IEEE Access
Multidisciplinary | Rapid Review | Open Access Journal

Received 12 June 2022, accepted 8 July 2022, date of publication 3 August 2022, date of current version 29 September 2022.

Digital Object Identifier 10.1109/ACCESS.2022.3196014

RESEARCH ARTICLE

Optimal Green Degree and Pricing Decisions of the E-Tailer and Supplier With Alternative Choices

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This work was supported by the Social Science Fund Project of Hebei Province, China, under Grant HB17GL044.

ABSTRACT The decision making of all e-commerce members is an important issue, such as the optimal green degree and pricing decisions of the e-tailer and supplier when they choose whether to provide green products or normal products for the market. As many people begin to focus on environmental protection, green products will become increasingly popular, although their prices are higher than that of normal ones, and the supplier should pay more to obtain green products than normal ones. Based on different choices, this study builds four e-teiler and supplier models, presents four proportions, analyzes their optimal decisions with different scenarios, and evaluates the influences of the green elasticity coefficient, distribution cost, manufacturing cost and green innovation factor on the e-tailer and supplier. In addition, the influences of the green elasticity coefficient, distribution cost, manufacturing cost, and green innovation factor on the green degree of green products are also considered. Through experimental simulations, we illustrate the optimal green degree and pricing decisions of the e-tailer and supplier, and find that the green elasticity coefficient and green degree are positively correlated, but distribution cost, manufacturing cost, green innovation factor, and green degree are negatively correlated. These results have valuable guiding significance for e-tailers and suppliers making operational decisions with green products.

INDEX TERMS Green degree, pricing decisions, green products, alternative choices.

I. INTRODUCTION

As many countries and societies focus on green development, an increasing number of customers are consciously buying products with green factors. To satisfy the green preferences of customers, the e-tailer should order products with green factors from the supplier. In other words, the supplier should invest more resources in reforming and innovating the production or procurement of products with green factors, which would subsequently increase the unit cost of producing or buying these products and the wholesale price. In this case, the supplier should determine whether to supply products with green factors or to sell normal products. When the supplier sells products with green factors at a higher wholesale price than normal products to the e-tailer, the latter should also decide whether to sell products with green factors at a high retail price or sell normal products at a low retail price.

As all sectors of society are paying increasing attention to environmental protection and green development, it is necessary to study green supply chains [1], [2]. The concept of green supply chain can be traced back to the green procurement proposed by Webb in 1994 [3], but the concept of green supply chain was first proposed by the Manufacturing Research Council of Michigan State University in 1996, and the team was working on "environmentally responsible transformation research" at that time. In 1997, Handfield *et al.* argued that the green supply chain included all activities related to the flow and transfer of goods and information from raw materials to end users [4]. Paksoy, Zceylan, and Weber developed a multi-objective linear programming model of a

The associate editor coordinating the review of this manuscript and approving it for publication was Nikhil Padhi.

closed-loop supply chain network, which starts with suppliers and recycles with decomposition centers [5]. Lakshmimeera and Palanisamy designed a conceptual model of GSCM practices in the Indian context [6]. Meera and Chitramani believed that green is a strategy implemented to improve environmental sustainability and competitive advantage; and completed an empirical study on 155 manufacturing industries in Tamil Nadu, India [7]. Combining manufacturers' investment in green products with the retailer's risk-aversion behavior, Li, Jiang, and Qu found the optimal decisions of a green supply chain with a risk-neutral manufacturer and a risk-averse retailer [8]. Tang and Wei agreed that the GSCM theory in China is still not mature compared to some developed countries, and analyzed green supplier selection problems in green supply chain management [9]. Wei, Chen, and Qin considered the pricing policy and product greenness in a green supply chain with asymmetric heterogeneous preferences, and obtained the optimal decisions on product greenness and pricing strategy based on a game analytic model [10]. Based on evidence from manufacturing factories in Accra Metropolis, Emmanuel *et al.* evaluated the relationship between supplier innovation initiative, manufacturing firms' performance and green supply chain adoption. They found that green supply chain management adoption had a statistically significant positive impact on manufacturing firms' performance [11]. Tra *et al.* examined how internal green activities achieve environmental performance in 452 South Korean firms using a structural equation model. These activities included green managerial innovation, green supply chain management, and green innovation facilitating firms [12]. Based on traditional supply chain performance evaluation theory, Dai and Ye studied five main elements in the optimal regulation of green supply chains with low carbon. These were financial value, internal supply chain process, customer service level, innovation and learning, and low-carbon development [13]. Mondal and Giri considered a closed-loop green supply chain with governmental intervention and cap-and-trade policy. They investigated competition and cooperation between retailers and developed a transfer payment mechanism to achieve Pareto improvement for all channel members [14]. In general, with more than 20 years of continuous research on the green economy, green logistics and green supply chain by many experts and scholars, the fruitful results have great positive significance to the sustainable and healthy development of the economy and society, especially environmental protection.

