)}{\partial p_e}+\left(p_e-c_s\right)\cdot e_m\cdot\frac{\partial^2 q^{*}(p_e)}{\partial p_e^2}$. Among them:

$$\begin{aligned}&\frac{\partial q^{*}(p_e)}{\partial p_e}=\frac{\partial q^{*}(p_e)}{\partial F(q^{*})}\cdot\frac{\partial F(q^{*})}{\partial p_e}=-\frac{e_m}{p\cdot f(q^{*})},\frac{\partial^2 q^{*}(p_e)}{\partial p_e^2}=-\frac{e_m}{p}\cdot\left[\frac{1}{f(q^{*})}\right]^{'}=-\frac{e_m}{p}\cdot\frac{-\partial f(q^{*})/\partial p_e}{f^2(q^{*})}\\ &=\frac{e_m}{p\cdot f^2(q^{*})}\cdot\frac{\partial f(q^{*})}{\partial F(q^{*})}\cdot\frac{\partial F(q^{*})}{\partial p_e}=-\frac{e_m}{p\cdot f^2(q^{*})}\cdot\frac{e_m}{p}\cdot\frac{\partial f(q^{*})/\partial q^{*}}{\partial F(q^{*})/\partial q^{*}}=-\frac{e_m^2}{p^2\cdot f^2(q^{*})}\cdot\frac{f^{'}(q^{*})}{f(q^{*})}\end{aligned}\tag{7}$$

put function (7) into $\frac{\partial^2\Pi_S(p_e)}{\partial p_e^2}$, it can be obtained that:

$$\frac{\partial^2\Pi_S\left(p_e\right)}{\partial p_e^2}=-\frac{2e_m^2}{p\cdot f\left(q^{*}\right)}-\frac{e_m^2}{p}\cdot\left(p_e-c_s\right)\cdot\frac{1}{f^2\left(q^{*}\right)}\cdot\frac{e_m\cdot f^{'}\left(q^{*}\right)}{p\cdot f\left(q^{*}\right)}=-\frac{e_m^2}{p\cdot f\left(q^{*}\right)}\cdot\left[2+\frac{\left(p_e-c_s\right)\cdot e_m\cdot f^{'}\left(q\right.}{p\cdot f^2\left(q^{*}\right)}\right.\tag{8}$$

Since $\frac{(p_e-c_s)\cdot e_m\cdot f^{'}(q^{*})}{p\cdot f^2(q^{*})}\geq-\frac{(p_e-c_s)\cdot e_m}{p}\cdot\frac{1}{[1-F(q^{*})]}=-\frac{(p_e-c_s)\cdot e_m}{p}\cdot\frac{p}{e_m\cdot p_e+c_m}>-1$

Therefore, $\frac{\partial^2\Pi_S(p_e)}{\partial p_e^2}<0$ is obtained. There exists the optimal p_e for the electricity supplier to achieve the best profit $\prod_s(p_e)$.Make $\frac{\partial\Pi_s(p_e)}{\partial p_e}=0$, it can be obtained that:

$$p_e^{*}=\frac{\left(e_m\cdot q^{*}-E_m\right)\cdot p\cdot f\left(q^{*}\right)}{e_m^2}+c_s\tag{9}$$

At this time, it can be get that $E_r^{*}=e_m\cdot F^{-1}\left(\frac{p-c_m-e_m\cdot p_e^{*}}{p}\right)-E_m$.

The optimal profits can be get respectively:

$$\Pi_M^{*}\left(q^{*}\right)=p\cdot S\left(q^{*}\right)-c_m\cdot q^{*}-p_e^{*}\cdot\left(e_m\cdot q^{*}-E_m\right)\tag{10}$$

$$\Pi_S^*\left(p_e^*\right)=\left(p_e^*-c_s\right)\cdot\left(e_m\cdot q^*-E_m\right) \tag{11}$$

4.2. The Relationship between Electric Energy and Regulation

By the optimal value (p_e^*,q^*) of the expression, it can be seen that the optimal product quantity and the electric energy price are functions of the government's power limit E_m and the product's unit energy consumption e_m.On the part of Upper limit of government power E_m, the optimal value can be expressed as $p_e^*=p_e\left(E_m\right)$ and $q^*=q\left(E_m\right)$.

