ISSN: 2692-7608 DOI: 10.6981/FEM.202305_4(5).0026

Analysis of a Dual-channel Supply Chain Pricing Strategy Considering Technological Innovation under Carbon Trading

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Abstract

The thesis discusses two types of product pricing scenarios, in which the manufacturer bears the cost of carbon reduction by improving its own carbon reduction technology, and transfers the cost of carbon reduction to retailers and consumers through price increases. The study also compares the benefits to the manufacturer, the retailer and the supply chain as a whole, and concludes that the overall benefits to the supply chain are higher in the form of the manufacturer's own carbon reduction technology, which bears the costs of carbon reduction, than in the form of price increases.

Keywords

Carbon Emissions; Supply Chains; Dual Channels; Starkberg Games; Technological Innovation.

1. Introduction

In order to cope with the pollution and excessive carbon dioxide emissions brought about by economic development, China has been actively promoting the green transformation of its economy and continuously raising the intensity of action against climate change on its own. The two allocation methods of the paid model include auction and fixed-price sale to determine the allocation of carbon allowances respectively. The non-remunerated model consists of a "grandfathered approach" based on historical levels and a "benchmark approach" based on standard emission rates.

Either carbon allowance allocation model will have an impact on the more energy-consuming and polluting manufacturing companies, and will force them to bear the cost of carbon emissions from their production processes. Manufacturing companies in the supply chain will be faced with the choice of upgrading their energy-efficient and emission-reducing technologies, or increasing the wholesale price of their products to pass on the cost of carbon emissions to downstream retailers or consumers. These two different strategies by manufacturers will also have inevitable impacts on midstream retailers and downstream consumers in the supply chain, as well as different transmission effects and impacts on the benefits to manufacturers, retailers and the supply chain as a whole.

2. Current Status and Review of Research

In terms of decision problems in dual-channel supply chains, Dumrong siri et al. (2008) study the decision making in dual-channel supply chains regarding issues related to manufacturer's pricing, and retailer's ordering.[1]Huang et al. use game theory to study the cooperative advertising model in the context of a single supply chain consisting of a manufacturer, and a retailer, and give suggestions on the cooperative advertising strategy that the manufacturer and retailer should adopt in the The study also gives suggestions on the cooperative advertising strategies that manufacturers and retailers should adopt in the corresponding context.[2] Xie et al. (2009) study the optimal decision of distribution channels in the context of advertising

ISSN: 2692-7608 DOI: 10.6981/FEM.202305_4(5).0026

costs and different prices in market distribution. They conclude that players in the market should cooperate to increase their overall returns.[3] Tsay and Agrawal et al. study the hypothesis of prices in different channels and find that adjusting prices allows all participating players to gain more in the market than they would otherwise.[4] Kurata et al. investigate the use of price mechanisms in a competitive market to make network distribution, traditional distribution under price intervention The price mechanism was used to achieve a balance between network distribution, traditional distribution and price intervention.[5]

In the dual-channel supply chain pricing problem, production decision problem, Xiao Jian, Dan Bin et al. (2009) considered whether the manufacturer cooperates with the retailer in the electronic channel and leaves all orders in the electronic channel to the retailer for revenue sharing, the study and analysis showed that the demand for the electronic channel is not affected by whether the retailer cooperates or not. The research and analysis concluded that demand for the electronic channel is not affected by whether retailers cooperate or not and examined the wholesale price when the electronic channel is independent of the retailer and the retailer's decision. When the electronic channel is independent of the retailer, the effect of wholesale price and the manufacturer's share of the electronic channel revenue on cooperation was examined using arithmetic simulations.[6]Milyuan Shan, Chao Liu et al. (2016) and others argue that external subsidies can create financial incentives for market participants to engage in research and technology development, leading to a win-win situation for all market participants.[7]Yue Liuqing, Liu Yongmei et al. (2016), used a differential game approach to analyse and compare the optimal decisions of two parties in a retailer-managed dual-channel fresh produce supply chain under a wholesale price contract and a revenue sharing contract.[8]

