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Research on Financing Strategies of Capital-Constrained Green Product Manufacturers Under Manufacturer Competition

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ABSTRACT

This paper investigates the financing strategies of capital-constrained green product manufacturers under manufacturer competition. Considering the competition between capital-constrained green product manufacturers, three game models corresponding to external financing, internal financing, and mixed external-internal financing are constructed respectively, and comparative analysis is conducted on the three proposed game models. The results show that the profit dominance of Manufacturer 1 and Manufacturer 2 under different financing models is closely related to the financing interest rate and the product competition intensity coefficient. The retail pricing of retailers across various financing modes is also highly dependent on financing interest rates. In contrast, manufacturers' green technology investment levels and retailers' profits are only determined by financing interest rates.

KEYWORDS

Financing strategy; Capital constraint; Manufacturer competition

1. INTRODUCTION

With the increasingly prominent problems of resource scarcity, environmental degradation and climate change, green development, as the fundamental guarantee for sustainable development, has attracted extensive attention from government departments and all sectors of society. In 2016, ten national departments including the National Development and Reform Commission, the Publicity Department of the Communist Party of China Central Committee, and the Ministry of Science and Technology jointly issued the Guiding Opinions on Promoting Green Consumption, which clearly encourages enterprises to promote green supply chain construction, implement green supply chain management, and develop and produce green products. In 2020, the National Development and Reform Commission and the Ministry of Justice jointly issued the Opinions on Accelerating the Establishment of a Legal and Policy System for Green Production and Consumption, proposing a series of measures including promoting green design, strengthening industrial clean production, expanding the consumption of green products, and advocating green lifestyles. These policy initiatives have clarified the direction of green and sustainable development for enterprises. Meanwhile, consumers' environmental awareness has been continuously improved, and they are increasingly inclined to purchase green and low-carbon products [1-2].

In response to national policies and produce products that conform to consumers' green concepts, a growing number of manufacturers have continuously increased investment in the research and development of green products during production [3-4]. In practice, Foxconn collaborated with Xuzhi Capital in 2024 to launch a 7 billion-yuan green energy development fund to deploy the sustainable green energy industry. In 2021, Toyota planned to invest 35 billion US dollars in the next eight years

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to research and manufacture electric vehicles that better align with green consumption concepts. In 2022, Apple Inc. invested 4.7 billion US dollars in the development of green technologies [5]. However, compared with the production of traditional products, the production of green products requires substantial capital investment. This makes many enterprises face capital constraints and unable to carry out green technology investment [6], which weakens the market competitiveness of their products and restricts the sustainability of low-carbon supply chain operations [7-9]. It is evident that capital constraints seriously hinder the implementation of green supply chain management for enterprises, which not only impedes the improvement of their market competitiveness but also reduces the overall operational efficiency and benefits of the supply chain [10-11]. Therefore, solving the capital constraint problem of green technology investment for green product manufacturing enterprises is a crucial practical issue at present.

Financing, as an effective means to solve corporate capital shortages, has been widely applied in practical production and operation. Common financing modes include external financing and internal financing. External financing means that capital-constrained enterprises raise funds from third-party financial institutions outside the supply chain system (e.g., banks) [12]. As a vital financing method, it is widely adopted in the Internet, automobile manufacturing, battery manufacturing and other industries. For instance, Alibaba has obtained external financing from SoftBank Group and Vanguard Group; NIO has received external financing from Tencent and Baidu; in 2022, CATL issued external financing worth no more than 10 billion yuan. At the same time, capital-abundant enterprises within the same supply chain can provide financial support for capital-constrained enterprises, namely internal financing. For example, capital-sufficient retailers such as Walmart and Marks & Spencer have provided internal financing for green production projects of their upstream manufacturers [13]. In 2013, some enterprises on the JD.com platform obtained internal financing through JD's financial products such as "Jing Baobei" and "Jing Xiao Dai". Huawei has provided at least 1 billion US dollars of internal financing for high-quality suppliers [14-15].

Nevertheless, given the diversity of financing modes, it is a practical and worthy research issue for capital-constrained enterprises to select the optimal financing strategy. Accordingly, this paper focuses on the following research questions: What is the optimal financing strategy for capital-constrained green product enterprises to achieve profit maximization? What factors affect the financing strategy selection of green product enterprises? Based on the above questions, this paper constructs three game models of external financing, internal financing, and mixed external-internal financing under manufacturer competition, and explores the optimal financing strategies of capital-constrained green product manufacturers.

