LOW-CARBON INNOVATION DECISION CONSIDERING QUALITY DIFFERENCES AND GOVERNMENT SUBSIDIES UNDER THE THREE-PARTY TRADING PLATFORM

Xu Wang[1,*], Longzhen Zhou[1], Zusheng Zhang[1], Yingbo Wu[2] and Longxiao Li[3]

[1]College of Mechanical and Vehicle Engineering, Chongqing University, Chongqing, 400030, China
[2]School of Big Data & software engineering, Chongqing University, Chongqing, 401331, China
[3]School of Business Administration, Chongqing University of Science and Technology, Chongqing, 401331, China

ABSTRACT

In the context of low-carbon innovation, reasonable subsidy, innovation, and pricing strategies are important to achieve resource decarbonization and supply-demand matching, while the quality differentiation of resources has a significant impact on the strategy formulation. In this paper, we study low-carbon innovation and government subsidy in different innovation scenarios with two providers offering differentiated manufacturing resources on a resource trading platform, integrating two variables of resource quality difference and demand-side low-carbon preference. Using utility theory and the Stackelberg game, a decision model of low carbon innovation and government subsidy is constructed, and the equilibrium solution is obtained with inverse induction. Then, the low-carbon innovation and subsidy strategies under different innovation scenarios are compared and the effects of relative coefficients of quality and innovation cost coefficients on the strategies are analyzed. The findings show that when the difference in resource quality is small, the level of green innovation is higher in the low carbon innovation scenario with high-quality resources compared to the low carbon innovation scenario with low-quality resources, and the rate of government subsidy for innovation investment is also higher. In case of the large difference in resource quality, the relative magnitudes of green innovation level and government subsidy rate for innovation inputs in different scenarios are related to innovation cost coefficients.

KEYWORDS

Low-carbon innovation, Quality differentiation of resources, Government subsidies, Manufacturing resource trading platform.

1. INTRODUCTION

With the reduction of renewable resources, ecological destruction, and increasing pressure on environmental protection, especially the convening of the United Nations Climate Change Conference, more and more countries begin to pay attention to environmental protection[1].Some governments subsidize enterprises and consumers who produce or use green and energy-saving products to improve the environment and support the development of the environmental protection industry. In recent years, subsidies for green manufacturing enterprises have been

David C. Wyld et al. (Eds): AI, AIMLNET, BIOS, BINLP, CSTY, MaVaS, SIGI - 2022
pp. 259-278, 2022. CS & IT - CSCP 2022 DOI: 10.5121/csit.2022.121823

introduced in Beijing, Shenzhen, Guangzhou, and other places in China, including subsidies for low-carbon products, support for low-carbon projects, and one-time funding incentives.

In this context, some scholars began to study the impact of government intervention on the green supply chain. Sheu studied the impact of government financial intervention on the competitive green supply chain. The study shows that the government should adopt green tax and subsidy policies to ensure that the profit of green product production is non-negative[2]. Madani first discussed the competition strategy between the green supply chain and the non-green supply chain under the leadership of the government, considering the government subsidies for green products, and taxing non-green products. The study shows that the impact of the government to improve the subsidy rate is far greater than the tax rate, which will also lead to increased profits for the government and the supply chain and product sustainability[3]. Zhu Qinghua studied the green supply chain management problem based on government subsidies and considered the three-stage game model of product green degree and government subsidies. The research shows that when the production cost coefficient of green products is high and the consumer's environmental awareness is low, the government should appropriately reduce the lower limit of subsidies and reduce the green input of products. When the production cost coefficient of green products is low and consumers ' environmental awareness is high, the opposite is true[4].

In response, a growing number of firms have devoted attention to green technologies investment in R&D and production processes to curb carbon emissions[5, 6]. For example, Apple invested heavily in green technologies such as renewable energy in 2017. With these investments, the company cut emissions by nearly 2m tonnes from last year. However, green investment is not free; Companies have to bear a lot of investment costs, which may reduce the benefits of green investment and even become an important obstacle to the adoption of green technology[7, 8]. Therefore, whether to invest in green technology has become an important issue for enterprises. In addition to the price and greenness of the product, the quality of the product is also a powerful means of attracting customers and even determines the position of an enterprise in the market. When enterprises with different product quality choose low-carbon innovation strategies, they will be different due to different market positions or consumer preferences. How to improve their product's greenness to improve their profitability in the context of product quality that cannot be improved simply has become a key issue for enterprises in the competitive environment, especially in the transformation to green production. However, so far, most studies haven't studied the quality differentiation in low-carbon innovation decisions. Quality is defined as the environmental quality that reflects the green degree of products[8] or considers the relationship between quality improvement investment and low-carbon innovation investment[9].

The third-party platforms can reduce the technological input of manufacturing enterprises and integrate resources and capabilities among manufacturing enterprises, which is of great significance to promoting the development of the platform economy and manufacturing industry. With the continuous integration of information technology and the manufacturing industry, the third-party platform of the manufacturing industry has developed rapidly, which has attracted the attention of many scholars. For example, studies have shown that the main motivation for enterprises to join the platform is that the services provided by the platform can help enterprises improve efficiency and reduce transaction costs[10]. Yoo compares the profits obtained by enterprises joining the third-party platform with those that have self-built platforms respectively and comprehensively analyzes the influence factors of enterprises joining the third-party platform. They found that companies' IT capabilities, costs, and purchasing needs were the main drivers and revealed that SMEs were better suited to join third-party platforms[11]. Many scholars have studied the third-party platform from the basic functions, architecture, operation model, and implementation technology of the platform[12-14]. In addition, there are few studies on service investment and pricing strategies on third-party platforms, especially on resource quality or greenness improvement on third-party platforms.

Based on the above research, considering the impact of third-party platform transactions and resource quality differences on resource providers' low-carbon innovation strategy and government subsidies strategy, this paper studies the problem of low-carbon innovation of third-party platform resource providers under government subsidies. This paper considers a third-party trading platform composed of low-quality resource providers( ), high-quality resource providers( ), and resource demanders( ). The government will issue a certain subsidy strategy for low-carbon innovation projects, and resource providers are likely to invest in low-carbon innovation of resources. Through the research of this paper, some different results are obtained from previous studies. Firstly, resource quality differences and low-carbon innovation cost coefficients will affect the low-carbon innovation decisions of quality resource providers, and low-quality resource providers should also consider platform transaction rates. Different from previous studies, this paper finds that high-quality resource providers have lower innovation willingness than low-quality resource providers in terms of market share and profit. Then, government subsidies are not always biased towards high-quality resource providers, and low-quality resource providers are given higher rates of subsidies when the quality differences between the two sides are large and innovation cost coefficients are low. Finally, the platform development is not necessarily committed to improving the overall level of resources, in different cases, different resource providers can have different incentive strategies.

2. PROBLEM DESCRIPTION AND SYMBOLIC DESCRIPTION

2.1. Problem Description

On the third-party manufacturing resource trading platform, a type of manufacturing resource is provided by two competing manufacturing resource providers $RSP_i (i = 1, 2)$, and the two providers provide two differentiated resources $R_1 \backslash R_2$, which R_2 has a more reliable quality level and R_1 is inferior R_2 in this respect. RSD can choose any of the resources for direct transactions, while RSP_i paying a certain commission fee to the resource-sharing platform. As two competing suppliers, they will invest in low-carbon innovation projects to improve their product green degree, thereby affecting the choice of resource demanders to maximize their profits. At the same time, the regulatory authorities of the government also have the responsibility to enhance social-environmental benefits and to give resource providers certain project subsidies. Therefore, under the influence of different government subsidy strategies on the low-carbon innovation level of resource providers, how do subsidies affect their low-carbon innovation decisions and pricing for suppliers with different quality resources?

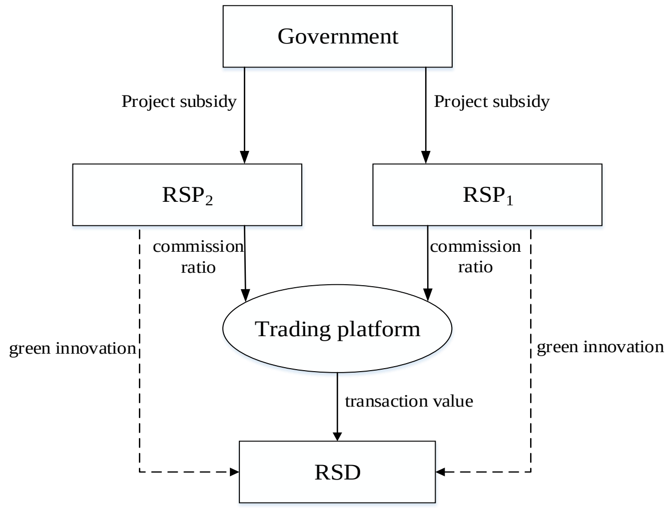

Figure 1. Operation Mode of Tripartite Trading Platform

2.2. Symbolic Description

The relevant symbols in this paper are as follows shows:

Table 1. Symbolic Description

	Symbolic	Description
Parameter	v	the initial utility of resource demanders for high-quality manufacturing resources $(0<v<1)$
	θ	relative coefficients of resources quality $(0<\theta<1)$
	β	transaction rates on trading platforms
	k	low-carbon innovation cost coefficients
	$u_i(i=1,2)$	utility of resource demanders
	$Q_i(i=1,2)$	market share of resource providers
Decision variable	$P_i(i=1,2)$	transaction prices of resource
	$m_i(i=1,2)$	low-carbon innovation effort coefficient of resource providers
	η	government subsidy rate
Other symbols	RSD	resource demanders
	RSP_i	resource providers
	R_i	resources
	$\pi_i(i=1,2,g)$	profit (utility) of different themes)

3. MODEL CONSTRUCTION AND SOLUTION

Hypothesis 1: In some literature, the linear combination of price and non-price variables is generally used to represent the demand function[15-17], and some empirical studies also found that the level of green degree of enterprise products can affect consumers' purchasing behavior. This paper refers to Gao Juhong's research[18], the relationship between the nature of manufacturing resources and perceived utility is expressed by the following utility function: $u = V - e_1P + e_2m$ (wherein, the initial utility is expressed as $v \sim U(0,1)$, a is the price elasticity coefficient, b is the environmental sensitivity coefficient of demand, and the impact of the green degree of resources on demand is bm). To facilitate the analysis results, and without losing generality, set $e_1 = e_2 = 1$.