In a study of supply chain emissions reduction in the context of carbon trading, Ji et al. explored the comparison of individual and joint energy saving and low carbon reduction strategies of supply chain members, taking into account consumer preferences, and found that joint reduction strategies were beneficial to supply chain members.[9]Jiang Shiying,Li Suicheng (2015) considered the difficulty of carbon reduction strategies for the whole supply chain under a cap-and-trade system, which lies in modelling and quantifying the optimal reduction plan for supply chain carbon reduction. And a supply chain decarbonization strategy model is established, where the core enterprises coordinate with other enterprises in the supply chain to develop the optimal supply chain emission reduction plan and achieve the supply chain emission reduction target by optimizing the allocation of carbon emission rights in the supply chain.[10]Yang Lei and Zhang Qin (2017) hypothesized that the more free CO2 quotas allocated by the government, the greater the incentive for producers to actively reduce emissions. In administrative practice, producers and retailers can benefit together by giving consumers access to greener products, mainly because by reducing emissions, companies can sell the amount of CO2 saved through the emissions trading market and thus make a profit, and producers are thus motivated to reduce emissions.[11]Sun, Jia-Nan and Xiao, Zhong-Dong (2018) argue that manufacturers can reduce the cost of reducing emissions by upgrading low-carbon technologies and adopting low-carbon management, while increasing consumer recognition of low-carbon products through low-carbon certification and advertising.[12]Liang Xi and Zhang Yu Ting (2020) argue that manufacturers' optimal unit reductions can be effectively increased when they introduce direct online sales and distribution channels; traditional retailers' profits always decrease when new channels are opened, while manufacturers' profits increase when consumer preferences for online sales channels are within a certain range.[13]Weiyue Zhang and Chenguang Liu (2021) argue that in a supply chain game, companies at the top of the supply chain take on more reductions and assume greater responsibility and commitment to reduce emissions than those at the back.[14]Wang Yilei, Xia Xiqiang (2021) argue that implementing an emissions trading policy based on historical data on firms' carbon emissions can improve the carbon reduction levels of

ISSN: 2692-7608 DOI: 10.6981/FEM.202305_4(5).0026

manufacturers' products and retailers' promotion of low emissions in the long term without emissions trading, while increasing the final goodwill of products and retailers' profits.[15]Wu Jiang (2021) developed a centralised and decentralised decision game model to create a two-level coordination contract to promote cooperation between manufacturers and retailers. The study concludes that the environmental performance of the product, sales through the distribution channel and profitability of the entire supply chain are higher with centralised than decentralised decision making. An effective two-level coordination contract facilitates the sale of green products in the marketplace and increases the profitability of both manufacturers and retailers.[16]

At this stage, research on dual-channel supply chains under carbon quotas is focused on three aspects: First, the government's research on innovative subsidies for dual-channel supply chain subjects under carbon emission reduction. Second, research on the supply chain emission reduction strategies under the low carbon preference of consumers. Third, a study of carbon emission reduction and sales channels in dual-channel supply chains under carbon trading policies, discussing the opening of new sales channels under carbon trading and the profit analysis of each participant and the overall supply chain. This paper considers the impact of the market demand for a firm's goods in the context of trading carbon credits, which is influenced by the cost of carbon trading and the pricing of that good. The impact of different pricing strategies chosen by wholesalers on the earnings of retailers downstream in the supply chain and on the total earnings of the supply chain is explored in the context of the two strategies chosen by manufacturer firms to bear the cost of carbon trading on their own through the development of low carbon emission reduction technologies and the choice to transfer the cost of carbon trading directly to consumers.

3. Description of the Problem

The supply chain in this paper refers to a two-tier supply chain, and these two tiers consist of manufacturers and suppliers respectively. In the supply chain, the retailer dominates the wholesale price bargaining and the supplier dominates the wholesale price pricing decision.

In the manufacturer to upgrade energy-saving and emission reduction technology to bear the cost of carbon emissions, in which the manufacturer to supply products to retailers at the price of w, retailers have two channels, e-commerce channels, traditional channels, respectively, at the price of Pe and Pt for the sale of goods, customers use the price of different channels as a decision-making criterion for the choice of purchase channel.

When the manufacturer raises the wholesale price to bear the cost of carbon emissions, the manufacturer supplies the downstream retailer at a price of w+t, where t is the unit cost of carbon emissions, i.e. the cost of carbon emissions paid to produce a unit of product. Retailers have two channels, the e-commerce channel and the traditional channel, to sell goods at Pe+t and Pt+t respectively, and customers use the prices of the different channels as a decision criterion for their choice of purchase channel.

4. Model Construction and Parameter Setting

4.1. Model Assumptions

In scenario (i) where the manufacturer bears the cost of carbon emissions, the linear demand functions for consumers offline and online are: $Dt := 1\text{-}Pt+\theta*Pe$, $De := 1\text{-}Pe+\theta*Pt$ respectively. where 1 denotes the meaning of the potential market size for online and offline respectively. θ is the cross-price elasticity coefficient of the offline and online channels, which indicates that when the online price is higher than the offline price, $\theta*Pt$ of customers buy the product through the traditional offline channel. The converse is also true.

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Assume that the retailer's unit cost of sales is 0, the manufacturer's unit cost of production is c, and the manufacturer's unit cost of carbon emissions is t. The manufacturer can reduce the unit cost of carbon emissions by developing energy-efficient and emission-reducing technologies. Assume that the manufacturer invests t2 in developing energy-efficient and emission-reducing technologies to reduce the cost of carbon emissions per unit of product λt . Where, note u = 1- λ . and λ < c.