2. PROBLEM DESCRIPTION AND ASSUMPTIONS

2.1. Problem Description

This section considers a two-echelon competitive green supply chain consisting of two green product manufacturers and one retailer. The two manufacturers engage in Nash competition and act as the dominant leaders in the supply chain, who have the decision-making rights regarding green technology investment levels and product wholesale prices. Both Manufacturer 1 (M1) and Manufacturer 2 (M2) adopt innovative production methods and carry out technological innovation to produce green products. However, both manufacturers are subject to capital constraints. To address capital shortages, they can either obtain external financing from third-party financial institutions (e.g., banks) or acquire internal financing support provided by the retailer. Against this research background, this paper mainly investigates the financing strategy selection of capital-constrained green product manufacturers.

To solve the above research problem, three game models with different financing modes are established in this paper: ① AB Model (pure external financing game model): Both capital-

constrained manufacturers M1 and M2 adopt pure external financing and obtain funds from third-party financial institutions. ② AR Model (pure internal financing game model): Both capital-constrained manufacturers M1 and M2 adopt pure internal financing and obtain financial support from the retailer. ③ AM Model (mixed external-internal financing game model): The capital-constrained manufacturer M1 adopts external financing, while M2 adopts internal financing.

2.2. Model Assumptions

To facilitate quantitative analysis, the following basic assumptions are proposed in this paper:

Assumption 1: The two manufacturers produce green products simultaneously. When confronted with capital constraints, they may select external financing or internal financing according to their own interests. The competition between Manufacturer 1 and Manufacturer 2 follows Nash equilibrium. The two manufacturers and the retailer engage in a Stackelberg game, where the manufacturers act as the leaders.

Assumption 2: The manufacturers have initial capital for producing traditional products but face capital constraints when producing green products. In this case, the manufacturers can obtain external financing from third-party financial institutions. Meanwhile, the capital-abundant retailer can provide internal financing to the manufacturers. The green technology investment cost is assumed to be $C(e) = ke^2$, where e denotes the green technology investment level of the product, and k represents the cost coefficient of green technology investment.

Assumption 3: The product demand function is given by:

$$\begin{cases} d_1 = a - p_1 + \lambda p_2 + e_1 - \tau e_2 \\ d_2 = a - p_2 + \lambda p_1 + e_2 - \tau e_1 \end{cases} \tag{1}$$

Consumers in the market have homogeneous preferences for green low-carbon products, and the two products compete in the marketplace. a is the potential market demand; p_1 and p_2 are the selling prices of the two products; λ stands for the price competition intensity between the two products. A larger λ indicates fiercer competition and stronger substitutability between the two products. τ is the green sensitivity coefficient of demand. A lower product price, a higher price of the competing product, and a higher green level exert positive effects on market demand.

Assumption 4: The manufacturers and the retailer in the supply chain participate in a manufacturer-led Stackelberg game. As the supply chain leaders, the two manufacturers simultaneously determine the green technology investment level and wholesale price of products while competing with each other. After observing the manufacturers' decisions, the retailer determines the retail price and order quantity of the products.

The notations and their definitions used in this chapter are shown in Table 1.

Table 1. Parameter Definitions

Notation	Definition	Notation	Definition
p_i	Retail price of products sold by Retailer i	τ	Ratio of the green sensitivity coefficient of demand
e_i	Green technology investment level of Retailer i's product	$r_\omega(\omega \in 1,2)$	{External financing interest rate, Internal financing interest rate}
d_i	Demand quantity for Retailer i	π_{Mi}^{j}	Manufacturer i's profit under Model j
w_i	Wholesale price of products for retailers i	π_{Ri}^{j}	Retailer i's profit under model j
k	Cost coefficient of green technology investment	BB	External financing model
a	Market demand scale	BR	Internal financing model
λ	Product competition intensity coefficient	BM	Mixed external-internal financing model
$i \in \{1,2\}$	{Manufacturer 1, Manufacturer 2}		$j \in \{AB, AR, AM\}$