The remainder of this manuscript is structured as follows: Section 2 presents the notations used in this study. Section 3 introduces models of the e-tailer and supplier, and describes their profit function with normal and green products. Section 4 describes the optimal decisions of the e-tailer and supplier for normal and green goods. Section 5 illustrates the influences of the green elasticity coefficient, distribution cost, manufacturing cost, and green innovation factor on e-tailers and suppliers through simulation experiments. Section 6 concludes.

II. NOTATIONS

The notations used in this manuscript and their meanings are listed in Table 1. In addition, for the sake of generality, it also use assumptions which include $p_e^i > w_s^i > mc_s^i$, $i \in \{n, g\}$, $p_e^n > w_s^n + dc_e$, $p_e^g > w_s^g + dc_e$, $w_s^n > mc_s^n$ and $w_s^g > mc_s^g$ to ensure that both the e-tailer and supplier can earn profits.

TABLE 1. Notations.

Notations	Contents
p_e^i	**Unit retail price of the e-tailer for selling products to customers, a decision variable,** $i \in \{n, g\}$.
w_s^i	**Unit wholesale price of the supplier for providing products to the e-tailer, a decision variable,** $i \in \{n, g\}$.
a	**Total customer demand on the market.**
b	**Elasticity coefficient of customer demand on the retail price of normal products,** $b > 0$。
r	**Elasticity coefficient of customer demand on the green degree of green products,** $0 < r < b$。
θ_s	**Green degree of green products which are provided by the supplier, a decision variable.**
g	**Green innovation factor of the supplier's green products,** $g > 0$.
d	**Customer demand on the market.**
mc_s^i	**Unit manufacturing cost, which is the cost of supplier in producing or obtaining products,** $i \in \{n, g\}$ **and** $mc_s^g > mc_s^n$.
dc_e	**Unit distribution cost of the e-tailer which sends products to customers.**
π_e^i	**Profit function of the e-tailer,** $i \in \{n, g\}$.
π_s^i	**Profit function of the supplier,** $i \in \{n, g\}$.

III. MODELS OF THE E-TAILER AND SUPPLIER

In the operational process of the market, where the e-tailer and supplier provide normal products, the supplier initially sets the wholesale price w_s^n of normal products, and then the e-tailer decides on retail price p_e^n. When the market supplies green products, the supplier should determine the wholesale price w_s^g and green degree θ_s of green products, whereas the e-tailer should set the retail price p_e^g of green products.

The demand of customers in a market that supplies normal products can be calculated using equation (1). Following Ghosh [15], this study proposes that the demand function of customers for green products is linear and inversely proportional to retail price and directly proportional to the green degree. The demand for green products in the market can be calculated using equation (2):

$$d = a - bp_e^n. \tag{1}$$

$$d = a - bp_e^g + r\theta_s. \tag{2}$$

When choosing to provide green products, the supplier must invest resources and costs in green transformation and innovation. This additional cost, which is recoded as $g(\theta_s)$, is only related to the green degree θ_s of green products following Ghosh [15] and Swami [16] and can be obtained using equation (3).

$$g(\theta_s) = \frac{g\theta_s^2}{2}. \quad (3)$$

A. MODELS WITH NORMAL PRODUCTS

The e-tailer has an inventory system for product storage. When customers order the normal products through the e-tailer, the products will be delivered directly to them. To replenish the inventory system, the e-tailer needs to place orders on the supplier, and the latter provides normal products to the former at a low wholesale price. The supplier must invest resources in producing or obtaining normal products. To make a profit, the wholesale price of normal products provided by the supplier should exceed their cost, and this price is determined by the supplier. Meanwhile, the e-tailer procures normal products at the wholesale price set by the supplier and then decides on the retail price before selling these products to customers. In the e-fulfillment process, as the e-tailer should bear the cost of distributing or delivering normal products to customers, the retail price of normal products, as set by the e-tailer, should be higher than the sum of the wholesale price and distribution cost to obtain margins.