Manufacturer profit function: $\Pi\mathrm{m} = (w - c - t + \lambda t)(1 + \theta w - w) - t^2$

Retailer profit function: $\Pi r = (Pt - w)Dt + (Pe - w)De$

Total supply chain profit: $\Pi = \Pi m + \Pi r$

In scenario (ii) where the manufacturer increases prices to pass on the cost of carbon emissions to the user, the linear demand functions for consumers offline and online are: $\mathrm{Dt} = 1\text{-}(\mathrm{Pt}+\mathrm{t})+\theta^*(\mathrm{Pe}+\mathrm{t})$, $\mathrm{De} = 1\text{-}(\mathrm{Pe}+\mathrm{t})+\theta^*(\mathrm{Pt}+\mathrm{t})$ respectively. where 1 denotes the potential market size for online and offline respectively. $\theta$is the cross-price elasticity coefficient of the offline and online channels, which indicates that when the online price is higher than the offline price, $\theta^*(\mathrm{Pt}+\mathrm{t})$ of customers buy the product through the traditional offline channel. The converse is also true.

Table 1. Relevant symbols and meanings

Symbols	Significance
Dt /De	Dt represents the consumer demand function for the traditional channel De represents the consumer demand function for the online channel
Pt /Pe	Pt represents the retail price in the traditional channel Pe represents the retail price in the online channel
θ (0< θ <1)	Cross-Channel Price Elasticity Factor
t	Cost of carbon emissions per unit of product for manufacturers
c	Manufacturer's production costs per unit of product
λ (0< λ <1 and λ <c) (note u=1- λ)	Manufacturers invest t2 in energy saving and emission reduction technologies to save t of carbon emissions per unit of product λ , the technology innovation factor.
w	Wholesale prices for manufacturer's products
$\prod_m$	Manufacturer benefits
$\prod_r$	Retailer revenue
$\prod$	Total supply chain revenue
*	Manufacturers make the most profit when

ISSN: 2692-7608 DOI: 10.6981/FEM.202305_4(5).0026

Assume that the retailer's unit cost of sales is 0, the manufacturer's unit cost of production is c, and the manufacturer's unit cost of carbon emissions is t. The manufacturer can reduce its unit cost of carbon emissions by increasing the price per unit of product by t from the original price per unit of product. The retailer also increases the price per unit of product online and offline by t correspondingly.

Manufacturer profit function: $\Pi m=(w-c+\lambda t)(1+\theta w-w)-t^2$

Retailer profit function: $\Pi r=(Pt-w)Dt+(Pe-w)De$

Total supply chain profit: $\Pi=\Pi m+\Pi r$

4.2. Model Analysis

Scenario (i) Manufacturer bears the cost of carbon emissions

The retailer dominates, and the manufacturer and retailer play a two-stage stackelberg game: the supplier first decides on the innovation input t, and then the retailer determines the wholesale price w, which is Pt and Pe for the traditional and electronic channels respectively. the manufacturer and retailer make their own decisions to maximise their respective profits.

The retailer's profit function is $\Pi r=(Pt-w)Dt+(Pe-w)De$, with separate derivatives for Pe and Pt. The retailer's profit is maximised when:

$$\text{Pe=Pt=}\frac{\theta w-w-1}{2(\theta-1)} \tag{1}$$

$$\text{Dt=De=}\frac{1}{2}+\frac{(\theta-1)w}{2} \tag{2}$$

So $\Pi_{m(t)}=(-tu-c+w)(\theta w-w+1)-t^2$, where the retailer determines w, and deriving for t yields the innovation input when the manufacturer's profit is maximized

$$t=\frac{-u(\theta w-w+1)}{2} \tag{3}$$

At this point the manufacturer's profit is

$$\prod_m=-\frac{(\theta w-w+1)\left(-\theta u^2 w+u^2 w-u^2+4c-4w\right)}{4}$$

(1) When the manufacturer's profit is zero, the retailer's bargain with the supplier is

$w=\dfrac{-u^2+4c}{\theta u^2-u^2+4}$, taking this into (1), (2) and (3) gives

$$\text{Pt=Pe=}\frac{(-u^2+2c)\theta+u^2-2c-2}{(\theta u^2-u+4)(\theta-1)}$$

$$\text{t=}-\frac{2(1+c(\theta-1))u}{4+u^2(\theta-1)}$$

At this point it is possible to obtain

$$\Pi r=-\frac{8(1+c(\theta-1))^2}{\left(\theta u^2-u^2+4\right)^2(\theta-1)}$$

$$\Pi m=0$$

(2) The wholesale price given by the retailer to the wholesaler when the manufacturer's profit is maximum is