3. GAME MODEL CONSTRUCTION AND SOLUTION

3.1. External Financing Game Model (Model AB)

Both Manufacturer 1 and Manufacturer 2 adopt the external financing mode when facing capital constraints. The specific decision sequence is as follows: (1) As the leaders, the manufacturers first determine the product wholesale price and green technology investment level; (2) As the follower, the retailer decides the retail price of green products; (3) At the beginning of the production period, the capital-constrained manufacturers M1 and M2 borrow an amount of $I = ke^2$ from external institutions such as banks; (4) The manufacturers use the loan to produce green products and sell them to the retailer; (5) The retailer sells green products to consumers; (6) The manufacturers repay the loan principal and interest of $(1+r_1)ke^2$.

Under the pure external financing model, the profit functions of the manufacturers and the retailer are expressed respectively as:

$$\begin{cases} \pi_{M1}^{AB}(e_1, w_1) = (w_1 - c)d_1 - (1+r_1)k(e_1)^2 \\ = (w_1 - c)(a - p_1 + \lambda p_2 + e_1 - \tau e_2) - (1+r_1)k(e_1)^2 \\ \pi_{M2}^{AB}(e_2, w_2) = (w_2 - c)d_2 - (1+r_1)k(e_2)^2 \\ = (w_2 - c)(a - p_2 + \lambda p_1 + e_2 - \tau e_1) - (1+r_1)k(e_2)^2 \\ \pi_{R}^{AB}(p_1, p_2) = (p_2 - w_2)d_2 + (p_1 - w_1)d_1 \\ = (p_2 - w_2)(a - p_2 + \lambda p_1 + e_2 - \tau e_1) + (p_1 - w_1)(a - p_1 + \lambda p_2 + e_1 - \tau e_2) \end{cases} \tag{2}$$

Backward induction is adopted to derive the equilibrium wholesale price, retail price, equilibrium green technology investment level, order quantity and profits of the manufacturers and the retailer under Model AB. Accordingly, Proposition 1 can be obtained.

Proposition 1 Under Model AB, when $2k(1+r_1) - \frac{1}{4} > 0$, the equilibrium decisions of the manufacturers and the retailer are:

$$\begin{cases} w_1^{AB*} = w_2^{AB*} = -\dfrac{4k(a+c)(1+r_1)+c(\tau-1)}{1+4k(\lambda-2)(1+r_1)-\tau} \\ e_1^{AB*} = e_2^{AB*} = \dfrac{-(a-c+c\lambda)}{1+4k(\lambda-2)(1+r_1)-\tau} \\ p_1^{AB*} = p_2^{AB*} = \dfrac{2ak(1+r_1)(3-2\lambda)+c(1-\lambda)(2k+\tau-1+2kr_1)}{(\lambda-1)[1+4k(\lambda-2)(1+r_1)-\tau]} \\ d_1^{AB*} = d_2^{AB*} = -\dfrac{2k(a-c+c\lambda)(1+r_1)}{1+4k(\lambda-2)(1+r_1)-\tau} \end{cases} \tag{3}$$

The equilibrium profits of the manufacturers and the retailer at this time are:

$$\begin{cases} \pi_{M1}^{AB*} = \pi_{M2}^{AB*} = \dfrac{k(a-c+c\lambda)^2(1+r_1)(8k+8kr_1-1)}{[1+4k(\lambda-2)(1+r_1)-\tau]^2} \\ \pi_R^{AB*} = \dfrac{8k^2(a-c+c\lambda)^2(1+r_1)^2}{(1-\lambda)[1+4k(\lambda-2)(1+r_1)-\tau]^2} \end{cases} \tag{4}$$

3.2. Internal Financing Game Model (Model AR)

Under Model AR, the upstream and downstream supply chain members engage in a Stackelberg game, while the two upstream manufacturers play a Nash game with each other. At this stage, both Manufacturer 1 and Manufacturer 2 face capital constraints arising from green technology investment and adopt internal financing with a total financing amount of $I = ke^2$ and an internal financing interest rate of r_2. The dynamic game sequence between the two competing manufacturers and the retailer is described as follows: the two manufacturers simultaneously determine their green technology investment levels and wholesale prices, and then the retailer sets the retail price as the follower. The profit functions of the manufacturers and the retailer are given by:

$$\begin{cases} \pi_{M1}^{AR}(e_1, w_1) = (w_1 - c)d_1 - (1+r_2)k(e_1)^2 \\ = (w_1 - c)(a - p_1 + \lambda p_2 + e_1 - \tau e_2) - (1+r_2)k(e_1)^2 \\ \pi_{M2}^{AR}(e_2, w_2) = (w_2 - c)d_2 - (1+r_2)k(e_2)^2 \\ = (w_2 - c)(a - p_2 + \lambda p_1 + e_2 - \tau e_1) - (1+r_2)k(e_2)^2 \\ \pi_R^{AR}(p_1, p_2) = (p_2 - w_2)d_2 + (p_1 - w_1)d_1 + r_2k[(e_1)^2 + (e_2)^2] \\ = (p_2 - w_2)(a - p_2 + \lambda p_1 + e_2 - \tau e_1) + (p_1 - w_1)(a - p_1 + \lambda p_2 + e_1 - \tau e_2) + r_2k[(e_1)^2 + (e_2)^2] \end{cases} \tag{5}$$

Backward induction is used to derive the equilibrium wholesale price, retail price, green technology investment level, order quantity and profits of the manufacturers and the retailer. Accordingly, Proposition 2 can be obtained.

Proposition 2 Under Model AR, the equilibrium decisions of the manufacturers and the retailer are:

$$\begin{cases} w_1^{AR*} = w_2^{AR*} = -\dfrac{4k(a+c)(1+r_2)+c(\tau-1)}{1+4k(\lambda-2)(1+r_2)-\tau} \\ e_1^{AR*} = e_2^{AR*} = \dfrac{-(a-c+c\lambda)}{1+4k(\lambda-2)(1+r_2)-\tau} \\ p_1^{AR*} = p_2^{AR*} = \dfrac{2ak(1+r_2)(3-2\lambda)+c(1-\lambda)(2k+\tau-1+2kr_2)}{(\lambda-1)[1+4k(\lambda-2)(1+r_2)-\tau]} \\ d_1^{AR*} = d_2^{AR*} = -\dfrac{2k(a-c+c\lambda)(1+r_2)}{1+4k(\lambda-2)(1+r_2)-\tau} \end{cases} \tag{6}$$

The equilibrium profits of the manufacturers and the retailer are:

$$\begin{cases} \pi_{M1}^{AR*} = \pi_{M2}^{AR*} = \dfrac{k(a-c+c\lambda)^2(1+r_2)(8k+8kr_2-1)}{[1+4k(\lambda-2)(1+r_2)-\tau]^2} \\ \pi_R^{AR*} = \dfrac{2k(a-c+c\lambda)^2[4k+r_2(1+8k-\lambda+4kr_2)]}{(1-\lambda)[1+4k(\lambda-2)(1+r_2)-\tau]^2} \end{cases} \tag{7}$$

3.3. Mixed External-Internal Financing Game Model (Model AM)

When both M1 and M2 are subject to capital constraints, they need to raise funds with a financing amount of $I = ke^2$. Without loss of generality, M1 chooses external financing while M2 adopts internal financing. The external financing interest rate is denoted by r_1, and the internal financing interest rate is denoted by r_2. The profit functions of all supply chain members are given by:

$$\begin{cases} \pi_{M1}^{AM}(e_1, w_1) = (w_1 - c)d_1 - (1+r_1)k(e_1)^2 \\ = (w_1 - c)(a - p_1 + \lambda p_2 + e_1 - \tau e_2) - (1+r_1)k(e_1)^2 \\ \pi_{M2}^{AM}(e_2, w_2) = (w_2 - c)d_2 - (1+r_2)k(e_2)^2 \\ = (w_2 - c)(a - p_2 + \lambda p_1 + e_2 - \tau e_1) - (1+r_2)k(e_2)^2 \\ \pi_R^{AM}(p_1, p_2) = (p_2 - w_2)d_2 + (p_1 - w_1)d_1 + r_2k(e_2)^2 \\ = (p_2 - w_2)(a - p_2 + \lambda p_1 + e_2 - \tau e_1) + (p_1 - w_1)(a - p_1 + \lambda p_2 + e_1 - \tau e_2) + r_2k(e_2)^2 \end{cases} \tag{8}$$

Under Model AM, backward induction is adopted to derive the retailer's equilibrium retail price, order quantity and profit, as well as the manufacturers' optimal wholesale price, green technology investment level and profit. Accordingly, Proposition 3 can be obtained.