Generally, the retail and wholesale prices of normal products are determined by the e-tailer and supplier, respectively, in these models. On one hand, the supplier invests a certain amount of resources to produce or procure normal products and then sells them to the e-tailer at a wholesale price. In contrast, the e-tailer provides and distributes normal products to customers.

When the supplier and e-tailer sell normal products, their profit functions can be obtained using equation (1). The resulting profit functions are shown in equations (4) and (5).

$$\pi_e^n = (p_e^n - w_s^n - dc_e)(a - bp_e^n). \quad (4)$$

The unit income obtained by the e-tailer from selling normal products is computed by subtracting the wholesale and distribution costs from the retail price. Meanwhile, the total profit can be computed by multiplying unit income by customer demand.

$$\pi_s^n = (w_s^n - mc_s^n)(a - bp_e^n). \quad (5)$$

The unit margin of green products for the supplier is calculated as the wholesale price minus the manufacturing cost, whereas total income is computed by multiplying the unit margin by the customer demand for normal products in the market.

B. MODELS WITH GREEN PRODUCTS

Compared with the e-tailer that provides normal products, the stocks in the supplier's inventory systems are all products with green factors, and the e-fulfillment process is the same. To simplify the discussion, this study refers to the e-tailer and supplier that provide products with green factors as "the green e-tailer" and "the green supplier," respectively, and refers to the products with green factors as "green products." Apart from catering to customer orders, the green e-tailer is also responsible for delivering green products. Meanwhile, the green supplier must provide green products to the green e-tailer. In the process of producing or acquiring green products, the green supplier should invest additional resources and costs in implementing green transformation and innovation to obtain green products. Therefore, for the green supplier, the cost of producing or acquiring green products is higher than that of producing or acquiring normal products. Furthermore, these additional costs change the wholesale price of green products, and such changes directly impact the retail price of these products. This study also uses the green degree to measure the green transformation and innovation of green products, which, along with the retail price of green products, are believed to have an important influence on customer demand. Specifically, the retail price of green products and customer demand are negatively correlated, whereas green degree and customer demand are positively correlated.

In summary, the retail price of green products is determined by the green e-tailer, whereas the green degree and wholesale price of green products are determined by the green supplier in this operational condition. After customers order green products from green e-tailer, the latter is responsible for delivering green products to the former.

When customers purchase green products from the green e-tailer, the latter sells them at retail price and distributes them directly to customers. Customer demand can be computed using equation (2), and the profit function of the green e-tailer is computed using equation (6).

$$\pi_e^g = (p_e^g - w_s^g - dc_e)(a - bp_e^g + r\theta_s). \quad (6)$$

Before providing green products to the green e-tailer at a wholesale price higher than that of normal products, the green supplier needs to invest additional resources to implement green transformation and innovation, whose cost is computed using equation (3). The total margins obtained by the green supplier are calculated using equation (7).

$$\pi_s^g = (w_s^g - mc_s^g)(a - bp_e^g + r\theta_s) - \frac{g\theta_s^2}{2}. \quad (7)$$

IV. OPTIMAL DECISIONS OF THE E-TAILER AND SUPPLIER

A. OPTIMAL PRICINGS OF THE E-TAILER AND SUPPLIEER WITH NORMAL PRODUCTS

Equation (4) shows that $\frac{\partial^2 \pi_e^n}{\partial [p_e^n]^2} = -2b < 0$, and the retail price solution of $\frac{\partial \pi_e^n}{\partial p_e^n} = 0$ is obtained in equation (8).

$$p_e^n = \frac{a + b(w_s^n + dc_e)}{2b}. \quad (8)$$

Equation (8) is then substituted into equation (7) to obtain equation (9) and derive $\frac{\partial^2 \pi_s^n}{\partial [w_s^n]^2} = -b < 0$ based on this equation. The wholesale price solution for $\frac{\partial \pi_s^n}{\partial w_s^n} = 0$ is shown in equation (10), and the retail price solution can be computed using equation (11) when equation (10) is substituted into equation (8).