$$\text{W=}\frac{(-u^2+2c)\theta+u^2-2c-2}{(\theta-1)(\theta u^2-u+4)}$$

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Substituting this into (1), (2) and (3) gives

$$Pt^* = Pe^* = \frac{(-u^2+c)\theta+u^2-c-3}{(\theta-1)(\theta u^2-u+4)}$$

$$t^* = -\frac{(1+c(\theta-1))u}{4+u^2(\theta-1)}$$

At this time

$$\prod\nolimits_m^* = -\frac{(1+c(\theta-1))^2}{\left((\lambda-1)^2\theta-\lambda^2+2\lambda+3\right)(\theta-1)}$$

$$\prod\nolimits_r^* = -\frac{2(1+c(\theta-1))^2}{\left((\lambda-1)^2\theta-\lambda^2+2\lambda+3\right)^2(\theta-1)}$$

Table 2. Optimal solutions for decision making under scenario (i)

Projects	Manufacturer retained profit of 0	Manufacturers retain maximum profit
t	$-\frac{2(1+c(\theta-1))u}{4+u^2(\theta-1)}$	$-\frac{(1+c(\theta-1))u}{4+u^2(\theta-1)}$
w	$\frac{-u^2+4c}{\theta u^2-u^2+4}$	$\frac{(-u^2+2c)\theta+u^2-2c-2}{(\theta-1)(\theta u^2-u+4)}$
Pt=Pe	$\frac{(-u^2+2c)\theta+u^2-2c-2}{(\theta u^2-u+4)(\theta-1)}$	$\frac{(-u^2+c)\theta+u^2-c-3}{(\theta-1)(\theta u^2-u+4)}$
$\prod_m$	0	$-\frac{(1+c(\theta-1))^2}{(\theta-1)\left(\theta u^2-u^2+4\right)}$
$\prod_r$	$-\frac{8(1+c(\theta-1))^2}{\left(\theta u^2-u^2+4\right)^2(\theta-1)}$	$-\frac{2(1+c(\theta-1))^2}{\left(\theta u^2-u^2+4\right)^2(\theta-1)}$
$\prod$	$-\frac{8(1+c(\theta-1))^2}{\left(\theta u^2-u^2+4\right)^2(\theta-1)}$	$-\frac{(1+c(\theta-1))^2}{(\theta-1)\left(\theta u^2-u^2+4\right)}$

Through Table 2, it can be seen that in the case of manufacturers bearing the cost of carbon emissions through the development of energy-saving and emission reduction technologies, $\prod_m < \prod_m^*$, t>t* , w < w* , $\prod_r > \prod_r^*$, t the cost of manufacturers' carbon emission reduction innovation technology decreases, $\prod > \prod^*$. That is, in the case where the manufacturer bears the cost of the firm's carbon emissions through the development of energy-efficient and emission-reducing technologies, in order to enhance corporate efficiency, the manufacturer can increase the wholesale price of the product w to w* , at which point the manufacturer's innovation cost decreases, the manufacturer's revenue increases, the retailer's revenue decreases, and the total supply chain revenue decreases.

Where u=1-λ , equivalence substitution of u in Table 1 gives Table 3.

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Table 3. Decision optimal solutions after substitution for u=1-λ under scenario (i)

Projects	Manufacturer retained profit of 0	Manufacturers retain maximum profit
t	$\frac{2(1+c(\theta-1))(-1+\lambda)}{(\theta-1)\lambda^2+(-2\theta+2)\lambda+\theta+3}$	$\frac{(1+c(\theta-1))(-1+\lambda)}{(\theta-1)\lambda^2+(-2\theta+2)\lambda+\theta+3}$
w	$\frac{-(1-\lambda)^2+4c}{\theta(1-\lambda)^2-(1-\lambda)^2+4}$	$\frac{(-\theta+1)\lambda^2+(2\theta-2)\lambda+(2c-1)\theta-2c-1}{(\theta-1)\lambda^2+((-2\theta+2)\lambda+\theta+3)(\theta-1)}$
Pt=Pe	$\frac{(-\theta+1)\lambda^2+(2\theta-2)\lambda+(2c-1)\theta-2c-1}{((\theta-1)\lambda^2+(-2\theta+2)\lambda+\theta+3)(\theta-1)}$	$\frac{(-\theta+1)\lambda^2+(2\theta-2)\lambda+(c-1)\theta-c-2}{(\theta-1)\lambda^2+((-2\theta+2)\lambda+\theta+3)(\theta-1)}$
$\prod_m$	0	$-\frac{(1+c(\theta-1))^2}{((\lambda-1)^2\theta-\lambda^2+2\lambda+3)(\theta-1)}$
$\prod_r$	$-\frac{8(1+c(\theta-1))^2}{(\theta(-1+\lambda)^2-\lambda^2+2\lambda+3)^2(\theta-1)}$	$-\frac{2(1+c(\theta-1))^2}{((\lambda-1)^2\theta-\lambda^2+2\lambda+3)^2(\theta-1)}$
$\prod$	$-\frac{8(1+c(\theta-1))^2}{(\theta(-1+\lambda)^2-\lambda^2+2\lambda+3)^2(\theta-1)}$	$-\frac{((\theta-1)\lambda^2+(-2\theta+2)\lambda+\theta+5)(c\theta-c+1)^2}{(\theta-1)((\theta-1)\lambda^2+(-2\theta+2)\lambda+\theta+3)^2}$