Proposition 3 Under Model AM, the equilibrium decisions and profits of the manufacturers and the retailer are expressed as:

$$
\begin{cases}
w_1^{AM*} = -\dfrac{\left[\begin{array}{l}4ak(1+r_1)H_4 + c[1+16k^2(1+r_1)(1+r_2)(\lambda+2)\\ -4k(3+r_1+2r_2+\lambda+r_1\lambda)+4k(1+r_1+\lambda+r_2\lambda)\tau-\tau^2]\end{array}\right]}{H_3} \\
w_2^{AM*} = -\dfrac{\left[\begin{array}{l}4ak(1+r_2)H_5 + c[1+16k^2(1+r_1)(1+r_2)(\lambda+2)\\ -4k(3+2r_1+r_2+\lambda+r_2\lambda)+4k(1+r_2+\lambda+r_1\lambda)\tau-\tau^2]\end{array}\right]}{H_3} \\
p_1^{AM*} = \dfrac{\left[\begin{array}{l}c(\lambda-1)\{1+\lambda+8k^2(1+r_1)(1+r_2)(1+\lambda)(2+\lambda)-2k\\ \times[5+r_1+4r_2+(7+4r_1+3r_2)\lambda+2(1+r_1)\lambda^2]+2k\tau(3+2\lambda)\\ \times(1+r_1+\lambda+r_2\lambda)-(1+\lambda)\tau^2\}+2ak\{4k(1+r_1)(1+r_2)(1+\lambda)\\ \times(2+\lambda)(2\lambda-3)+[3(1+r_1)+(1+r_2)\lambda-2(1+r_1)\lambda^2](1+\tau)\}\end{array}\right]}{(1-\lambda^2)H_3} \\
p_2^{AM*} = \dfrac{\left[\begin{array}{l}c(\lambda-1)\{1+\lambda+8k^2(1+r_1)(1+r_2)(1+\lambda)(2+\lambda)-2k\\ \times[5+r_2+7\lambda+r_1(4+3\lambda)+2\lambda^2+2\lambda r_2(2+\lambda)]+2k\tau(3+2\lambda)\\ \times(1+r_2+\lambda+r_1\lambda)-(1+\lambda)\tau^2\}+2ak\{4k(1+r_1)(1+r_2)(1+\lambda)\\ \times(2+\lambda)(2\lambda-3)+[3(1+r_2)+(1+r_1)\lambda-2(1+r_2)\lambda^2](1+\tau)\}\end{array}\right]}{(1-\lambda^2)H_3} \\
e_1^{AM*} = -\dfrac{(a-c+c\lambda)H_4}{H_3} \\
e_2^{AM*} = -\dfrac{(a-c+c\lambda)H_5}{H_3} \\
d_1^{AM*} = -\dfrac{2k(1+r_1)(a-c+c\lambda)H_4}{H_3} \\
d_2^{AM*} = -\dfrac{2k(1+r_2)(a-c+c\lambda)H_5}{H_3}
\end{cases}
\tag{9}
$$

The equilibrium profits of the manufacturers and the retailer are:

$$
\begin{cases}
\pi_{M1}^{AM*} = \dfrac{k(1+r_1)(8k+8kr_1-1)(a-c+c\lambda)^2[4k(\lambda+2)(1+r_2)-1-\tau]^2}{{H_3}^2} \\
\pi_{M2}^{AM*} = \dfrac{k(1+r_2)(8k+8kr_2-1)(a-c+c\lambda)^2[4k(\lambda+2)(1+r_1)-1-\tau]^2}{{H_3}^2} \\
\pi_R^{AM*} = \dfrac{\left[\begin{array}{l}k(a-c+c\lambda)^2\{128k^3(1+r_1)^2(1+r_2)^2(1+\lambda)(2+\lambda)^2+r_2(1-\lambda^2)(1+\tau)^2\\ -16k^2(1+r_1)(1+\lambda)(2+\lambda)\{4(1+\tau)+r_2[4+\lambda+\lambda^2+6\tau+2r_2(1+\tau)]\\ +r_1[2(1+\tau)+r_2(\lambda+\lambda^2+2\tau)]\}+4k(1+\tau)\{r_1^2(1+\tau)+r_2^2(1+\tau)+2(1+\lambda)\\ \times(1+\tau)+2r_2(1+\lambda)(\lambda+\lambda^2+\tau-1)+2r_1\times\{1+\lambda+\tau+\lambda\tau+r_2[\lambda(2\lambda+\lambda^2)+\tau-2]\}\}\}\end{array}\right]}{(1-\lambda^2){H_3}^2}
\end{cases}
\tag{10}
$$