$$\pi_s^n = \frac{(w_s^n - mc_s^n)[a - b(w_s^n + dc_e)]}{2}. \tag{9}$$

$$w_s^n = \frac{a + b(mc_s^n - dc_e)}{2b}. \tag{10}$$

$$p_e^n = \frac{3a + b(mc_s^n + dc_e)}{4b}. \tag{11}$$

Substituting equations (10) and (11) into equations (4) and (5), respectively, the profit functions of the e-tailer and supplier are as follows:

$$\pi_e^n = \frac{[a - b(mc_s^n + dc_e)]^2}{16b}. \tag{12}$$

$$\pi_s^n = \frac{[a - b(mc_s^n + dc_e)]^2}{8b}. \tag{13}$$

B. OPTIMAL PRICINGS OF THE E-TAILER AND SUPPLIEER WITH GREEN PRODUCTS

In the operational environment of green products, the green e-tailer sets the retail price of green products after the green supplier determines their green degree and the wholesale price. From equation (6), equation (14) can be obtained as follows:

$$\frac{\partial \pi_e^g}{\partial p_e^g} = a - 2bp_e^g + r\theta_s + b(w_s^g + dc_e). \tag{14}$$

Equation (14) shows that $\frac{\partial^2 \pi_e^g}{\partial [p_e^g]^2} = -2b < 0$, which has a maximum value. Let $\frac{\partial \pi_e^g}{\partial p_e^g} = 0$, and the best reaction function of the green e-tailer be obtained using equation (15).

$$p_e^g = \frac{a + r\theta_s + b(w_s^g + dc_e)}{2b}. \tag{15}$$

Equation (16) can be obtained by substituting equation (15) into equation (7). Equations (17) and (18) are obtained from the first derivative of equation (16) with respect to w_s^g and θ_s.

$$\pi_s^g = \frac{(w_s^g - mc_s^g)[a + r\theta_s - b(w_s^g + dc_e)] - g\theta_s^2}{2}. \tag{16}$$

$$\frac{\partial \pi_s^g}{\partial w_s^g} = \frac{1}{2}[a - 2bw_s^g + r\theta_s + b(mc_s^g - dc_e)]. \tag{17}$$

$$\frac{\partial \pi_s^g}{\partial \theta_s} = \frac{1}{2}[r(w_s^g - mc_s^g) - 2g\theta_s]. \tag{18}$$

$$\frac{\partial^2 \pi_s^g}{\partial [w_s^g]^2} = -b < 0, \quad \frac{\partial^2 \pi_s^g}{\partial w_s^g \partial \theta_s} = \frac{1}{2}r, \quad \frac{\partial^2 \pi_s^g}{\partial \theta_s^2} = -g < 0$$

and $\frac{\partial^2 \pi_s^g}{\partial \theta_s \partial w_s^g} = \frac{1}{2}r$ can be computed from equations (17) and (18). The following Hessian matrix is then obtained:

$$\begin{vmatrix} \frac{\partial^2 \pi_s^g}{\partial \theta_s^2} & \frac{\partial^2 \pi_s^g}{\partial \theta_s \partial w_s^g} \\ \frac{\partial^2 \pi_s^g}{\partial w_s^g \partial \theta_s} & \frac{\partial^2 \pi_s^g}{\partial [w_s^g]^2} \end{vmatrix} = \begin{vmatrix} -g & \frac{1}{2}r \\ \frac{1}{2}r & -b \end{vmatrix} = gb - \frac{r^2}{4}. \tag{19}$$

Although $-g < 0$, π_s^g is a convex function of θ_s and w_s^g when $gb - r^2/4 > 0$, the condition of π_s^g maximizing its value can be simplified as equation (20).

$$4gb - r^2 > 0. \tag{20}$$

Let $\frac{\partial \pi_s^g}{\partial w_s^g} = 0$ and $\frac{\partial \pi_s^g}{\partial \theta_s} = 0$, then obtain the solutions of wholesale price w_s^g and green degree θ_s.