Scenario (2) Manufacturers pass on the cost of carbon emissions to consumers

The retailer is dominant and the manufacturer and retailer play a two-stage stackelberg game: the supplier now decides to pass on the cost of carbon emissions to the middle and lower reaches of the supply chain by increasing the unit product price t. The retailer also increases the unit product price by t in the traditional and electronic channels and the retailer sets the wholesale price w. The selling prices in the traditional and electronic channels are respectively The manufacturer and retailer make their own decisions to maximise their respective profits.

The retailer's profit function is $\Pi r=(Pt-w)Dt+(Pe-w)De$, and the retailer's profit maximised when derived for Pe and Pt respectively is

$$\text{Pe=Pt=}\frac{(-t+w)\theta+t-w-1}{2\theta-2} \tag{4}$$

$$\text{Dt=De=}\frac{(t+w)\theta}{2}-\frac{t}{2}-\frac{w}{2}+\frac{1}{2} \tag{5}$$

So

$$\prod_{m(t)}=(\lambda t-c+w)(\theta w-w+1)-t^2$$

With the retailer determining w, the innovation input to maximize the manufacturer's profit is obtained by deriving t

$$\text{t=}\frac{\lambda(\theta w-w+1)}{2} \tag{6}$$

The manufacturer's profit function at this point is

$$\Pi m=-\frac{(\theta w-w+1)(-\lambda^2\theta w+\lambda^2 w-\lambda^2+4c-4w)}{4}$$

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The following two scenarios are discussed

(1) The wholesale price given by the retailer to the supplier when $\prod_m$ retained profit is 0 is

W= $\frac{-\lambda^2+4c}{\lambda^2\theta-\lambda^2+4}$

Substituting this into (3), (4) and (5) gives

Pt=Pe= $\frac{(1-\theta)\lambda^2-(\theta-1)(c\theta-c+1)\lambda+2c\theta-2c-2}{(4+(\theta-1)\lambda^2)(\theta-1)}$

t= $\frac{2(1+(\theta-1)c)\lambda}{4+(\theta-1)\lambda^2}$

At this time

$$\Pi r = -\frac{2\,(c\,\theta-c+1)^2\,(2+(\theta-1)\,\lambda)^2}{\left(4+(\theta-1)\,\lambda^2\right)^2\,(\theta-1)}$$

$$\prod_m = 0$$

(2) When $\prod_m$ profit is maximum, the retailer gives the supplier a wholesale price of

w* = $\frac{(-\theta+1)\lambda^2+2c\theta-2c-2}{(\theta-1)(4+(\theta-1)\lambda^2)}$

Pe* =Pt =* $\frac{-(\theta-1)(t\theta-t+2)\lambda^2+(2c-4t)\theta-2c+4t-6}{2(4+(\theta-1)\lambda^2)(\theta-1)}$

t = * $\frac{\lambda(1+(\theta-1)c)}{4+(\theta-1)\lambda^2}$

At this time

$$\prod_m^* = -\frac{(1+(\theta-1)\,c)^2}{(\theta-1)\left(4+(\theta-1)\,\lambda^2\right)}$$

$$\prod_r^* = -\frac{(2+(\theta-1)\,\lambda)^2\,(c\,\theta-c+1)^2}{2\,(\theta-1)\left(4+(\theta-1)\,\lambda^2\right)^2}$$

Through Table 4, it can be seen that in the case where the manufacturer passes on the cost of carbon emissions to the consumer, $\prod_m < \prod_m^*$, t>t* , $\prod_r > \prod_r^*$, t the cost of the manufacturer's carbon reduction innovation technology decreases, $\prod < \prod^*$. That is, in the case where the manufacturer is responsible for carbon emissions, the wholesale price per unit w+t can be increased in order to reduce the production burden on the firm, at which point the firm's innovation costs are reduced, the manufacturer's revenue increases, the retailer's revenue decreases and the total supply chain revenue increases.