The first order derivative of the optimal output $q\left(E_m\right)$ pair to $q\left(E_m\right)$ is obtained:

$$\frac{\partial q\left(E_m\right)}{\partial E_m}=\frac{\partial q\left(E_m\right)}{\partial F\left(q\left(E_m\right)\right)}\cdot\frac{\partial F\left(q\left(E_m\right)\right)}{\partial E_m}=-\frac{e_m}{p\cdot f\left(q\left(E_m\right)\right)}\cdot\frac{\partial p_e\left(E_m\right)}{\partial E_m} \tag{12}$$

From formula (12), we can get the product output and power price is inversely proportional, that is $\frac{\partial q(E_m)}{\partial p_e(E_m)}=-\frac{e_m}{p\cdot f(q(E_m))}$. This conclusion will be used in the back analysis of marginal profit. Next, The relationship between the power price and the upper limit is required to be researched.

$$\begin{aligned}\frac{\partial p_e(E_m)}{\partial E_m}&=\frac{p}{e_m^2}\cdot\left\{\left[e_m\cdot\frac{\partial q(E_m)}{\partial E_m}-1\right]\cdot f\left(q\left(E_m\right)\right)+\left[e_m\cdot q\left(E_m\right)-E_m\right]\cdot\frac{\partial f(q(E_m))}{\partial E_m}\right\}\\&=\frac{p}{e_m^2}\cdot\left\{\left[e_m\cdot\frac{\partial q(E_m)}{\partial E_m}-1\right]\cdot f\left(q\left(E_m\right)\right)+\left[e_m\cdot q\left(E_m\right)-E_m\right]\cdot\frac{\partial f(q(E_m))}{\partial q(E_m)}\cdot\frac{\partial q(E_m)}{\partial E_m}\right\}\end{aligned} \tag{13}$$

Take the equation (11) into the equation (13), available:

$$\frac{\partial p_e\left(E_m\right)}{\partial E_m}=-\frac{p}{e_m}\cdot\frac{f^2\left(q\left(E_m\right)\right)}{2e_m\cdot f\left(q\left(E_m\right)\right)+\left[e_m\cdot q\left(E_m\right)-E_m\right]\cdot\frac{\partial f(q(E_m))}{\partial q(E_m)}} \tag{14}$$

Substituting the equation (12) into the equation (14), we can get:

$$\frac{\partial q\left(E_m\right)}{\partial E_m}=\frac{f\left(q\left(E_m\right)\right)}{2e_m\cdot f\left(q\left(E_m\right)\right)+\left[e_m\cdot q\left(E_m\right)-E_m\right]\cdot\frac{\partial f(q(E_m))}{\partial q(E_m)}} \tag{15}$$

Substituting the equation (15) into the equation (13), we can get:

$$\begin{aligned}\Theta\left(q\left(E_m\right)\right)&=2+\frac{e_m\cdot[p_e(E_m)-c_s]}{p}\cdot\frac{\partial f(q(E_m))/\partial q(E_m)}{f^2(q(E_m))}>2+\frac{e_m\cdot[p_e(E_m)-c_s]}{p}\cdot\left[-\frac{1}{1-F(q(E_m))}\right]\\&=2-\frac{e_m\cdot[p_e(E_m)-c_s]}{p}\cdot\frac{p}{e_m\cdot p_e(E_m)+c_m}>0\end{aligned} \tag{16}$$

Take the equation (16) into the equation (15), available:

$$\frac{\partial p_e\left(E_m\right)}{\partial E_m}=-\frac{\partial q\left(E_m\right)}{\partial E_m}\cdot\frac{p\cdot f\left(q\left(E_m\right)\right)}{e_m}=-\frac{p\cdot f\left(q\left(E_m\right)\right)}{e_m^2}\cdot\frac{1}{\Theta\left(q\left(E_m\right)\right)}<0 \tag{17}$$

It can be seen that in the obtained optimal values of variables $\left(p_e\left(E_m\right),q\left(E_m\right)\right)$, optimal production $q(E_m)$ is positively related to government power limit E_m,and its correlation coefficient is $\gamma_{q,E_m} = \frac{1}{e_m} \cdot \frac{1}{\Theta(q(E_m))}$. In addition, from the formula (16), it can also be seen that the output of the product γ_{q,E_m} is less than the upper limit of the government power $\frac{1}{e_m}$, and the absolute value of the price of the power $|\gamma_{p_e,E_m}|$ is less than that of the upper limit of the government power$\frac{p\cdot f(q(E_m))}{e_m^2}$.