$$w_s^g = \frac{a + r\theta_s + b(mc_s^g - dc_e)}{2b}. \tag{21}$$

$$\theta_s = \frac{r(w_s^g - mc_s^g)}{2g}. \tag{22}$$

Equation (23) can be derived by substituting equation (22) into equation (21), and equation (24) is obtained based on equation (20) and the positive correlation between the wholesale price and manufacturing cost.

$$w_s^g = \frac{2g(a - bdc_e) + (2gb - r^2)mc_s^g}{4gb - r^2}. \tag{23}$$

$$2gb - r^2 > 0. \tag{24}$$

Equation (22) is transformed into equation (25) based on equation (23). Equation (26) is calculated from equations (15), (23), and (25), and equation (27) is derived based on equation (20) and the positive correlation between wholesale price and distribution cost.

$$\theta_s = \frac{r[a - b(mc_s^g + dc_e)]}{4gb - r^2}. \tag{25}$$

$$p_e^g = \frac{3ga + (gb - r^2)(mc_s^g + dc_e)}{4gb - r^2}. \tag{26}$$

$$gb - r^2 > 0. \tag{27}$$

After substituting equations (23), (25), and (26) into equations (6) and (7), the profit functions of the e-tailer and supplier with green products are computed using equations (28) and (29), respectively.

$$\pi_e^g = \frac{g^2 b[a - b(mc_s^g + dc_e)]^2}{(4gb - r^2)^2}. \tag{28}$$

$$\pi_s^g = \frac{g[a - b(mc_s^g + dc_e)]^2}{2(4gb - r^2)}. \tag{29}$$

Proportion 1 $w_s^g > w_s^n$.

Proportion 1 shows that the supplier's wholesale price of green products is higher than that of the normal ones.

Proportion 2 $p_e^g > p_e^n$.

Proportion 2 indicates that the e-tailer's retail price of green products is also higher than that of normal products.

Proportion 3 $\pi_e^g > \pi_e^n$.

Proportion 3 implies that the e-tailer obtains more profits from selling green products than that from normal ones.

Proportion 4 $\pi_s^g > \pi_s^n$.

Proportion 4 proves that the supplier makes more margins in providing green products to the e-tailer than normal products.

V. EXPERIMENTS

The experimental platform consisted of a Lenovo E450 (RAM: 8G, CPU: Intel Core i5-5200U 2.20GHz, HDD: 1T) and MATLAB (v.R2010b). In the experimental analysis, the influence of the green elasticity coefficient, distribution cost, manufacturing cost, and green innovation factor on the e-tailer and supplier are discussed, including not only the green degree, wholesale price, retail price, and profits of the e-tailer and supplier from green products but also their wholesale price, retail price, and margins when providing normal products. The optimal selection decisions of the e-tailer and supplier were confirmed through a comparative analysis. The parameter values used in the experiments are listed in Table 2.

A. INFLUENCE OF GREEN ELASTICITY COEFFICIENT ON THE E-TAILER AND SUPPLIER

An increasing green elasticity coefficient indicates an increase in the demand for green products in the market. Therefore, the e-tailer raises the retail price for green products, which in turn causes the supplier to raise the wholesale price of these products. Finally, both the e-tailer and supplier earn more profits when selling green products. Table 3 presents the influence of the green elasticity coefficient on wholesale and retail prices. As the coefficient gradually increases, both wholesale and retail prices of green products also increase. Specifically, when the green elasticity coefficient increases from 35.0 to 40.0, the wholesale price of green products increases from \$14.4109 to \$14.9071, whereas the retail price increases from \$18.8163 to \$19.5607.

TABLE 2. The values of parameters.

Notations	Values	Notations	Values
a	1000	b	50
r	40	dc_e	\$0.7
mc_s^n / mc_s^g	\$6/\$7	g	36

Meanwhile, the wholesale and retail prices of green products are always higher than those of normal products as the supplier must invest additional resources in the green transformation and innovation of green products. In this case, green products always have a higher wholesale price than normal products, and an increase in the wholesale price also drives an increase in retail price. In addition, the wholesale and retail prices of normal commodities are not affected by the green elasticity coefficient and remain unchanged throughout the process.