For a comparison of the manufacturer's profit function in the two scenarios where the manufacturer's retained profit is maximised, note that the manufacturer's retained profit function for scenario 1, where the manufacturer bears the cost of carbon emissions, is $\prod_{m1} = -\frac{\left(1+c(\theta-1)\right)^2}{\left((\lambda-1)^2\theta-\lambda^2+2\lambda+3\right)(\theta-1)}$, and note that the manufacturer's retained profit function for scenario 2, where the cost of carbon emissions is passed on to consumers, is

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$\prod_{m2}=-\frac{\left(1+(\theta-1)c\right)^2}{(\theta-1)\left(4+(\theta-1)\lambda^2\right)}$, such that $\prod_m=\prod_{m1}-\prod_{m2}$, is calculated to give the following result:

Table 4. Optimal solutions under scenario (ii)

Projects	Manufacturer retained profit of 0	Manufacturers retain maximum profit
t	$\frac{2(1+(\theta-1)c)\lambda}{4+(\theta-1)\lambda^2}$	$\frac{\lambda(1+(\theta-1)c)}{4+(\theta-1)\lambda^2}$
w	$\frac{-\lambda^2+4c}{\lambda^2\theta-\lambda^2+4}$	$\frac{(-\theta+1)\lambda^2+2c\theta-2c-2}{(\theta-1)(4+(\theta-1)\lambda^2)}$
Pe=Pt	$\frac{(1-\theta)\lambda^2-(\theta-1)(c\theta-c+1)\lambda+2c\theta-2c-2}{(4+(\theta-1)\lambda^2)(\theta-1)}$	$\frac{-(\theta-1)(t\theta-t+2)\lambda^2+(2c-4t)\theta-2c+4t-6}{2(4+(\theta-1)\lambda^2)(\theta-1)}$
$\prod_m$	0	$-\frac{(1+(\theta-1)c)^2}{(\theta-1)\left(4+(\theta-1)\lambda^2\right)}$
$\prod_r$	$-\frac{2(c\theta-c+1)^2(2+(\theta-1)\lambda)^2}{\left(4+(\theta-1)\lambda^2\right)^2(\theta-1)}$	$-\frac{(2+(\theta-1)\lambda)^2(c\theta-c+1)^2}{2(\theta-1)\left(4+(\theta-1)\lambda^2\right)^2}$
$\prod$ *	$-\frac{2(c\theta-c+1)^2(2+(\theta-1)\lambda)^2}{\left(4+(\theta-1)\lambda^2\right)^2(\theta-1)}$	$-\frac{(c\theta-c+1)^2\left(12+(\theta^2-1)\lambda^2+(4\theta-4)\lambda\right)}{2(\theta-1)\left(4+(\theta-1)\lambda^2\right)^2}$

$\Pi=\frac{(2\lambda-1)(c\theta-c+1)^2}{((\theta-1)\lambda^2+(-2\theta+2)\lambda+\theta+3)(4+(\theta-1)\lambda^2)}$ The comparison of the manufacturer's profit function when the manufacturer's retained profit is maximised in the first and second scenarios depends mainly on $2\lambda-1$. When $\lambda>\frac{1}{2}$, Π > 0, i.e. at this point the manufacturer is making more retained profit by bearing the cost of carbon emissions than by transferring the cost of carbon emissions to the consumer. When $<\lambda\ \frac{1}{2}$, it means that at this point the manufacturer is making more retained profit by passing on the cost of carbon emissions to the consumer than it is by passing on the cost of carbon emissions to the manufacturer.

A comparison of the retailer's profit function when the manufacturer's retained profit is maximised in both scenarios, note that the retailer's retained profit function when the cost of carbon emissions is passed on to the consumer in Scenario 2 is $\prod_{r2}=-\frac{\left(2+(\theta-1)\lambda\right)^2(c\theta-c+1)^2}{2(\theta-1)\left(4+(\theta-1)\lambda^2\right)^2}$, note that the retailer's retained profit function when the manufacturer bears the cost of carbon emissions in Scenario 1 is

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$\prod_{r1}=-\frac{2\left(1+c\left(\theta-1\right)\right)^{2}}{\left(\left(\lambda-1\right)^{2}\theta-\lambda^{2}+2\lambda+3\right)^{2}\left(\theta-1\right)}$, and let $\prod_{r}=\prod_{r2}-\prod_{r1}$ be calculated to give the following result:

$\prod_{r}=-\frac{\left(2+(\theta-1)\lambda^{3}+(-2\theta+2)\lambda^{2}+(\theta-1)\lambda\right)(c\theta-c+1)^{2}\left((\theta-1)^{2}\lambda^{3}+\left(-2\theta^{2}+8\theta-6\right)\lambda^{2}+(\theta-1)^{2}\lambda+2\theta+14\right)}{2\left((\theta-1)\lambda^{2}+(-2\theta+2)\lambda+\theta+3\right)^{2}\left(4+(\theta-1)\lambda^{2}\right)^{2}}$ In the first and second scenarios, the retailer's profit function is compared when the manufacturer retains the largest profit. The denominator of the fraction is clearly greater than 0, and $\left(2+\left(\theta-1\right)\lambda^{3}+\left(-2\theta+2\right)\lambda^{2}+\left(\theta-1\right)\lambda\right)$ squares it completely to be greater than 0. $\left(-2\theta^{2}+8\theta-6\right)+14$ is clearly positive under $0<\theta<1$, and all other terms are > 0. But because the overall sign is negative, $\prod_{r2}$ is clearly smaller than . $\prod_{r1}$