In the same way, the optimal value (p_e^*,q^*) can be expressed as a function of the electric energy of the unit product e_m, that is $p_e^* = p_e(e_m)$ and then the first derivative is obtained:

$$\frac{\partial q(e_m)}{\partial e_m} = \frac{\partial q(e_m)}{\partial F(q(e_m))} \cdot \frac{\partial F(q(e_m))}{\partial e_m} = -\frac{1}{p \cdot f(q(e_m))} \cdot \left[p_e(e_m) + e_m \cdot \frac{\partial p_e(e_m)}{\partial e_m}\right] \tag{18}$$

Because

$$\begin{aligned}\frac{\partial p_e(e_m)}{\partial e_m} &= \frac{p}{e_m^2} \cdot \left\{\left[q(e_m) + e_m \cdot \frac{\partial q(e_m)}{\partial e_m}\right] \cdot f(q(e_m)) + [e_m \cdot q(e_m) - E_m] \cdot \frac{\partial f(q(e_m))}{\partial e_m}\right\}\\ &= \frac{p}{e_m^2} \cdot \left\{\left[q(e_m) + e_m \cdot \frac{\partial q(e_m)}{\partial e_m}\right] \cdot f(q(e_m)) + [e_m \cdot q(e_m) - E_m] \cdot \frac{\partial f(q(e_m))}{\partial q(e_m)} \cdot \frac{\partial q(e_m)}{\partial e_m}\right\}\end{aligned}, \tag{19}$$

take the equation (18) into the equation (19), available:

$$\frac{\partial p_e(e_m)}{\partial e_m} = \frac{\frac{p}{e_m^2} \cdot f(q(e_m)) \cdot q(e_m) - \left\{1 + \left[q(e_m) - \frac{E_m}{e_m}\right] \cdot \frac{f'(q(e_m))}{f(q(e_m))}\right\} \cdot \frac{p_e(e_m)}{e_m}}{2 + \left[q(e_m) - \frac{E_m}{e_m}\right] \cdot \frac{f'(q(e_m))}{f(q(e_m))}} \tag{20}$$

As for $\frac{\frac{p}{e_m^2}\cdot f(q(e_m))\cdot q(e_m)}{2+\left[q(e_m)-\frac{E_m}{e_m}\right]\cdot\frac{f'(q(e_m))}{f(q(e_m))}} > \frac{p_e(e_m)}{e_m}$ and $1+\left[q(e_m) - \frac{E_m}{e_m}\right]\cdot\frac{f'(q(e_m))}{f(q(e_m))} < 2+\left[q(e_m) - \frac{E_m}{e_m}\right]\cdot \frac{f'(q(e_m))}{f(q(e_m))}$, therefore, $\frac{\partial p_e(e_m)}{\partial e_m}>0$ are obtained. This shows that the electricity price p_e and the unit product power e_m can be positively correlated. Again by formula $\frac{\partial q(e_m)}{\partial e_m}<0$(18) can be known:. That the output q and the unit product energy e_m is negatively correlated.

In addition, as a result of $\frac{\frac{p}{e_m^2}\cdot f(q(e_m))\cdot q(e_m)-\left\{1+\left[q(e_m)-\frac{E_m}{e_m}\right]\cdot\frac{f'(q(e_m))}{f(q(e_m))}\right\}\cdot\frac{p_e(e_m)}{e_m}}{2+\left[q(e_m)-\frac{E_m}{e_m}\right]\cdot\frac{f'(q(e_m))}{f(q(e_m))}} > \frac{p_e(e_m)}{e_m}$, that is $\frac{\partial p_e(e_m)}{\partial e_m} > \frac{p_e(e_m)}{e_m}$, the power price with the unit product energy change rate γ_{p_e,e_m} is greater than $\frac{p_e(e_m)}{e_m}$. By the same way, the product output with the unit product energy change rate of absolute value γ_{q,e_m} is greater than $\frac{2p_e(e_m)}{p\cdot f(q(e_m))}$.

Two main body's relationship between profits' value and government power limit E_m and unit electricity consumption $e_m$are analyzed. First of all, taking the two main profit function $\Pi_M^*(q^*)$,$\Pi_S^*(p_e^*)$ as a function of the government power limit E_m, they can be written separately:

$$\Pi_M(q(E_m)) = p \cdot S(q(E_m)) - c_m \cdot q(E_m) - p_e(E_m) \cdot [e_m \cdot q(E_m) - E_m] \tag{21}$$

Next, the first derivative E_m of the power supplier's profit function is obtained:

$$\Pi_S\left(p_e\left(E_m\right)\right)=\left[p_e\left(E_m\right)-c_s\right]\cdot\left[e_m\cdot q\left(E_m\right)-E_m\right] \tag{22}$$