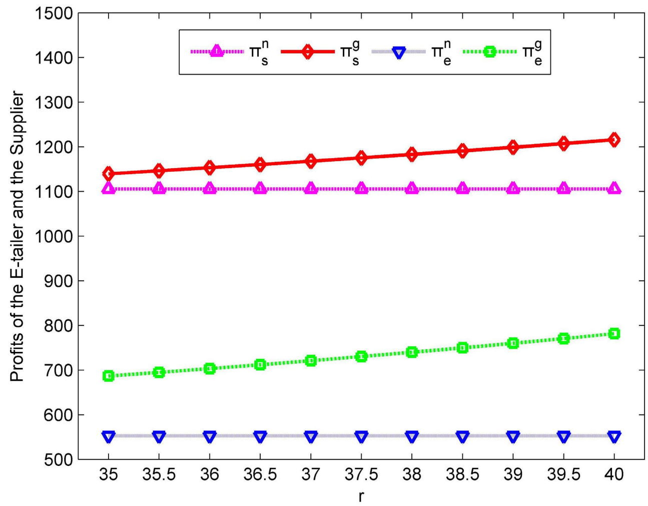

FIGURE 1. Influence of green elasticity coefficient on the profits of the e-tailer and supplier.

TABLE 3. Influence of green elasticity coefficient on wholesale and retail prices.

r	w_s^n	p_e^n	w_s^g	p_e^g
35.0	\$12.6500	\$16.6750	\$14.4109	\$18.8163
35.5	\$12.6500	\$16.6750	\$14.4549	\$18.8823
36.0	\$12.6500	\$16.6750	\$14.5000	\$18.9500
36.5	\$12.6500	\$16.6750	\$14.5463	\$19.0195
37.0	\$12.6500	\$16.6750	\$14.5939	\$19.0908
37.5	\$12.6500	\$16.6750	\$14.6427	\$19.1641
38.0	\$12.6500	\$16.6750	\$14.6928	\$19.2393
38.5	\$12.6500	\$16.6750	\$14.7443	\$19.3165
39.0	\$12.6500	\$16.6750	\$14.7971	\$19.3957
39.5	\$12.6500	\$16.6750	\$14.8514	\$19.4771
40.0	\$12.6500	\$16.6750	\$14.9071	\$19.5607

With an increasing green elasticity coefficient, the profits of the e-tailer and supplier demonstrate an obvious upward trend when both wholesale and retail prices increase. However, this trend does not affect the profits of the e-tailer and supplier when selling normal products. Figure 1 shows the impact of the green elasticity coefficient on the profits of the e-tailer and supplier. As the green elasticity coefficient increases from 35.0 to 40.0, the profits of the e-tailer providing green products increase from \$686.5140 to \$781.5364, whereas those of the supplier increase from \$1139.4 to \$1215.7. However, the profits of the e-tailer and supplier with normal products remain at \$552.7813 and \$1105.6, respectively. The e-tailer and supplier always earn more from selling green products than from selling normal products. In this case,

$$\pi_e^g > \pi_e^n, \quad \pi_s^g > \pi_s^n.$$

B. INFLUENCE OF DISTRIBUTION COST ON THE E-TAILER AND SUPPLIER

As shown in Table 4, as the distribution cost of the e-tailer increases, the wholesale prices determined by the supplier for both the normal and green products decrease. However, the retail price determined by the e-tailer increase. For example, when the distribution cost increases from \$0.10 to \$0.70, the wholesale prices of normal and green products decrease from \$12.9500 and \$15.2929 to \$12.6500 and \$14.9071, respectively; however, their retail prices increase from \$16.5250 and \$19.5393 to \$16.6750 and \$19.5607, respectively. This phenomenon shows that when the distribution cost increases, the e-tailer hedges this part of the cost by increasing the retail price, which in turn gradually decreases the optimal wholesale price decided by the supplier. For the e-tailer, both the decrease in wholesale price and the increase in retail price can reduce the adverse effects of rising distribution costs. Furthermore, $w_s^g > w_s^n$ and $p_e^g > p_e^n$ hold under these conditions.