A comparison of the total supply chain profit function for two scenarios where the manufacturer's retained profit is zero. Denote the total supply chain profit function as $\prod_{2}=-\frac{2\left(c\theta-c+1\right)^{2}\left(2+\left(\theta-1\right)\lambda\right)^{2}}{\left(4+\left(\theta-1\right)\lambda^{2}\right)^{2}\left(\theta-1\right)}$ for scenario 2, where the manufacturer's retained profit is 0.

Denote the total supply chain profit function as $\prod_{1}=-\frac{8\left(1+c\left(\theta-1\right)\right)^{2}}{\left(\theta-1\right)\left(\left(-1+\lambda\right)^{2}\theta-\lambda^{2}+2\lambda+3\right)^{2}}$ for scenario 1, where the manufacturer's retained profit is 0. Denote $\prod=\prod_{2}-\prod_{1}$ and the following results will be obtained after calculation:

$\prod=-\frac{2(c\theta-c+1)^{2}\left(2+(\theta-1)\lambda^{3}+(-2\theta+2)\lambda^{2}+(\theta-1)\lambda\right)\left((\theta-1)^{2}\lambda^{3}+\left(-2\theta^{2}+8\theta-6\right)\lambda^{2}+(\theta-1)^{2}\lambda+2\theta+14\right)}{\left((\theta-1)\lambda^{2}+(-2\theta+2)\lambda+\theta+3\right)^{2}\left(4+(\theta-1)\lambda^{2}\right)^{2}}$ At this point it is easy to see that the denominator is greater than zero, as calculated by $\prod=(\prod_{2}-\prod_{1})<0$, which means that the total supply chain profit under scenario two is lower than the total supply chain profit under scenario one when the manufacturer's retained profit is zero under scenarios one and two.

A comparison of the total supply chain profit function when the manufacturer's retained profit is maximized in two scenarios. In Scenario 2, the total supply chain profit function is $\prod_{2}=-\frac{\left(12+\left(\theta^{2}-1\right)\lambda^{2}+\left(4\theta-4\right)\lambda\right)\left(c\theta-c+1\right)^{2}}{2\left(\theta-1\right)\left(4+\left(\theta-1\right)\lambda^{2}\right)^{2}}$ when the manufacturer's retained profit is maximised. In Scenario 1, the total supply chain profit function is when the manufacturer's retained profit is maximised. $\prod_{1}=-\frac{\left(\left(\theta-1\right)\lambda^{2}+\left(-2\theta+2\right)\lambda+\theta+5\right)\left(c\theta-c+1\right)^{2}}{\left(\left(\theta-1\right)\lambda^{2}+\left(-2\theta+2\right)\lambda+\theta+3\right)^{2}\left(\theta-1\right)}$

Let $\prod=\prod_{2}-\prod_{1}$, which is calculated to give

$$\Pi=-\frac{\left((\theta-1)^{3}\lambda^{6}-4(\theta-1)^{3}\lambda^{5}+\left(6\theta^{3}-16\theta^{2}+14\theta-4\right)\lambda^{4}+\left(-4\theta^{3}+12\theta^{2}-28\theta+20\right)\lambda^{3}+\left(\theta^{3}-9\theta^{2}+39\theta-31\right)\lambda^{2}+\left(4\theta^{2}-24\theta-44\right)\lambda+12\theta+52\right)(c\theta-c+1)^{2}}{2\left(4+(\theta-1)\lambda^{2}\right)^{2}\left((\theta-1)\lambda^{2}+(-2\theta+2)\lambda+\theta+3\right)^{2}}$$

From the above equation, it is clear that $\Pi>0$ or $\Pi<0$, depending on the positivity or negativity of $(\theta-1)^{3}\lambda^{6}-4(\theta-1)^{3}\lambda^{5}+\left(6\theta^{3}-16\theta^{2}+14\theta-4\right)\lambda^{4}+\left(-4\theta^{3}+12\theta^{2}-28\theta+20\right)\lambda^{3}+\left(\theta^{3}-9\theta^{2}+39\theta-31\right)\lambda^{2}+\left(4\theta^{2}-24\theta-44\right)\lambda+12\theta+52$, so a graphical analysis of the equation is shown in Figure 1 below.