Hypothesis 2: With the continuous improvement of the green degree of manufacturing resources, it is more and more difficult to improve the green degree, so the cost function of low-carbon innovation should have the characteristics of increasing marginal cost. At the same time, combined with reality, there is a certain fixed investment in green innovation that can't be recovered in time. This paper sets this fixed cost as a. Therefore, the cost function of green innovation of manufacturing resources can be expressed as $f(m) = 1/2km^2 + a$, which k is the low-carbon innovation cost coefficient.

Hypothesis 3: To simplify the calculation without losing generality, the cost of providing unit manufacturing resources is assumed to be zero.

Hypothesis 4: Referring to previous research results[19], social welfare is composed of total industry profits and environmental benefits. So the industry social welfare function considered by the government can be set to:

$$\pi_g = \pi_1 + \pi_2 + \pi_p + m_lQ_1 + m_hQ_2 \tag{1}$$

Hypothesis 5: The resource sharing platform introduces manufacturing resources with an audit mechanism, the quality difference between the two RSP_i would not be too large, assuming the quality difference $0.6 < \theta < 0.99$.

Hypothesis 6: The above information is public knowledge.

3.1. Basic model

This paper constructs a government- resource trading platform -manufacturing resource providers and demands decision-making model composed of two manufacturing resource platform suppliers and demanders, which meets the manufacturing resource demand at the transaction price P_i and pays a certain tariff as βP_i to the platform. At this time, the government has not issued the low-carbon innovation subsidy policy and RSP_i has decided not to carry out low-carbon innovation, only through price decision-making to maximize its profits. According to the above assumptions, the initial utility RSD is:

$$u_1 = \theta v - P_1 \tag{2}$$

$$u_2 = v - P_2 \tag{3}$$

When the conditions $\theta v - P_1 > 0$ $\theta v - P_1 < v - P_2$ are satisfied, RSD select R_1 to trade. So after simplification, we get when $P_1 < \theta P_2$ is satisfied, the high-quality resources and low-quality resources on the platform exist in the market and compete with each other, and the demand function R_1 is:

$$Q_1^0 = \int_{\frac{P_1}{\theta}}^{\frac{P_2-P_1}{1-\theta}} dv = \frac{P_2-P_1}{1-\theta} - \frac{P_1}{\theta} \tag{4}$$

When $P_1 > \theta P_2$ we get high-quality resources completely replace low-quality resources RSP_1 and exit the competition on the platform, high-quality resources form a monopoly RSD and have only one choice on this platform. This paper does not consider this situation. Similarly, when RSD chosen R_2, at this point satisfies conditions $v-P_2>0$ $\theta v-P_1>v-P_2$, the demand function R_2 is:

$$Q_2^0 = \int_{\frac{P_2-P_1}{1-\theta}}^{1} dv = 1-\frac{P_2-P_1}{1-\theta} \tag{5}$$

At this time, the profit functions of RSP_i the resource trading platform are:

$$\pi_1 = (1-\beta)P_1Q_1^0, \quad \pi_2 = (1-\beta)P_2Q_2^0, \quad \pi_p = \beta(P_1Q_1^0 + P_2Q_2^0)$$

The RSP_i trader will determine the transaction price of manufacturing resources according to the known market conditions, to maximize profits. The decision model is:

$$\max_{\{P_1,P_2\}}(\pi_l^0,\pi_h^0), s.t.: P_1>0,\ \ P_2>0,\ \ P_1<\theta P_2$$

Theorem 1: When RSP_i does not carry out low-carbon innovation, there is a balanced price strategy P_1^{0*} P_2^{0*}, and the optimal profits of RSP_i and platform profit are respectively:

$$P^{0*}:\begin{cases} P_1^{0*} = \dfrac{(\theta-1)\theta}{\theta-4} \\ P_2^{0*} = \dfrac{2(\theta-1)}{\theta-4} \end{cases} \tag{6}$$

The optimal profit RSP_i and platform profit obtained from Equation (6) are:

$$\pi^{0*}:\begin{cases} \pi_1^{0*} = \dfrac{\theta(-1+\theta)(-1+\beta)}{(\theta-4)^2} \\ \pi_2^{0*} = \dfrac{4(-1+\theta)(-1+\beta)}{(\theta-4)^2} \end{cases} \tag{7}$$

$$\pi_p^0 = -\frac{(\theta+4)(-1+\theta)\beta}{(\theta-4)^2} \tag{8}$$

Theorem 1 shows that in the absence of government intervention, P_1^{0*} is always less than P_2^{0*}, and the equilibrium price strategy is only affected by the relative coefficients of quality.

Lemma 1: In the basic model, the equilibrium price strategy of RSP_i decreases with the increase θ. For the three profit functions, they all decrease with the increase θ. Lemma 1 is in line with traditional cognition. When the resource trading platform doesn't conduct such behavior as low-carbon innovation to enhance the utility of demanders at the other end, its income will not increase with the homogenization of manufacturing resources, that is, such trading intermediaries as the platform need to provide sufficient choices of demanders to maximize their interests. For RSP_1, when the quality difference between the two RSP_i is large, the price can rise by improving their resource quality. However, when the relative coefficients of quality are small, the two RSP_i are at the same consumption level. To maximize their profit, the price war can only be used to occupy the market, RSP_2. But when both sides take such a price war, their profit margins will all decline.

3.2. Model for Low-Carbon Innovation of Resource Provider

When implementing the government subsidy mechanism, the decision-making problem of the government-enterprise low-carbon innovation-decision problem can be understood as the Stackelberg game of the government as a leader and the enterprise as a follower. At the same time, considering that low-carbon innovation investment is a strategic decision, so the decision-making order is shown in figure2, and the inverse order solution method is used to obtain the equilibrium results. Considering the different innovation ability of RSP_i in improving the green degree of resources, two scenarios are set: (1) RSP_1 conducts low-carbon innovation; (2) RSP_2 conducts low-carbon innovation.

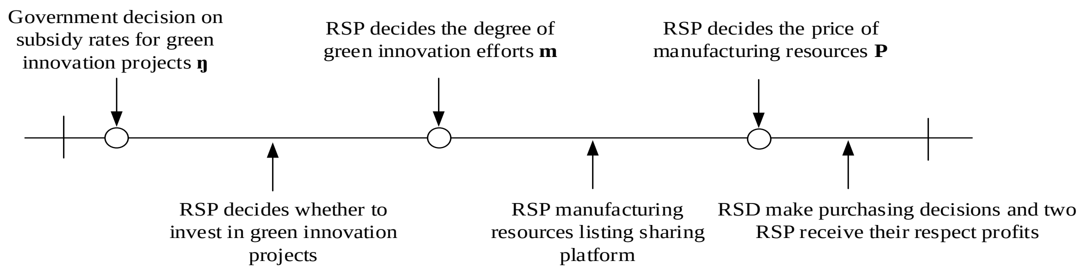

Figure 2. Game timeline

3.2.1. RSP_1 conducts low-carbon innovation

After the government released the subsidy policy for low-carbon innovation projects, in this scenario RSP_1 becomes an innovative enterprise for project investment, its profit function is $\pi_l^1 = (1-\beta)P_1Q_1^1 - (\frac{km_1^2}{2} + a)\cdot(1-\eta)$, and the profit functions of RSP_2 and platform unchanged. Similarly, the demand functions R_i are: $Q_1^1 = \frac{P_2 + m_1 - P_1}{1-\theta} - \frac{P_1 - m_1}{\theta}$ and $Q_2^1 = 1 - \frac{P_2 + m_1 - P_1}{1-\theta}$, the industry social welfare function considered by the government is $\pi_g^1 = \pi_h^1 + \pi_l^1 + \pi_p^1 + m_l^1 Q_1^1$. At this time the two enterprises play Bertrand games, the decision model is:

First stage: $\max\limits_{\{\eta\}}(\pi_g^1), s.t.: 0 < \eta < 1$

The second stage: $\max\limits_{\{P_1, P_2, m_1\}}(\pi_l^1, \pi_h^1), s.t.: P_1 > 0,\ P_2 > 0, m_1 > 0,\ P_1 < \theta P_2 + m_1$