Where $H_3 = [4k(\lambda-2)+1-\tau][4k(\lambda+2)-1-\tau]+4k(r_1+r_2)[4k(\lambda^2-4)+2-\lambda\tau]+16k^2r_1r_2(\lambda^2-4)<0$.

4. COMPARATIVE ANALYSIS

In the green supply chain with capital constraints, manufacturers focus on product greenness and their own profits, whereas the retailer is mainly concerned with its own profit. Based on the solved optimal decisions under the manufacturers' financing strategies, this paper compares the external and internal financing interest rates, and explores the performance of decision indicators under different interest

rate relationships and product competition intensities. Furthermore, the manufacturers' optimal financing strategies under various rate relationships and competition intensities are identified.

Proposition 4 Comparing the wholesale prices of Manufacturer 1 under the AB, AR and AM models yields the following results:

1) When $r_1 = r_2$, then $w_1^{AM*} = w_1^{AR*} = w_1^{AB*}$;

2) When $r_1 > r_2$ and $\lambda > 2\tau$, then $w_1^{AR*} > w_1^{AM*} > w_1^{AB*}$;

3) When $r_1 > r_2$ and $\lambda < 2\tau$, then $w_1^{AR*} > w_1^{AB*} > w_1^{AM*}$;

4) When $r_1 < r_2$ and $\lambda < 2\tau$, then $w_1^{AM*} > w_1^{AB*} > w_1^{AR*}$;

5) When $r_1 < r_2$ and $\lambda > 2\tau$, then $w_1^{AB*} > w_1^{AM*} > w_1^{AR*}$.

Proposition 4 demonstrates that when the external financing interest rate is equal to the internal financing interest rate, Manufacturer 1's wholesale price remains identical across the three models. When the external financing interest rate is higher than the internal financing interest rate and the competition coefficient is large and satisfies condition $\lambda > 2\tau$, Manufacturer 1's wholesale price is maximized under the internal financing model, followed sequentially by the mixed external-internal financing model and the external financing model. When the external financing interest rate is higher than the internal financing interest rate and the competition coefficient is small and satisfies condition $\lambda < 2\tau$, Manufacturer 1's wholesale price is the highest under the internal financing model, followed by the external financing model and the mixed external-internal financing model. When the external financing interest rate is lower than the internal financing interest rate and the competition coefficient is small and satisfies condition $\lambda < 2\tau$, Manufacturer 1's wholesale price reaches its maximum under the mixed external-internal financing model, followed by the external financing model and the internal financing model. When the external financing interest rate is lower than the internal financing interest rate and the competition coefficient is large and satisfies condition $\lambda > 2\tau$, Manufacturer 1's wholesale price is the highest under the external financing model, followed by the mixed external-internal financing model and the internal financing model.

Proposition 5 Comparing the wholesale prices of Manufacturer 2 under the AB, AR and AM models yields the following results:

1) When $r_1 = r_2$, then $w_2^{AM*} = w_2^{AR*} = w_2^{AB*}$;

2) When $r_1 > r_2$ and $\lambda > 2\tau$, then $w_2^{AR*} > w_2^{AM*} > w_2^{AB*}$;

3) When $r_1 > r_2$ and $\lambda < 2\tau$, then $w_2^{AM*} > w_2^{AR*} > w_2^{AB*}$;

4) When $r_1 < r_2$ and $\lambda < 2\tau$, then $w_2^{AB*} > w_2^{AR*} > w_2^{AM*}$;

5) When $r_1 < r_2$ and $\lambda > 2\tau$, then $w_2^{AB*} > w_2^{AM*} > w_2^{AR*}$.