ISSN: 2692-7608 DOI: 10.6981/FEM.202305_4(5).0026

Analysis of the graph shows that under the conditions of $\lambda \in (0,1), \theta \in (0,1)$, most of the time $\prod$ < 0, i.e., the vast majority of the time, $\prod_2 < \prod_1$.

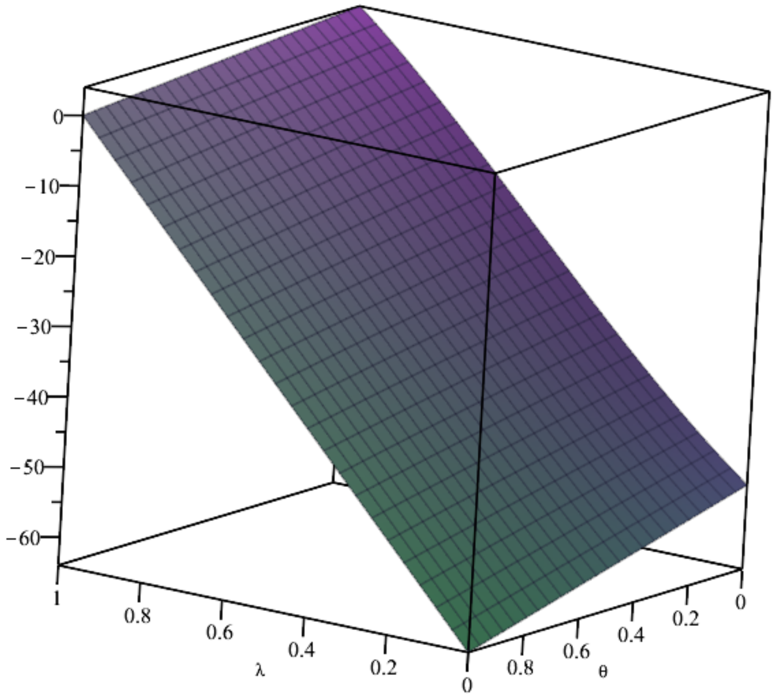

Figure 1. Graphical analysis

5. Conclusion

By analysing two scenarios: manufacturers bearing the cost of carbon emission reduction and manufacturers passing on the cost of carbon emission reduction to downstream consumers through price increases, this paper develops a two-channel Stackelberg game model and analyses the impact of manufacturers developing energy-efficient and emission-reducing technologies on the economic benefits of different subjects such as retailers, manufacturers and the entire supply chain, and compares the impact of manufacturers passing on the cost of carbon emission reduction directly to downstream consumers through price increases with The impact on the economic benefits of different subjects such as retailers, manufacturers and the entire supply chain when manufacturers directly transfer the cost of carbon reduction to consumers through price increases is compared. And the following conclusions were drawn:

(i) A comparison of the manufacturer's profit function when the manufacturer's retained profit is maximised in the first and second scenarios depends mainly on $2\lambda - 1$. When $\lambda > \frac{1}{2}$, Π > 0, i.e. at this point the manufacturer will have more retained profit by bearing the cost of carbon emissions than by transferring the cost of carbon emissions to the consumer. When $< \lambda \frac{1}{2}$, it means that at this point the manufacturer is making more retained profit by passing on the cost of carbon emissions to the consumer than it is by passing on the cost of carbon emissions to the manufacturer.

(ii) Where the manufacturer retains the greatest profit, the profit of the retailer in scenario 1 when the manufacturer bears the cost of carbon abatement is greater than the profit of the retailer in scenario 2 when the manufacturer would pass on the cost of carbon abatement to the consumer in the form of price increases.

ISSN: 2692-7608 DOI: 10.6981/FEM.202305_4(5).0026

(iii) When the manufacturer's retained profit is zero, the total supply chain profit in Scenario 2 is lower when the manufacturer transfers costs to consumers in the form of price increases than in Scenario 1 when the manufacturer develops carbon reduction technologies.

(iv) The total supply chain profit function comparing the two scenarios when the manufacturer retains the greatest profit is in most cases greater than the total supply chain profit from the manufacturer's development of low carbon technologies than the total supply chain profit from the manufacturer's transfer of carbon abatement costs to the consumer.

6. Summary and Outlook

This paper has only analysed one scenario under the marketplace sales model, and there are a variety of other distribution models that could continue to be studied in depth to discuss products under carbon trading under different marketplace sales models.

In a subsequent study, the range of values of the innovation technology coefficient and the channel cross-price coefficient can be studied and calculated for each industry or specific company to discuss whether it should opt for a price increase strategy or a technological innovation strategy.

Research can also be conducted from the perspective of government subsidies in subsequent studies. As research into the development of carbon reduction technologies requires long-term investment by enterprises and the returns are not immediately visible, government subsidies can be introduced to balance the long-term and short-term interests of enterprises, both to encourage them to develop a green and low-carbon economy and to promote the green and sustainable development of society.

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