Theorems 2: When RSP_1 conducting green innovation, the optimal subsidy rate of the government, the low-carbon innovation effort coefficient RSP_1, the pricing policies of RSP_i P_1^{1*} and P_2^{1*}, their optimal profits and platform profits are respectively:

$$\eta^{1*}=\frac{k(2\beta+1)\theta^3+(-6\beta-1)k\theta^2+(4\beta k+2\beta-2)\theta-4\beta+4}{k\theta(3\theta^2-7\theta+4)} \tag{9}$$

$$m_1^{1*}=\frac{-3\theta^3+7\theta^2-4\theta}{24+k\theta^4-9k\theta^3+(24k+4)\theta^2+(-16k-18)\theta} \tag{10}$$

$$P^{1*}:\begin{cases}P_1^{1*}=\dfrac{\theta(-1+\theta)(\theta-4)(k\theta^2-k\theta+1)}{24+k\theta^4-9k\theta^3+(24k+4)\theta^2+(-16k-18)\theta}\\ P_2^{1*}=\dfrac{(-1+\theta)(2k\theta^3-10k\theta^2+8k\theta+5\theta-12)}{24+k\theta^4-9k\theta^3+(24k+4)\theta^2+(-16k-18)\theta}\end{cases} \tag{11}$$

The optimal profit and platform profit obtained from Equations (9)-(11) are :

$$\pi^{1*}:\begin{cases}\pi_l^{1*}=\dfrac{2(k\theta^2-k\theta+1)(k(a+\frac{3}{2})\theta^5+(-11a-5)k\theta^4+((42a+\frac{11}{2})k+4a)\theta^3+((-64a-2)k-26a)\theta^2+(32ak+60a)\theta-48a)(-1+\beta)}{3k\theta(\theta-\frac{4}{3})(-1+\theta)(24+k\theta^4-9k\theta^3+(24k+4)\theta^2+(-16k-18)\theta)}\\ \pi_h^{1*}=\dfrac{4(-1+\beta)(-6+k\theta^3-5k\theta^2+(4k+\frac{5}{2})\theta)^2(-1+\theta)}{(24+k\theta^4-9k\theta^3+(24k+4)\theta^2+(-16k-18)\theta)^2}\end{cases} \tag{12}$$

$$\pi_p^1=-\frac{\beta(k^2\theta^7-6k^2\theta^6+(-7k^2+2k)\theta^5+(92k^2+2k)\theta^4+(-144k^2-100k+1)\theta^3+(64k^2+288k+17)\theta^2+(-192k-104)\theta+144)(-1+\theta)}{(24+k\theta^4-9k\theta^3+(24k+4)\theta^2+(-16k-18)\theta)^2} \tag{13}$$

Lemma 2: In this scenario, all k values satisfying the constraint are $(\frac{-5\theta+12}{2\theta^3-10\theta^2+8\theta},\frac{-2(\theta-2)(\beta-1)}{\theta(-1+\theta)(2\beta\theta-4\beta+\theta)})$. $\frac{\partial m_1^{1*}}{\partial k}<0$, and for $\frac{\partial m_1^{1*}}{\partial \theta}$: (1) When $\theta\in(0.6,-\frac{(1052+12\sqrt{5865})^{\frac{1}{3}}}{6}-\frac{32}{3(1052+12\sqrt{5865})^{\frac{1}{3}}}+\frac{11}{3})$, for $\frac{-5\theta+12}{2\theta^3-10\theta^2+8\theta}<k<\frac{12\theta^4-108\theta^3+326\theta^2-336\theta+96}{3(\theta+\frac{4}{3})(\theta-1)^2(\theta-4)\theta^2}$ we get $\frac{\partial m_1^{1*}}{\partial \theta}>0$ .and for $\frac{12\theta^4-108\theta^3+326\theta^2-336\theta+96}{3(\theta+\frac{4}{3})(\theta-1)^2(\theta-4)\theta^2}<k<\frac{-2(\theta-2)(\beta-1)}{\theta(\theta-1)(2\beta\theta-4\beta+\theta)}$ we get $\frac{\partial m_1^{1*}}{\partial \theta}<0$;(2) When $\theta\in(-\frac{(1052+12\sqrt{5865})^{\frac{1}{3}}}{6}-\frac{32}{3(1052+12\sqrt{5865})^{\frac{1}{3}}}+\frac{11}{3},0.8351771205)$ and $\beta<-\frac{\theta(\theta^3-11\theta^2+35\theta-20)}{5\theta^4-43\theta^3+128\theta^2-148\theta+48}$, $\frac{\partial m_1^{1*}}{\partial \theta}>0$ .But when $\theta\in(-\frac{(1052+12\sqrt{5865})^{\frac{1}{3}}}{6}-\frac{32}{3(1052+12\sqrt{5865})^{\frac{1}{3}}}+\frac{11}{3},0.8351771205)$ and $\beta>-\frac{\theta(\theta^3-11\theta^2+35\theta-20)}{5\theta^4-43\theta^3+128\theta^2-148\theta+48}$, for $\frac{-5\theta+12}{2\theta^3-10\theta^2+8\theta}<k<\frac{12\theta^4-108\theta^3+326\theta^2-336\theta+96}{3(\theta+\frac{4}{3})(\theta-1)^2(\theta-4)\theta^2}$ we get $\frac{\partial m_1^{1*}}{\partial \theta}>0$, and for $\frac{12\theta^4-108\theta^3+326\theta^2-336\theta+96}{3(\theta+\frac{4}{3})(\theta-1)^2(\theta-4)\theta^2}<k<\frac{-2(\theta-2)(\beta-1)}{\theta(\theta-1)(2\beta\theta-4\beta+\theta)}$ we get $\frac{\partial m_1^{1*}}{\partial \theta}<0$;(3) When $\theta\in(0.8351771205,1)$ we get $\frac{\partial m_1^{1*}}{\partial \theta}<0$. For the sensitivity of government subsidy rate: $\frac{\partial \eta^{1*}}{\partial k}<0$, $\frac{\partial \eta^{1*}}{\partial \beta}>0$, and for $\frac{\partial \eta^{1*}}{\partial \theta}<0$: (1) When $\theta\in(0.6,\frac{7}{4}-\frac{\sqrt{17}}{4})$ we get $\frac{\partial \eta^{1*}}{\partial \theta}>0$;(2) When $\theta\in\frac{7}{4}-\frac{\sqrt{17}}{4},0.830884198515145)$ we get $\frac{\partial \eta^{1*}}{\partial \theta}>0$;(3) When $\theta\in(0.830884198515145,1)$ and $k<\frac{6\theta^3-25\theta^2+28\theta-8}{2\theta^2(\theta-1)^2}$, we get $\frac{\partial \eta^{1*}}{\partial \theta}>0$. But when $\theta\in(0.830884198515145,1)$ and $k>\frac{6\theta^3-25\theta^2+28\theta-8}{2\theta^2(\theta-1)^2}$, we get $\frac{\partial \eta^{1*}}{\partial \theta}<0$. For equilibrium price: when $k\in(\frac{-5\theta+12}{2\theta^3-10\theta^2+8\theta},\frac{-\theta^2+9\theta-12}{\theta(\theta^3-7\theta^2+14\theta-8)})$ we get $P_1^{1*}>P_2^{1*}$, but when $k\in(\frac{-\theta^2+9\theta-12}{\theta(\theta^3-7\theta^2+14\theta-8)},\frac{-2(\theta-2)(\beta-1)}{\theta(\theta-1)(2\beta\theta-4\beta+\theta)})$ we get $P_1^{1*}<P_2^{1*}$. And $\frac{\partial P_1^{1*}}{\partial k}<0$, $\frac{\partial P_2^{1*}}{\partial k}>0$, $\frac{\partial P_2^{1*}}{\partial \theta}<0$.

Lemma 2 shows that with the increase of innovation cost coefficients, the government's subsidy rate would decrease, and RSP_1 would reduce the investment in low-carbon innovation. For the resource pricing that directly affects the RSP_1's profit, the increase in innovation cost will make the pricing lower. At this time, it will not choose to increase the resource pricing to recover the investment because of the increase of the previous investment and P_2^{1*} show the correlation of differentiated green innovation cost. Because there is no threat caused by low-carbon improvement RSP_2 and RSP_2 will seek greater profits by increasing the pricing, which causes the result that $P_1^{1*} < P_2^{1*}$. When the innovation cost is low, low-carbon behavior implementers, RSP_1 tend to take greater risks to improve pricing to obtain higher benefits and RSP_2 will reduce pricing because of the threat posed, so $P_1^{1*} > P_2^{1*}$.

Compared with the impact of low-carbon innovation cost on various strategies, the influencing mechanism of resource quality difference between the two sides is more complex: (1) When the θ is large, the η^{1*} is positively correlated with θ. In this situation, when the k is small, under the influence of low innovation cost and high government subsidy rate, RSP_1 is willing to carry out low-carbon innovation on its own high-quality resources to enhance its market position, so m_1^{1*} is positively correlated with θ. If the k is large, although low-carbon innovation is beneficial to the rise of market position, the reduction of θ and the high cost of innovation are also easy to make RSP_1 be content with the status quo, and then make m_1^{1*} negatively correlated with θ;(2) When the θ is small, the η^{1*} is positively correlated with θ. If the is small, with the narrowing of the quality difference and the improvement of η^{1*}, although the θ is not big, but RSP_1 also intends to stabilize their market position and carry out innovation investment, m_1^{1*} is positively correlated with θ. If the β is large and the k is small, the increase in the β will increase η^{1*}, and m_1^{1*} is also positively correlated with θ. However, when the β and k are large, although the η^{1*} increases appropriately with the increase of θ and β, the high innovation cost hinders the low-carbon innovation behavior of RSP_1, so m_1^{1*} is negatively correlated with θ; (3) When the resource quality of both sides is very close and the k is small, the η^{1*} increases with the increase of θ, while m_1^{1*} decreases with the increase of θ. When the k is large, the η^{1*} decreases with the increase of θ, which is different from the situation that the quality difference is obvious before or the k is small. The larger θ let the government is more convinced that at this time RSP_1 has enough capital to carry out low-carbon innovation, and the increase of subsidy cost reduces the support, and m_1^{1*} always decreases with the increase of θ, so in this situation, regardless of the level of k, RSP_1 thinks that its resources have been able to meet the requirements of market competition and reduce the investment in low-carbon innovation. In this case, market resources are in the most difficult stage of low-carbon innovation.