We can easily get that:

$$\frac{\partial\Pi_S\left(p_e\left(E_m\right)\right)}{\partial E_m}=\frac{p\cdot f\left(q\left(E_m\right)\right)}{e}\cdot\left[e_m\cdot q\left(E_m\right)-E_m\right]\cdot\left[e_m\cdot\frac{\partial q\left(E_m\right)}{\partial E_m}-2\right] \tag{23}$$

As the front $0<\frac{\partial q(E_m)}{\partial E_m}<\frac{1}{e_m}$, $\frac{\partial\Pi_s(p_e(E_m))}{\partial E_m}<0$ has been proved, so can be obtained. This shows that the optimal profit of the manufacturer $\Pi_M\left(E_m\right)$ is positively correlated with the upper limit of the government power E_m, while the optimal profit of the retailer $\Pi_S\left(E_m\right)$ is negatively related to the upper limit of the government power E_m.

In the same way, the profit function of the two subject $\Pi_M^*\left(q^*\right)$,$\Pi_S^*\left(p_e^*\right)$ is regarded as a function of the power consumption of the unit product e_m, and the first order derivative of the manufacturer's profit function e_m is obtained:

$$\frac{\partial\Pi_M\left(q\left(e_m\right)\right)}{\partial e_m}=-\frac{\partial p_c\left(e_m\right)}{\partial e_m}\cdot\left[e_m\cdot q\left(e_m\right)-E_m\right]-p_e\left(e_m\right)\cdot q\left(e_m\right) \tag{24}$$

Because $\frac{\partial p_e(e_m)}{\partial e_m}>\frac{p_e(e_m)}{e_m}$, so it can be obtained that:

$$\begin{aligned}&\tfrac{\partial\Pi_M(q(e_m))}{\partial e_m}=-\tfrac{\partial p_e(e_m)}{\partial e_m}\cdot\left[e_m\cdot q\left(e_m\right)-E_m\right]-p_e\left(e_m\right)\cdot q\left(e_m\right)<-\tfrac{p_e(e_m)}{e_m}\cdot\left[e_m\cdot q\left(e_m\right)-E_m\right]-p_e\left(\right.\\&=p_e\left(e_m\right)\left[\tfrac{E_m}{e_m}-2q\left(e_m\right)\right]<0\end{aligned} \tag{25}$$

In the same way, the first derivative of the power supply e_m can be obtained from the power supplier's profit function $\Pi_S\left(p_c\left(e_m\right)\right)$, so we can get function (26).

$$\begin{aligned}&\tfrac{\partial\Pi_S(p_e(e_m))}{\partial e_m}=e_m\cdot\left\{\left[q\left(e_m\right)-\tfrac{E_m}{e_m}\right]-\tfrac{[p_e(e_m)-c_s]\cdot e_m}{p\cdot f(q(e_m))}\right\}\cdot\tfrac{\partial p_e(e_m)}{\partial e_m}\\&+\left[p_e\left(e_m\right)-c_s\right]\cdot q\left(e_m\right)-\tfrac{[p_e(e_m)-c_s]\cdot e_m}{p\cdot f(q(e_m))}\cdot p_e\left(e_m\right)\end{aligned} \tag{26}$$

As a result of $p_e\left(e_m\right)-c_s=\frac{(e_m\cdot q(e_m)-E_m)\cdot p\cdot f(q(e_m))}{e_m^2}$, so after simplification we can get $\frac{\partial\Pi_S(p_e(e_m))}{\partial e_m}=\left[q\left(e_m\right)-\frac{E_m}{e_m}\right]\cdot\left\{\frac{p\cdot q(e_m)\cdot f(q(e_m))}{e_m}-p_e\left(e_m\right)\right\}$(27)

Because $p\cdot q\left(e_m\right)\cdot f\left(q\left(e_m\right)\right)>e_m\cdot p_e\left(e_m\right)$, so $\frac{\partial\Pi_S(p_e(e_m))}{\partial e_m}>0$.