Proposition 5 demonstrates that when the external financing interest rate equals the internal financing interest rate, Manufacturer 2's wholesale price is the same under all three models. When the external financing interest rate is higher than the internal financing interest rate and the competition coefficient is large and satisfies condition $\lambda > 2\tau$, Manufacturer 2's wholesale price is maximized under the internal financing model, followed sequentially by the mixed external-internal financing model and the external financing model. When the external financing interest rate is higher than the internal financing interest rate and the competition coefficient is small and satisfies condition $\lambda < 2\tau$, Manufacturer 2's wholesale price is the highest under the mixed external-internal financing model, followed by the internal financing model and the external financing model. When the external financing interest rate is lower than the internal financing interest rate and the competition coefficient is small and satisfies condition $\lambda < 2\tau$, Manufacturer 2's wholesale price reaches its maximum under the external financing model, followed by the internal financing model and the mixed external-

internal financing model. When the external financing interest rate is lower than the internal financing interest rate and the competition coefficient is large and satisfies condition $\lambda > 2\tau$, Manufacturer 2's wholesale price is the highest under the external financing model, followed by the mixed external-internal financing model and the internal financing model.

Proposition 6 Comparing the green technology investment levels of Manufacturer 1 under the AB, AR and AM models yields the following results:

1) When $r_1 = r_2$, then $e_1^{AM*} = e_1^{AR*} = e_1^{AB*}$;

2) When $r_1 > r_2$ and $\lambda > 2\tau$, then $e_1^{AR*} > e_1^{AM*} > e_1^{AB*}$;

3) When $r_1 > r_2$ and $\lambda < 2\tau$, then $e_1^{AR*} > e_1^{AB*} > e_1^{AM*}$;

4) When $r_1 < r_2$ and $\lambda < 2\tau$, then $e_1^{AM*} > e_1^{AB*} > e_1^{AR*}$;

5) When $r_1 < r_2$ and $\lambda > 2\tau$, then $e_1^{AB*} > e_1^{AM*} > e_1^{AR*}$.

Proposition 6 demonstrates that when the external financing interest rate is equal to the internal financing interest rate, Manufacturer 1's green technology investment level is identical across the three models. When the external financing interest rate is higher than the internal financing interest rate and the competition coefficient is large and satisfies condition $\lambda > 2\tau$, Manufacturer 1's green technology investment level is maximized under the internal financing model, followed sequentially by the mixed external-internal financing model and the external financing model. When the external financing interest rate is higher than the internal financing interest rate and the competition coefficient is small and satisfies condition $\lambda < 2\tau$, Manufacturer 1's green technology investment level is the highest under the internal financing model, followed by the external financing model and the mixed external-internal financing model. When the external financing interest rate is lower than the internal financing interest rate and the competition coefficient is small and satisfies condition $\lambda < 2\tau$, Manufacturer 1's green technology investment level reaches its maximum under the mixed external-internal financing model, followed by the external financing model and the internal financing model. When the external financing interest rate is lower than the internal financing interest rate and the competition coefficient is large and satisfies condition $\lambda > 2\tau$, Manufacturer 1's green technology investment level is the highest under the external financing model, followed by the mixed external-internal financing model and the internal financing model.

Proposition 7 Comparing the green technology investment levels of Manufacturer 2 under the AB, AR and AM models yields the following results:

1) When $r_1 = r_2$, then $e_2^{AM*} = e_2^{AR*} = e_2^{AB*}$;

2) When $r_1 > r_2$ and $\lambda > 2\tau$, then $e_2^{AR*} > e_2^{AM*} > e_2^{AB*}$;

3) When $r_1 > r_2$ and $\lambda < 2\tau$, then $e_2^{AM*} > e_2^{AR*} > e_2^{AB*}$;

4) When $r_1 < r_2$ and $\lambda < 2\tau$, then $e_2^{AB*} > e_2^{AR*} > e_2^{AM*}$;

5) When $r_1 < r_2$ and $\lambda > 2\tau$, then $e_2^{AB*} > e_2^{AM*} > e_2^{AR*}$.