3.2.2. RSP_2 conducts low-carbon innovation

In this scenario, RSP_2 as an innovative enterprise to conduct low-carbon innovation, its profit function is: $\pi_h^2 = (1-\beta)P_2Q_2^2 - (\frac{km_2^2}{2} + a)\cdot(1-\eta)$, at this time the profit function of RSP_1 and the platform is unchanged. Similarly, the demand functions of R_1 are respectively: $Q_1^2 = \frac{P_2 - m_2 - P_1}{1-\theta} - \frac{P_1}{\theta}$ and $Q_2^2 = 1 - \frac{P_2 - m_2 - P_1}{1-\theta}$. The industry social welfare function considered by the government is: $\pi_g^2 = \pi_h^2 + \pi_l^2 + \pi_p^2 + m_2^2 Q_2^2$. At this time, the two enterprises conduct the Bertrand game, the decision model is:

First stage: $\max_{\{\eta\}}(\pi_g^2), s.t.: 0 < \eta < 1$

The second stage: $\max\limits_{\{P_1,P_2,m_2\}} (\pi_l^2, \pi_h^2), s.t.: P_1 > 0, P_2 > 0, m_2 > 0, P_1 < \theta P_2 - \theta m_2$

Theorems 3: When RSP_2 conducting green innovation, the optimal subsidy rate of the government, the low-carbon innovation effort coefficient of RSP_2, the pricing policies of RSP_i **:** P_1^{1*} and P_2^{1*}, their optimal profits and platform profits are respectively:

$$\eta^{2*} = \frac{(-1+\theta)(\theta-4)(\beta+1)k - 2\beta + 2}{(2\theta^2 - 10\theta + 8)k} \tag{14}$$

$$m_2^{2*} = -\frac{8(-1+\theta)(\theta-2)}{k\theta^3 + (-9k+4)\theta^2 + (24k-18)\theta - 16k + 24} \tag{15}$$

$$P^{2*}: \begin{cases} P_1^{2*} = \dfrac{(-1+\theta)(k\theta^2 + (-5k+4)\theta + 4k - 10)\theta}{k\theta^3 + (-9k+4)\theta^2 + (24k-18)\theta - 16k + 24} \\ P_2^{2*} = \dfrac{2(-1+\theta)(k\theta^2 - 5k\theta + 4k - 2)}{k\theta^3 + (-9k+4)\theta^2 + (24k-18)\theta - 16k + 24} \end{cases} \tag{16}$$

The optimal profit and platform profit obtained from Equations (14)-(16) are:

$$\pi^{2*}: \begin{cases} \pi_l^{2*} = \dfrac{(-1+\beta)(k\theta^2 + (-5k+4)\theta + 4k - 10)^2(-1+\theta)\theta}{(k\theta^3 + (-9k+4)\theta^2 + (24k-18)\theta - 16k + 24)^2} \\ \pi_h^{2*} = \dfrac{(-1+\beta)((a\theta^2 + (-8a+8)\theta + 16a - 8)(-1+\theta)k + 4a(\theta^2 - \frac{9}{2}\theta + 6))(-2 + k(\theta^2 - 5\theta + 4))}{2((\theta-4)^2(-1+\theta)k + 4\theta^2 - 18\theta + 24)(-1+\theta)k(\theta-4)} \end{cases} \tag{17}$$

$$\pi_p^{2*} = -\frac{(-1+\theta)\beta(k^2\theta^5 + (-6k^2+8k)\theta^4 + (-7k^2 - 60k + 16)\theta^3 + (92k^2 + 116k - 80)\theta^2 + (-144k^2 + 100)\theta + 64(-\frac{1}{2} + k)^2)}{(k\theta^3 + (-9k+4)\theta^2 + (24k-18)\theta - 16k + 24)^2} \tag{18}$$

Lemma 3: When considering RSP_2 conducting low-carbon innovation, $P_1 < \theta P_2 - \theta m_2$ would be satisfied if $k \in (\frac{-4\theta + 10}{\theta^2 - 5\theta + 4}, +\infty)$. $\frac{\partial m_2^*}{\partial k} < 0$, $\frac{\partial m_2^*}{\partial \theta} < 0$, $\frac{\partial \eta^{2*}}{\partial k} < 0$, $\frac{\partial \eta^{2*}}{\partial \theta} > 0$, $\frac{\partial \eta^{2*}}{\partial \beta} > 0$.For the equilibrium price: $P_1^{2*} < P_2^{2*}$, $\frac{\partial P_1^{2*}}{\partial k} > 0$, $\frac{\partial P_1^{2*}}{\partial \theta} < 0$, $\frac{\partial P_2^{2*}}{\partial k} < 0$, $\frac{\partial P_2^{2*}}{\partial \theta} < 0$.

Lemma 3 shows that when the k increases, the government also decreases. The investment in low-carbon innovation projects should be reduced to avoid risks. At the same time, the P_2^{2*} will also be reduced to improve market share to recover the investment, but the P_1^{2*} will be increased to seek profits, but $P_1^{2*} < P_2^{2*}$ holds.

When the θ increases, RSP_2 will reduce investment in a low-carbon innovation project, while reducing resource pricing to ensure market priority, but at this time the market competition is more intense, and transaction prices will be reduced. For the government, when the subsidy object is RSP_2, the η^{2*} will increase with the reduction of quality difference, that is, when the market lacks differentiated products, government incline to the enterprise caused more benefit social welfare.

4. COMPARATIVE ANALYSIS

The above analysis of resource sharing platforms with different quality levels of resource providers-government emission reduction model, the following from the social green innovation efficiency, government subsidies efficiency, and market share to be compared to get some management inspiration. By comparing the range of low-carbon innovation costs in the two cases, it can be obtained that when $k \in (\frac{-4\theta+10}{\theta^2-5\theta+4}, \frac{-2(\theta-2)(\beta-1)}{\theta(\theta-1)(2\beta\theta-4\beta+\theta)})$ the two scenarios can be compared at the same time.

4.1. Comparison of Environmental Benefits

Lemma 3: For low-carbon innovation efforts coefficient difference $m_1^{1*} - m_2^{2*}$, when $\theta \in (0.6, -\frac{(51+12\sqrt{13})^{\frac{1}{3}}}{4} - \frac{9}{4(51+12\sqrt{13})^{\frac{1}{3}}} + \frac{9}{4})$ and $k \in (\frac{-4\theta+10}{\theta^2-5\theta+4}, \frac{12\theta^4-102\theta^3+352\theta^2-576\theta+384}{5(\theta-4)^2(-1+\theta)(\theta-\frac{12}{5})\theta})$ we can get $m_1^{1*} > m_2^{2*}$, when then $k \in (\frac{-4\theta+10}{\theta^2-5\theta+4}, \frac{12\theta^4-102\theta^3+352\theta^2-576\theta+384}{5(\theta-4)^2(-1+\theta)(\theta-\frac{12}{5})\theta})$ we get $m_1^{1*} < m_2^{2*}$; When $\theta \in (-\frac{(51+12\sqrt{13})^{\frac{1}{3}}}{4} - \frac{9}{4(51+12\sqrt{13})^{\frac{1}{3}}} + \frac{9}{4}, 1)$ we get $m_1^{1*} < m_2^{2*}$.

Lemma 4 shows that even if RSP_i carrying out low-carbon innovation on the same resource trading platform, the degree of low-carbon innovation efforts is also very different: in most cases, RSP_2 can pay more cost to improve the green degree of its resources. Only when the quality difference between the two sides is large enough and the cost of green innovation is small, the investment cost of RSP_1 is higher than RSP_2. In this case, RSP_1 is at a disadvantage and the marginal cost of low-carbon innovation is low. At this time, RSP_1 has a greater determination to change than RSP_2.

4.2. Comparison of Government Subsidy Rate

Lemma 5: Comparing the η^{i*} in different scenes, when $\theta < \frac{7}{2} - \frac{\sqrt{33}}{2}$ and $k \in (\frac{-4\theta+10}{\theta^2-5\theta+4}, \frac{-10\theta^2+32\theta-32}{\theta(\theta-1)(\theta-4)^2})$ we get $\eta^{1*} > \eta^{2*}$, when $k \in (\frac{-10\theta^2+32\theta-32}{\theta(\theta-1)(\theta-4)^2}, \frac{-2(\theta-2)(\beta-1)}{\theta(\theta-1)(2\beta\theta-4\beta+\theta)})$ we get $\eta^{1*} < \eta^{2*}$; When $\theta > \frac{7}{2} - \frac{\sqrt{33}}{2}$ we get $\eta^{1*} < \eta^{2*}$ .Sensitivity analysis of government subsidy rate difference: $\frac{\partial(\eta^{1*}-\eta^{2*})}{\partial k} < 0$, and when $\theta < \frac{7}{2} - \frac{\sqrt{33}}{2}$ and $k \in (\frac{-4\theta+10}{\theta^2-5\theta+4}, \frac{-10\theta^2+32\theta-32}{\theta(\theta-1)(\theta-4)^2})$ we get $\frac{\partial(\eta^{1*}-\eta^{2*})}{\partial \beta} < 0$, but when $k \in (\frac{-10\theta^2+32\theta-32}{\theta(\theta-1)(\theta-4)^2}, \frac{-2(\theta-2)(\beta-1)}{\theta(\theta-1)(2\beta\theta-4\beta+\theta)})$ we get $\frac{\partial(\eta^{1*}-\eta^{2*})}{\partial \beta} > 0$; When $\theta > \frac{7}{2} - \frac{\sqrt{33}}{2}$ we get $\frac{\partial(\eta^{1*}-\eta^{2*})}{\partial \beta} > 0$.