5. Numerical Analysis

The verification process assumes that random variables ε are uniformly distributed in the interval [0,100]. So its distribution and probability density functions are $F\left(\varepsilon\right)=\frac{\varepsilon}{100}$,$f\left(\varepsilon\right)=\frac{1}{100}$ respectively, and then $h'\left(\varepsilon\right)=\frac{f'(\varepsilon)\cdot[1-F(\varepsilon)]+f^2(\varepsilon)}{[1-F(\varepsilon)]^2}>0$, it is conditions for satisfying Generalized Incremental Failure Rate Function. In addition, the retail price of the product is $p = 80$; the product unit power consumption is $g_m = 1$; the production cost of the product and the operating cost of the energy supplier is $c_m = 20, c_s = 10$. Therefore, under centralized decision-making, the optimal output quantity of the supply chain supply is $q_c^* = F^{-1}\left(\frac{80-10-1\times10}{80}\right) = 190$. Thereby the electricity limit set by the government is$G_m \in \left(0{,}g_m \cdot F^{-1}\left(\frac{p-c_m-g_m \cdot c_s}{p}\right)\right) =$ (0,285), while the actual power limit is$G_m = 120<G_m^+ = 285$, The optimum yield and electricity price are obtained by the above-mentioned solution that $\left(q^*{,}p_g^*\right) =$ (135,23.685).

Table 1 lists the upper limit when the power is selected by $G_m \in (0{,}200)$, and when the step size is gradually increased by 10(As the length of the table is longer, so only part of the data is intercepted, it is still able to explain the relationship between the variables), Optimal yield q^*, Optimal price p_g^*, The best profit and manufacturers bargaining power and other values are abtained. The above conclusions are consistent with the analysis of Part 4 of the article.

Table 1. Optimal production, electricity price and profit statistics of each subject

Serial number	Power cap	Optimal yield	Optimal price	Manufacturer Best profit	Power supplier Best profit	Supply chain Total profit	Manufacturers bargain Bargaining power
1	0	85.579	34.388	3091.982	3918.921	7010.903	0.441025
2	10	88.127	33.855	3590.192	3865.902	7456.094	0.481511
3	20	91.167	32.453	3989.920	3567.622	7557.542	0.527939
4	30	94.767	31.389	4490.921	3123.833	7614.754	0.589766
5	40	97.123	30.892	4800.820	2799.811	7600.631	0.631634
6	50	100.643	29.569	5290.102	2438.920	7729.022	0.684446
7	60	104.112	28.124	5689.832	2101.921	7791.753	0.730238
8	70	106.453	27.323	5904.321	1834.283	7738.604	0.76297
9	80	108.357	26.653	6242.678	1532.263	7774.941	0.802923
10	90	111.212	25.324	6548.578	1218.281	7766.859	0.843144

In addition, G_m/g_m can be seen as the government's distribution to the manufacturer, At this point the analysis process g_m and the analysis of the process G_m is just the opposite. Because the analysis of the principles and processes are the same, the analysis of $g_m$is not required to be repeated.

6. Concluding Remarks

The optimal decision-making problem of the supply chain system composed of a power supplier and its downstream product manufacturer from the points of government's electricity regulation and the market electricity transaction was studied in this paper. It is concluded that the profit of the two main bodies can be increased by the government's electricity regulation. With the helps of the upper limit of electricity reasonably set by the government and the power consumption of the product eectively controlled by the manufacturer, the main two bodies can reach to the optimum status. The results can provide a reference for the large manufacturing enterprises that are regulated by the government to make informed decisions in the conduct of electricity transactions and to set reasonable budgets for the government.

References

[1] B. Thi, P. Thao, M. Kasemsan: *Development ofan inventoryand temporal allocation profiles of emission from power plants and industrial facilities in Thailand.* Science ofthe Total Environment, *397* (2008), Nos. 1–3, 103–118.

[2] L. Li, Z. F. Tan, N. Li, J. Wang, Y. Hou: *Comparative study on several distribution modes of power generation emission rights.* East ChiElectric Power *38* (2010), No. 11, 1789–1792.

[3] X. D. Song, J. Mo, T. Y. Xiang: *Fundamental frequency of vibrating rectangular, non-homogeneous plates.* Electric PowerAutomation Equipment, *33* (2013), No. 1, 44–49.

[4] T. H. Mei, J. Xie, D. Q. Gan: *A study on incorporating multiple equity principles of power carbon emission allowan cesallocation based on claims.* Power System Technology *40* (2016), No. 2, 419–424.

[5] X. Zhou, J. Geoff, L. Ariel, Y. D. Zhao, Z. Carla: *Partial carbon permits allocation of potential emission trading scheme in Australian electricity market.* IEEE Transactions on Power Systems *25* (2010), No. 1, 543–553.

[6] Lewin, Y. Arie, V. Couto: *Next Generation Offshoring: The Globalization of Innovation.* Offshoring Research Network. March 2007 .

[7] J. C. Liu: *Research on BIC construction and collaborative decision making in power supply chain alliance.* doctoral dissertation of North China Electric Power University, 2013 .

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