Proposition 7 demonstrates that when the external financing interest rate is equal to the internal financing interest rate, Manufacturer 2's green technology investment level is identical across the three models. When the external financing interest rate is higher than the internal financing interest rate and the competition coefficient is large and satisfies condition $\lambda > 2\tau$, Manufacturer 2's green technology investment level is maximized under the internal financing model, followed sequentially by the mixed external-internal financing model and the external financing model. When the external financing interest rate is higher than the internal financing interest rate and the competition coefficient is small and satisfies condition $\lambda < 2\tau$, Manufacturer 2's green technology investment level is the highest under the mixed external-internal financing model, followed by the internal financing model

and the external financing model. When the external financing interest rate is lower than the internal financing interest rate and the competition coefficient is small and satisfies condition $\lambda < 2\tau$, Manufacturer 2's green technology investment level reaches its maximum under the external financing model, followed by the internal financing model and the mixed external-internal financing model. When the external financing interest rate is lower than the internal financing interest rate and the competition coefficient is large and satisfies condition $\lambda > 2\tau$, Manufacturer 2's green technology investment level is the highest under the external financing model, followed by the mixed external-internal financing model and the internal financing model.

Proposition 8 Comparing the retail prices of Product 1 and Product 2 under the AB, AR and AM models yields the following results:

1) When $r_1 = r_2$, then $p_i^{AM*} = p_i^{AR*} = p_i^{AB*}$, $i \in \{1,2\}$;

2) When $r_1 > r_2$, then $p_1^{AR*} > p_1^{AB*} > p_1^{AM*}$, $p_2^{AM*} > p_2^{AR*} > p_2^{AB*}$;

3) When $r_1 < r_2$, then $p_1^{AM*} > p_1^{AB*} > p_1^{AR*}$, $p_2^{AB*} > p_2^{AR*} > p_2^{AM*}$.

Proposition 8 demonstrates that if the external financing interest rate is equal to the internal financing interest rate, i.e., $r_1 = r_2$, the retail prices of Product 1 and Product 2 are equal under the three models. When the external financing interest rate is higher than the internal financing interest rate, i.e., $r_1 > r_2$, the retail price of Product 1 is the highest under the internal financing model, followed by the external financing model and the mixed external-internal financing model scenario; meanwhile, the retail price of Product 2 is maximized under the mixed external-internal financing model, followed by the internal financing model and the external financing model. When the external financing interest rate is lower than the internal financing interest rate, i.e., $r_1 < r_2$, the retail price of Product 1 is the highest under the mixed external-internal financing model, followed by the external financing model and the internal financing model; meanwhile, the retail price of Product 2 reaches its maximum under the external financing model, followed by the internal financing model and the mixed external-internal financing model.

5. CONCLUSIONS

This paper investigates the optimal decisions on green technology investment levels and wholesale prices for capital-constrained green product manufacturers. Three scenarios are considered: both competing manufacturers adopt external financing, both adopt internal financing, and Manufacturer 1 chooses external financing while Manufacturer 2 selects internal financing. Comparative analysis of optimal decisions and profits across the three scenarios is conducted. The main findings are summarized as follows:

1)The profit dominance of Manufacturer 1 and Manufacturer 2 under different financing models is closely related to financing interest rates and the product competition intensity coefficient. Specifically, when the external financing interest rate is lower than the internal financing interest rate and the product competition intensity is low, Manufacturer 1 achieves its maximum profit under mixed external-internal financing and minimum profit under internal financing; Manufacturer 2 attains the highest profit under external financing and the lowest profit under mixed external-internal financing. When the external financing interest rate is lower than the internal financing interest rate and the product competition intensity is high, both Manufacturer 1 and Manufacturer 2 obtain their maximum profits under external financing and minimum profits under internal financing. When the external financing interest rate is higher than the internal financing interest rate and the product competition intensity is low, Manufacturer 1's profit is maximized under internal financing and minimized under mixed external-internal financing; Manufacturer 2's profit reaches its maximum under mixed external-internal financing and minimum under external financing. When the external financing interest rate is higher than the internal financing interest rate and the product competition

intensity is high, both Manufacturer 1 and Manufacturer 2 gain their highest profits under internal financing and lowest profits under external financing.

2)The magnitude of the retailer's profit across different financing models exhibits relatively complex characteristics. Specifically, when the internal financing interest rate exceeds the external financing interest rate and the competition intensity coefficient is large, the retailer's profit is maximized under external financing and minimized under internal financing. In all other cases, the retailer's profit is the highest under internal financing and the lowest under external financing.

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