Lemma 5 shows that for the government when the θ is large and the k is low, $\eta^{1*} > \eta^{2*}$, RSP_1 with greater innovation risk will receive greater support to increase its willingness to innovate; when k is high, $\eta^{1*} < \eta^{2*}$, the government would measure the efficiency of subsidies for improving social and environmental benefits, that is, choosing RSP_2 with more market influence to subsidize, as well as when the θ is large. When k is small, the difference η^{i*} decreases with k's increase, while when k is large, the difference will increase with k increase. That is to say when encouraging the innovation willingness caused by the quality gap between R_i, the government does not ignore the cost, but fully considers the decisions made by the subsidies. For the rate of transaction cost, When RSP_i are on the platform with a higher transaction rate, if the quality difference is large but the k is small, the difference of the η^{i*} for different RSP_i will be smaller, but in this case, when the k is large, the difference of η^{i*} will become larger, and the government will become another factor to promote the differentiation of RSP_i's income. When the quality difference is not large, higher transaction rate will result in smaller subsidy rate differences, that is, when trading platforms tend to commercialize (higher transaction cost), η^{i*} will gradually increase market intervention.

4.3. Comparison of Market Share

Lemma 6: (1) Comparison of pricing strategies: The comparison of pricing strategies for RSP_i in different scenarios, we get $P_1^{2*} < P_1^{0*} < P_1^{1*}$ and $P_2^{1*} < P_2^{0*} < P_2^{2*}$. (2) Comparison of market share: For the comparison of market share of RSP_1 in different scenarios: $Q_1^1 > Q_1^0 > Q_1^2$ and $\frac{\partial Q_1^1}{\partial k} < 0$, when $\theta > -\frac{(63+8\sqrt{62})^{\frac{1}{3}}}{6} - \frac{1}{6(63+8\sqrt{62})^{\frac{1}{3}}} + \frac{3}{2}$ we get $\frac{\partial Q_1^1}{\partial \theta} > 0$, when $\theta < -\frac{(63+8\sqrt{62})^{\frac{1}{3}}}{6} - \frac{1}{6(63+8\sqrt{62})^{\frac{1}{3}}} + \frac{3}{2}$ and $\frac{-5\theta+12}{2\theta^3-10\theta^2+8\theta} < k < -\frac{-\theta^4+2\theta^3-14\theta^2+\sqrt{-15\theta^8+284\theta^7-1968\theta^6+6632\theta^5-11260\theta^4+8256\theta^3+128\theta^2-3072\theta+1024}+48\theta-32}{2\theta^2(\theta^4-10\theta^3+33\theta^2-40\theta+16)}$ we get $\frac{\partial Q_1^1}{\partial \theta} > 0$, so when $\frac{\theta^4-2\theta^3+14\theta^2-48\theta+32+\sqrt{-15\theta^8+284\theta^7-1968\theta^6+6632\theta^5-11260\theta^4+8256\theta^3+128\theta^2-3072\theta+1024}}{2\theta^2(\theta^4-10\theta^3+33\theta^2-40\theta+16)} < k < \frac{-2(\theta-2)(\beta-1)}{\theta(\theta-1)(2\beta\theta-4\beta+\theta)}$. But when $-\frac{-\theta^4+2\theta^3-14\theta^2+\sqrt{-15\theta^8+284\theta^7-1968\theta^6+6632\theta^5-11260\theta^4+8256\theta^3+128\theta^2-3072\theta+1024}+48\theta-32}{2\theta^2(\theta^4-10\theta^3+33\theta^2-40\theta+16)} < k < \frac{\theta^4-2\theta^3+14\theta^2-48\theta+32+\sqrt{-15\theta^8+284\theta^7-1968\theta^6+6632\theta^5-11260\theta^4+8256\theta^3+128\theta^2-3072\theta+1024}}{2\theta^2(\theta^4-10\theta^3+33\theta^2-40\theta+16)}$ We get $\frac{\partial Q_1^1}{\partial \theta} < 0$, $\frac{\partial Q_1^2}{\partial k} > 0$, $\frac{\partial Q_1^2}{\partial \theta} < 0$; For the comparison of market share of RSP_2 in different scenarios: When $\frac{-5\theta+12}{2\theta^3-10\theta^2+8\theta} < k < \frac{-\theta^2+14\theta-24}{\theta(\theta-1)(\theta-4)^2}$ we get $Q_2^1 < Q_2^0 < Q_2^2$, when $\frac{-\theta^2+14\theta-24}{\theta(\theta-1)(\theta-4)^2} < k < \frac{-2(\theta-2)(\beta-1)}{\theta(\theta-1)(2\beta\theta-4\beta+\theta)}$ we get $Q_2^0 < Q_2^1 < Q_2^2$, and $\frac{\partial Q_2^1}{\partial k} > 0$, $\frac{\partial Q_2^2}{\partial k} < 0$, $\frac{\partial Q_2^2}{\partial \theta} > 0$.(3) Comparison of platform trading volume: The sum of market share of RSP_1 and RSP_2 can be regarded as the total trading volume of the platform, when $\theta < \frac{7}{4} - \frac{\sqrt{17}}{4}$ and $\frac{-4\theta^2+18\theta-24}{4\theta^4-31\theta^3+75\theta^2-64\theta+16} < k < \frac{-2(\theta-2)(\beta-1)}{\theta(\theta-1)(2\beta\theta-4\beta+\theta)}$ we get $Q_1^0+Q_2^0 < Q_1^1+Q_2^1 < Q_1^2+Q_2^2$, but when $\frac{-4\theta+10}{\theta^2-5\theta+4} < k < \frac{-4\theta^2+18\theta-24}{4\theta^4-31\theta^3+75\theta^2-64\theta+16}$ we get $Q_1^0+Q_2^0 < Q_1^2+Q_2^2 < Q_1^1+Q_2^1$ $Q_1^0+Q_2^0 < Q_1^1+Q_2^1 < Q_1^2+Q_2^2$. And in scenes 2 and 3, we can get $\frac{\partial(Q_1^i+Q_2^i)}{\partial k} < 0$, $\frac{\partial(Q_1^i+Q_2^i)}{\partial \theta} > 0$.(4) Comparison of sensitivity: ①Comparing the sensitivity of resource pricing to k and θ in two innovation scenarios, we can get $\frac{\partial P_1^{1*}}{\partial k} < \frac{\partial P_2^{1*}}{\partial k}$, $\frac{\partial P_1^{1*}}{\partial k} < \frac{\partial P_1^{2*}}{\partial k}$, $\frac{\partial P_1^{2*}}{\partial k} > \frac{\partial P_2^{2*}}{\partial k}$, $\frac{\partial P_2^{1*}}{\partial k} > \frac{\partial P_2^{2*}}{\partial k}$, $\frac{\partial P_1^{1*}}{\partial \theta} > \frac{\partial P_2^{1*}}{\partial \theta}$.②Comparing the sensitivity of RSP_i's market share to k and θ in two innovation scenarios, we can get $\frac{\partial Q_1^1}{\partial k} < \frac{\partial Q_2^1}{\partial k}$, $\frac{\partial Q_1^{1*}}{\partial k} < \frac{\partial Q_1^{2*}}{\partial k}$, $\frac{\partial Q_1^2}{\partial k} > \frac{\partial Q_2^2}{\partial k}$, $\frac{\partial Q_2^{1*}}{\partial k} < \frac{\partial Q_2^{2*}}{\partial k}$, $\frac{\partial Q_1^2}{\partial \theta} < \frac{\partial Q_2^2}{\partial \theta}$.

Lemma 6 shows that when RSP_i carrying out green innovation, they always tend to higher pricing to recover the cost of investment, while the other RSP_i will take lower pricing to seek greater market share. At the same time, the sensitivity of the price strategy k is always lower than that of the other scenario, and in the same scenario, the RSP_i's price sensitivity k is always lower than that of the other the other RSP_i's, which indicates that the first one to invest would reduce the impact of low-carbon innovation cost on resource pricing.

When RSP_1 carrying out low-carbon innovation, its pricing sensitivity θ is higher than that of its counterpart, while RSP_2 also having the same effect on low-carbon innovation cost when conducting low-carbon innovation, but its sensitivity is less than RSP_1 when the low-carbon innovation cost is high. These show that when RSP_1 considering low-carbon innovation, it is more likely to carry out low-carbon innovation activities based on quality differences, and its pricing will be more sensitive with θ; when RSP_1 carries out green innovation, the larger k will make RSP_1 pay attention to the determination of RSP_2 and pay more attention to the impact of θ on the reasonable market price.

For the market share of RSP_1, the high pricing in the low-carbon innovation scene can also make it occupy the largest market share in three scenarios, while its market share in the basic model is slightly smaller and is the smallest in scene 3. But when its market share is the largest, if the k increases, its market share will gradually decline due to the increase in pricing; When the quality difference between R_i is large enough and the k is in a suitable area. The market share of RSP_1 will decrease with the narrowing of quality difference. In other cases, with the narrowing of quality difference, the market share of RSP_1 after low-carbon innovation tends to increase. When the low-carbon innovation cost is low, the market share of RSP_2 is the largest in scene 3, and it is the smallest under the basic model. When the k is high, the market share under the basic model is greater than that of scene 2. As above analysis of RSP_1, the changing trend of Q_2^i on k is only related to whether to conduct low-carbon innovation. However, the relationship between Q_1^2 and Q_2^2 with respect to θ is opposite. When RSP_2 carrying out low-carbon innovation, its original quality advantage is greater, and its market share advantage is smaller after low-carbon innovation.

For the total trading volume of the platform, when the quality difference is large and low-carbon innovation cost is small, the total market volume in scene 3 is the largest, followed by that of scene 2, and the smallest is in the basic model; when the quality difference is large but low-carbon innovation cost innovation is high, the total market volume of scene 2 is the largest, and the basic model is still the smallest. When the quality difference is not large, the total market volume of scene 3 is the largest. It can be seen that although the previous conclusion tells us that $m_2^{2*} > m_1^{1*}$ is always true, but m_2^{2*} will be relatively smaller when the quality difference is large and the low-carbon innovation cost is high. At the same time, due to a slightly higher P_2^{2*}, all these factors will make the market share of RSP_2, which is relatively larger, become smaller than that before, and the total market will become smaller. The platform trading volume is a reduction function of k and an increasing function of θ. However, for the trading platform, the total amount of transactions is directly related to the interests of the platform. Therefore, from the perspective of platform development, it can consider raising the upper limit threshold or providing appropriate low-carbon innovation subsidies to RSP_i for expanding the trading market.

5. NUMERICAL ANALYSIS

In order to analyze the equilibrium price strategy and profit of RSP_i under different scenarios more intuitively, the government's project subsidy rate and low-carbon innovation effort coefficient, and the influence of different factors on them, this section verifies the above model and conclusion through case analysis. The common parameters in the above model are set to: $\beta = 0.01, a = 0.1$ .Thus we can get the relationship between the price strategy of RSP_i and the difference of k and θ in scene 2 and 3, as figure 3-4 shows:

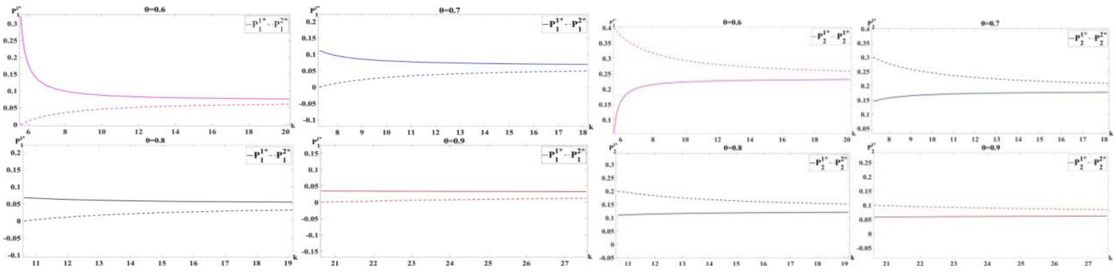

Figure 3. The price strategy of RSP_i in different scenes

It can be concluded from Figures 3-4 that the P_i^{i*} decreases with the increase of k, but tends to be stable. When RSP_i does not carry out low-carbon innovation, its pricing increases to a stable value with the increase of k. And under different quality differences, the decline/rise is not the same, it can be seen that the decline/rise trend will be significantly slowed down when the quality difference is small, that is, the market pricing of both sides will not change greatly with low carbon innovation investment. The smaller the quality difference is, the lower the price strategy for green innovation will be, and the P_i^{i*} will also be reduced. Comparing the price strategies of the two sides in different scenarios, it is found that P_x^{y*} is always less than P_x^{x*}, which also verifies the previous conclusion.

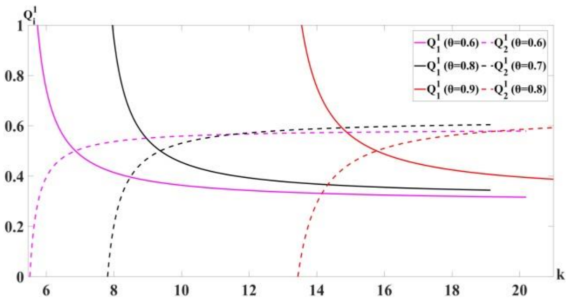

Figure 4. RSP_i 's market share in scene 2

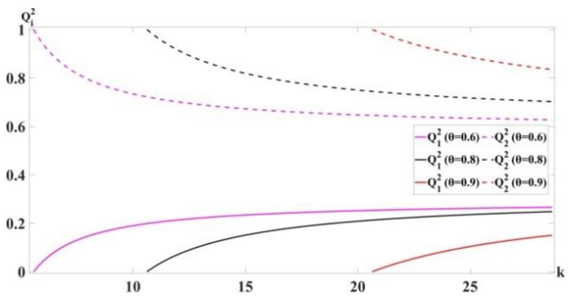

Figure 5. RSP_i 's market share in scene 3

As Figure 5-6 shows, under different θ values, k has different value range to make Q_1^i greater than zero, that is, our research is based on the competition between RSP_i, so we compare in the k value range under different scenes. It can be found that: compared with the market share gap between RSP_i under scene 2 and scene 3, the gap between the two sides under scene 2 is significantly smaller than that of scene 3, and when k is small in scene 2, the market share of RSP_1 is even higher than RSP_2, and this critical value increases with the increase of θ between R_i. When one party carries out green innovation, its market share will decrease with the increase of k, while the market share of the other party will increase with the increase of k, but eventually will tend to be flat. It is worth noting that the Q_1^* convergence value in Scene 2 is significantly greater than that in scene 3, while the Q_2^* convergence value when θ is small has no significant difference in the two scenes. When the θ is large, the convergence value in scene 3 is greater than that in scene 2. Therefore, no matter who carries out low-carbon innovation, it is beneficial for the expansion of its market. For RSP_1 in scene 2, its market share increases with the increase of θ, while for RSP_2, the correlation between market share and θ depends on the size of

k. But in scene 3, Q_1^* decreases with the increase of θ, and Q_2^* is monotonically positively correlated with θ.

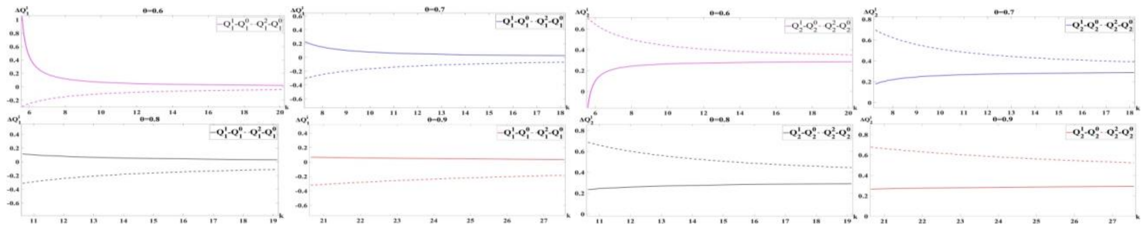

Figure 6. Comparison of RSP_i 's market share differences (scene2-1 and scene2-3)

For the market share difference of RSP_1 between scene 2\3 with scene 1, as shown in Figure 7-8, the market share of RSP_1 after green innovation is significantly higher than that of scenes 1 and 3. The market share difference between scenes 2-1, 3-1 and 2-3 decreases with the increase of k. Except for the situation that the θ is small and k is low, the market expansion of RSP_1 after low-carbon innovation is stable at a low level (the change relationship with k and θ is not obvious), but the maximum expectation of RSP_1 's market expansion is slightly higher when θ is small, but the minimum expectation is low.

For the market share of RSP_2, except for the case that the θ is small and k is low in scene 2, as long as RSP_i carries out green innovation, its market share will increase, but the increase in market share of itself is significantly greater than that of the other party when it carries out low-carbon innovation, and the difference decreases with the increase of k, but the decrease slows down with the increase of θ. This difference also increases with the increase of θ, indicating that RSP_2 's low-carbon innovation brings more benefits to its market expansion when the θ is large.

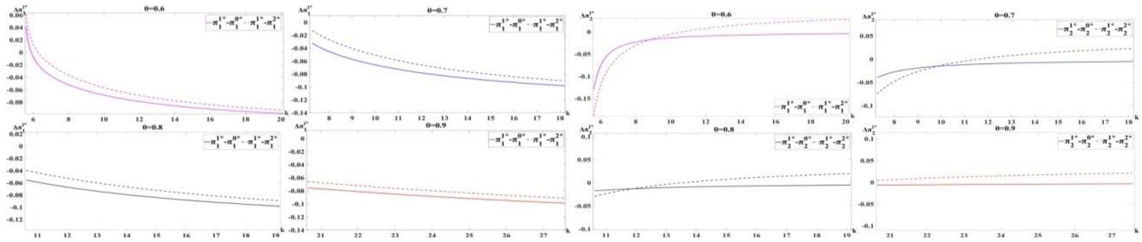

Figure 7. Comparison of RSP_i 's profit differences (scene2-1 and scene2-3)

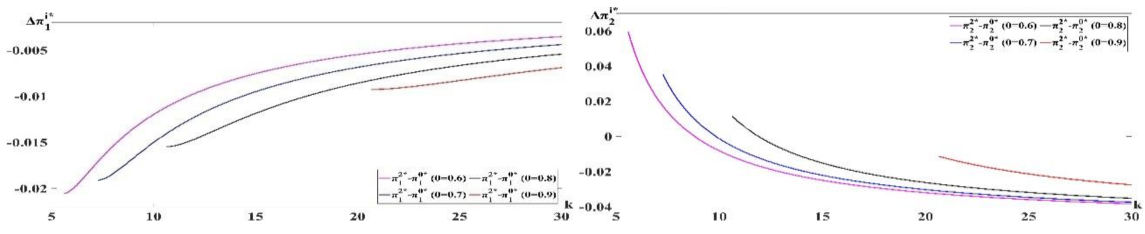

Figure 8. Comparison of RSP_i 's profit differences (scene3-1)

As shown in Figure 9-11, when RSP_1 conducting low-carbon innovation, the profit will increase relative to scenes 1 and 3 only when the θ and k are small, and the profit under scene 3 is always less than scene 1, that is, $\pi_1^{1*}<\pi_1^{2*}<\pi_1^{0*}$ is established in general and $\pi_1^{2*}<\pi_1^{0*}<\pi_1^{1*}$ is only established in special cases. The profit difference between scenes 2–1 and scenes 2–3 generally increases with the increase of k, and tends to be flat with the increase of θ. The expected value of RSP_1 profit loss (scene 2–1) increases with the increase of θ, while the profit difference of RSP_1 between scenes 3–1 decreases with the increase of k, and the profit difference is smaller with the decrease of the θ.

For the RSP_2 's profit in scene 2, compared with scene 1, its profit decreases, we can get $\pi_2^{0*}>\pi_2^{1*}$,and this difference decreases monotonically with k; The comparison with profits under scene 3 depends on the size of θ and k, when θ is relatively small $(\theta<0.9)$, there are two boundary points 1 and 2 of k, $\pi_2^{1*}<\pi_2^{0*}<\pi_2^{2*}$ when $k<k_1$, $\pi_2^{1*}<\pi_2^{2*}<\pi_2^{0*}$ when $k_1<k<k_2$, $\pi_2^{2*}<\pi_2^{1*}<\pi_2^{0*}$ when $k>k_2$; When θ is large $(\theta \geq 0.9)$ we get $\pi_2^{2*}<\pi_2^{1*}<\pi_2^{0*}$. The profit function of RSP_2 is always a decreasing function of k, and when k is large, the yield profit of RSP_2 in scene 3 is an increasing function of θ.

Combined with the above analysis, the innovation willingness of RSP_i for low-carbon innovation (equal to the estimated profit minus the basic profit) will show great differences with the difference in the θ and the k. In most cases, the innovation willingness of RSP_1 is generally low, which is far lower than that of RSP_2 for low-carbon innovation, and decreases with the increase of θ and the k. If RSP_1 starting from the perspective of their own short-term interests, because the reduction of profits may not lead to green innovation, but the market share in scene 1 or scene 3 will be lower than that in scene 2, and the pricing of RSP_1 in scene 2 is at the maximum value in three cases. The profit and loss of short-term profits are only due to the input of early innovation costs, so in the long run, RSP_1 should take the initiative to seek opportunities for the improvement of product greenness, so that the market share it occupies will increase significantly, and there is a chance to exceed the market share of RSP_2. For RSP_2, the smaller the quality difference is, the lower the innovation willingness is. That is to say, when the quality difference between the two sides is large, although the market expansion degree is small at this time, the pricing is slightly higher, so the profit gain of RSP_2 is larger at this time.

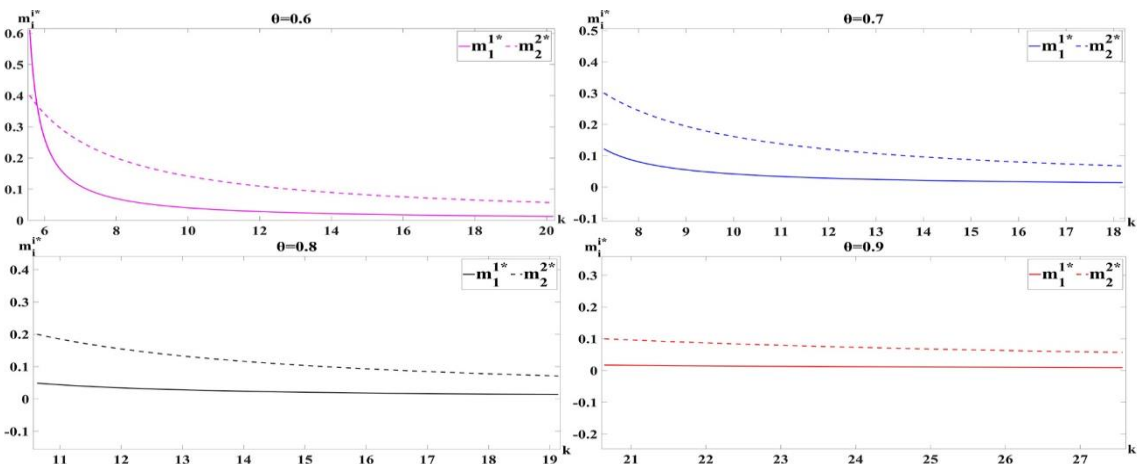

Figure 9. Comparison of RSP_i 's low-carbon innovation effort coefficient

As shown in Figure 12, only when θ and k are small, $m_1^{1*} > m_2^{2*}$, and m_i^{i*} is negatively correlated with k. When RSP_1 carrying out low-carbon innovation, the impact of k on its effort decreases with the increase of θ ,and m_1^{1*} tends to zero in most cases. When RSP_2 carries out low-carbon innovation, its effort decreases with the increase of θ, and the influence of k on its effort decreases with the increase of θ. It is worth noting that when m_i^{i*} reaches the maximum value, the corresponding θ and k values are consistent with the highest innovation intention, that is, innovation intention is positively correlated with innovation effort.

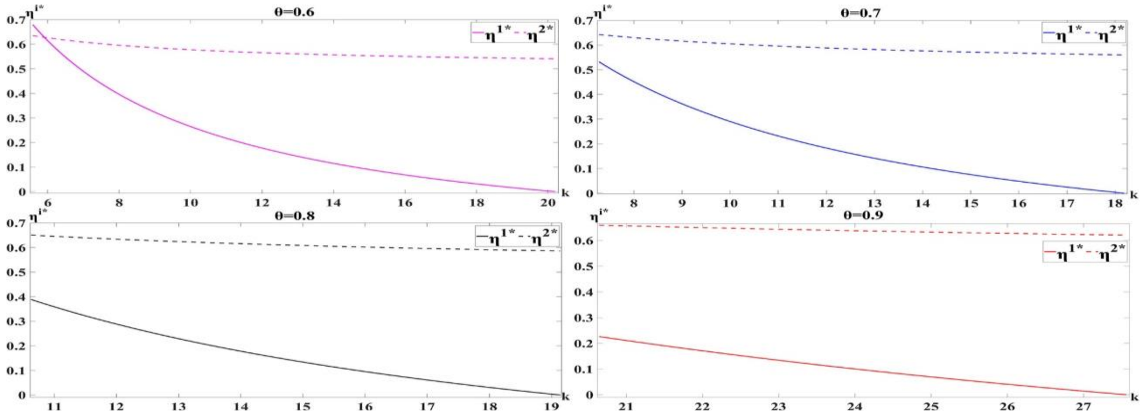

Figure 10. Comparison of government subsidy rate

As shown in Figure 13, only if the θ and k are small, $\eta^{1*} > \eta^{2*}$ can be obtained. But in other situations, we only can get $\eta^{1*} < \eta^{2*}$. And when k is larger, η^{i*} is smaller; With the increase of θ, the value range of η^{1*} will gradually become smaller, and the decrease rate of k will gradually slow down, while η^{2*} is maintained in a similar interval and slightly increased, and the influence of k on η^{2*} is gradually reduced.

6. CONCLUSION AND FORESIGHT

This paper studies the resource providers' low-carbon innovation strategy and government subsidy strategy under the background of collaborative sharing of manufacturing resources. Considering the impact of resource quality differences and low-carbon preferences of demanders on resource providers' low-carbon innovation investment, operation strategy, and government subsidy rate, under the three scenes of neither low-carbon innovation, low-quality resource providers' low-carbon innovation, and high-quality resource providers, the utility theory and Stackelberg game method are used to construct resource providers' decision model with profit maximization as the goal and the decision model with social welfare maximization as the goal. The optimal government subsidy rate, the optimal low-carbon innovation effort coefficient, and the optimal price strategy in different scenes are obtained by using the reverse induction method. Then it compares the equilibrium schemes of resource providers and government in different scenarios, and the influence of quality relative coefficient and innovation cost coefficient on the equilibrium scheme in different innovation scenes. Finally, in order to analyze the equilibrium results more intuitively, this paper makes further numerical analysis. In this process, the following research conclusions are obtained:

(1) The degree of low-carbon innovation efforts is only related to low-carbon innovation cost and quality differences between RSP_i, and when the cost of low-carbon innovation is high, both RSP_i should invest in low cost of innovation. ①For low-carbon innovation in scene 2:When RSP_1 deciding on low-carbon innovation, it should consider: **a.** When θ is small, it should avoid the impact of the high cost of low-carbon innovation and reduce investment appropriately, and instead choose lower resource pricing to compensate for market weaknesses; **b.** When θ is large, the investment in low-carbon innovation should be comprehensively considered by combining the platform transaction rate and innovation cost. In most cases, the investment should increase with the narrowing of the quality difference, but when the innovation cost and transaction rate are large, the investment in low-carbon innovation should be reduced to avoid risks with the narrowing of the quality difference; **c.** When the quality of resources between the two sides is very close, innovation input should be reduced and resource pricing should be reduced to gradually encroach on the market as quality differences narrow. ② For low-carbon innovation in scene 3: As the quality difference between the two sides shrinks, innovation input should be reduced.

(2) ①From the perspective of resource pricing: When RSP_i conducting low-carbon innovation, they should pay more attention to θ developing higher pricing to recover the cost of investment, but at this time they should also pay more attention to low-carbon innovation costs to adopt lower pricing to gain greater market share. ②From the perspective of market share: **a.** RSP_1 should consider k when to determine the amount of investment in innovation costs, after which only when is k too large, its market share will be lower than RSP_2, and innovation initiatives, in this case, can also significantly narrow the gap with RSP_2's market share. And in most cases (except that there is almost no difference in quality and the innovation cost is in the middle value, the greater the quality disadvantage is, the greater the benefit of low-carbon innovation is), the larger the θ is, and the larger the market share that this measure can occupy is. **b.** RSP_2 should be based on k to decide whether to carry out low-carbon innovation. When k is low, it is bound to carry out low-carbon innovation, and the greater its original quality advantage, the smaller its market share advantage after low-carbon innovation; When k is high, it is unnecessary to carry out low-carbon innovation. ③ From the perspective of RSP_i profits: **a.** When RSP_1 conducting low-carbon innovation, it is generally necessary to bear the early profit loss to obtain market expansion and reputation improvement. **b.** When low-carbon innovation is carried out by RSP_2, the θ and k should be considered to measure the profit and loss. When θ is relatively small($\theta < 0.9$), there are two boundary points for k. When k is low, the profit increases after innovation and the profit loss is the largest in the opposite situation. When the innovation cost is in the middle value, the profit is lost after innovation, but the loss is larger in the opposite situation. When the innovation cost is large, the profit is lost after innovation, and the profit loss is small in the opposite situation. Deciding to conduct low-carbon innovation is always the most defective decision of RSP_2 when there is no difference in resource quality between RSP_i. And the lost profit in scene 3 increases with the decrease of θ.

(3) For the government, the formulation of its subsidy rate is related to low-carbon innovation costs, resource quality differences, and platform transaction rates. ①Subsidy for low-carbon resource innovation on the same trading platform: When k is low and the quality of platform resources varies greatly, the government should support RSP_1 with higher risk to conduct low-carbon innovation with a higher subsidy rate; When k is high or θ is large, the government should fully measure the efficiency of subsidies for improving social and

environmental benefits, and make greater subsidies for RSP_2 with more market influence. However, the subsidy rate difference between them decreases with the increase of k. ② Low-carbon innovation subsidies for resources on platforms with different transaction rates: For the platform government with a high transaction rate, it should give a higher subsidy rate. If the quality of platform resources varies greatly and k is low, the government should set a smaller subsidy rate difference to encourage innovation, while the government should set a larger subsidy rate difference when k is high. And the government should set a smaller subsidy rate difference based on higher commission rates if the quality of platform resources varies a little.

(4) For the total market volume of trading on the platform, it has an extremely important impact on the development of the platform: When θ and k are small, the platform should introduce corresponding policies to encourage high-quality resource providers to carry out low-carbon innovation to promote the development of the platform, and when θ is small but k is high, the platform should introduce corresponding policies to encourage low-quality resource providers to carry out low-carbon innovation to promote the development of the platform; When θ is large, the platform should introduce corresponding policies to encourage high-quality resource providers to carry out low-carbon innovation to promote the development of the platform. In these low-carbon innovation scenes, the platform should also consider raising the quality threshold of resources online or publishing appropriate preferential subsidies for low-carbon innovation in order to achieve a better market expansion effect.

This study considers the impact of manufacturing resource quality on low-carbon innovation decision-making and effect, and further considers the after-sales service attributes of manufacturing resources. Low-carbon innovation under platform incentives is also a feasible way to improve the green degree of resources under the background of resource sharing. With the increasing awareness of environmental protection among consumers/manufacturers/markets, subsidy targets have become feasible research points affecting the green degree of resources, which have a crucial impact on the development and promotion of low-carbon products. Subsequent research can be carried out in combination with the relevant attributes of resources and different mechanisms of subsidies.

ACKNOWLEDGEMENTS

This paper is supported by the National Key Research and Development Program of China (2019YFB1706101) and the Humanities and Social Sciences Research Planning Project of Chongqing Education Commission in 2022 (No.22SKGH433). The authors would also like to express appreciation to the anonymous reviewers and editors for their very helpful comments that improved the paper.

REFERENCES

[1] Chinaenvironment.com. "United Nation Conference on Environment and Development (1992)." http://www.chinaenvironment.com/view/ViewNews.Aspx?k=1992060-3154607437 (accessed.

[2] J.-B. Sheu and Y. J. Chen, "Impact of government financial intervention on competition among green supply chains," International Journal of Production Economics, vol. 138, no. 1, pp. 201-213, 2012, DOI: 10.1016/j.ijpe.2012.03.024.

[3] S. R. Madani and M. Rasti-Barzoki, "Sustainable supply chain management with pricing, greening and governmental tariffs determining strategies: A game-theoretic approach," Computers & Industrial Engineering, vol. 105, pp. 287-298, 2017, doi:10.1016/j.cie.2017.01.017.

[4] Chen Z S. A Bargaining-Coordination Mechanism for Green Supply Chain of Wood-based Panel under the Government's Incentive Policy[J]. Chinese Journal of Management Science, 2016, 24(02): 115-124

[5] H. K. Chan, H. He, and W. Y. C. Wang, "Green marketing and its impact on supply chain management in industrial markets," Industrial Marketing Management, vol. 41, no. 4, pp. 557-562, 2012, doi: 10.1016/j.indmarman.2012.04.002.

[6] M. Frostenson and F. Prenkert, "Sustainable supply chain management when focal firms are complex: a network perspective," Journal of Cleaner Production, vol. 107, pp. 85-94, 2015, DOI: 10.1016/j.jclepro.2014.05.034.

[7] D. Krass, T. Nedorezov, and A. Ovchinnikov, "Environmental Taxes and the Choice of Green Technology," Production and Operations Management, pp. n/a-n/a, 2013, doi: 10.1111/poms.12023.

[8] A. C. da Silva, M. P. Méxas, and O. L. G. Quelhas, "Restrictive factors in implementation of clean technologies in red ceramic industries," Journal of Cleaner Production, vol. 168, pp. 441-451, 2017, DOI: 10.1016/j.jclepro.2017.09.086.

[9] X. Zhang, T. Chen, and C. Shen, "Green investment choice in a duopoly market with quality competition," Journal of Cleaner Production, vol. 276, 2020, doi: 10.1016/j.jclepro.2020.124032.

[10] Y. Yao and K. X. Zhu, "Research Note—Do Electronic Linkages Reduce the Bullwhip Effect? An Empirical Analysis of the U.S. Manufacturing Supply Chains," Information Systems Research, vol. 23, no. 3-part-2, pp. 1042-1055, 2012, doi: 10.1287/isre.1110.0394.

[11] "A Model of Neutral B2B Intermediaries," Journal of Management Information Systems, vol. 19, no. 3, pp. 43-68, 2014, doi: 10.1080/07421222.2002.11045734.

[12] W. Thitimajshima, V. Esichaikul, and D. Krairit, "A framework to identify factors affecting the performance of third-party B2B e-marketplaces: A seller's perspective," Electronic Markets, vol. 28, no. 2, pp. 129-147, 2017, doi: 10.1007/s12525-017-0256-3.

[13] A. W. Siddiqui and S. A. Raza, "Electronic supply chains: Status & perspective," Computers & Industrial Engineering, vol. 88, pp. 536-556, 2015, doi: 10.1016/j.cie.2015.08.012.

[14] O. Sohaib, M. Naderpour, W. Hussain, and L. Martinez, "Cloud computing model selection for e-commerce enterprises using a new 2-tuple fuzzy linguistic decision-making method," Computers & Industrial Engineering, vol. 132, pp. 47-58, 2019, doi: 10.1016/j.cie.2019.04.020.

[15] D. Ghosh and J. Shah, "A comparative analysis of greening policies across supply chain structures," International Journal of Production Economics, vol. 135, no. 2, pp. 568-583, 2012, doi: 10.1016/j.ijpe.2011.05.027.

[16] Z. Liu, T. D. Anderson, and J. M. Cruz, "Consumer environmental awareness and competition in two-stage supply chains," European Journal of Operational Research, vol. 218, no. 3, pp. 602-613, 2012/05/01/ 2012, doi: https://doi.org/10.1016/j.ejor.2011.11.027.

[17] R. C. Savaskan, S. Bhattacharya, and L. Wassenhove, "Closed-Loop Supply Chain Models with Product Remanufacturing," Management Science, vol. 50, no. 2, pp. 239-252, 2004.

[18] J. Gao, H. Han, L. Hou, and H. Wang, "Pricing and effort decisions in a closed-loop supply chain under different channel power structures," Journal of Cleaner Production, vol. 112, pp. 2043-2057, 2016, doi: 10.1016/j.jclepro.2015.01.066.

[19] A. Atasu and G. C. Souza, "How Does Product Recovery Affect Quality Choice?," Production and Operations Management, vol. 22, no. 4, pp. 991-1010, 2013, doi: 10.1111/j.1937-5956.2011.01290.x.