The distribution cost borne by the e-tailer gradually increases, which reduces the e-tailer's profit accordingly. Therefore, when selling green and normal products, the profits of the e-tailer show a downward trend, as shown in Figure 2. As the distribution cost increases from \$0.10 to \$0.70, the revenues of the e-tailer from green and normal products decrease from \$859.6435 and \$603.7813 to \$781.5364 and \$552.7813, respectively. Meanwhile, as the distribution cost of the e-tailer increases, the change in the supplier's profit is the same as that of the e-tailer, which also shows an obvious downward trend, mainly due to the decline in the wholesale price. When the distribution cost increases from \$0.10 to \$0.70, the revenues of the supplier from green and normal products decrease from \$1337.2 and \$1207.6 to \$1215.7 and \$1105.6, respectively. At this point, $\pi_e^g > \pi_e^n$ and $\pi_s^g > \pi_s^n$ hold.

TABLE 4. Influence of distribution cost on wholesale and retail prices.

dc_e	w_s^n	p_e^n	w_s^g	p_e^g
\$0.10	\$12.9500	\$16.5250	\$15.2929	\$19.5393
\$0.16	\$12.9200	\$16.5400	\$15.2543	\$19.5414
\$0.22	\$12.8900	\$16.5550	\$15.2157	\$19.5436
\$0.28	\$12.8600	\$16.5700	\$15.1771	\$19.5457
\$0.34	\$12.8300	\$16.5850	\$15.1386	\$19.5479
\$0.40	\$12.8000	\$16.6000	\$15.1000	\$19.5500
\$0.46	\$12.7700	\$16.6150	\$15.0614	\$19.5521
\$0.52	\$12.7400	\$16.6300	\$15.0229	\$19.5543
\$0.58	\$12.7100	\$16.6450	\$14.9843	\$19.5564
\$0.64	\$12.6800	\$16.6600	\$14.9457	\$19.5586
\$0.70	\$12.6500	\$16.6750	\$14.9071	\$19.5607

C. INFLUENCE OF MANUFACTURING COST ON THE E-TAILER AND SUPPLIER

The change in manufacturing cost directly affects both the e-tailer and the supplier. Specifically, increasing the manufacturing cost will increase the cost of products provided by the supplier, which the supplier responds to by increasing the wholesale price to maintain a certain profit. All

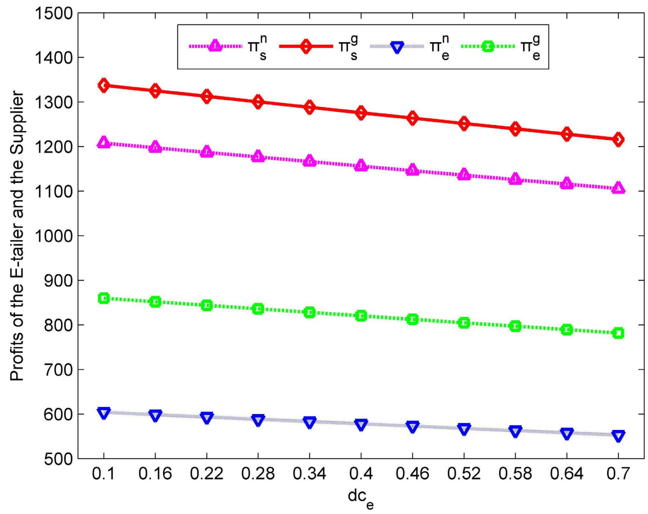

FIGURE 2. Influence of distribution cost on the profits of the e-tailer and supplier.

these increases will drive the e-tailer to raise retail price. As shown in Table 5, with an increasing manufacturing cost, the wholesale prices of the two commodities provided by the supplier show a significant upward trend. When the manufacturing cost of green and normal products gradually increases from \$7.0 and \$6.0 to \$8.0 and \$7.0, respectively, the wholesale prices increase from \$14.9071 and \$12.6500 to \$15.2643 and \$13.1500, whereas the retail prices increase from \$19.5607 and \$16.6750 to \$19.5964 and \$16.9250. $w_s^g > w_s^n$ and $p_e^g > p_e^n$ also hold true under these conditions.

TABLE 5. Influence of manufacturing cost on wholesale and retail prices.

mc_s^n	w_s^n	p_e^n	mc_s^g	w_s^g	p_e^g
6.0	\$12.6500	\$16.6750	7.0	\$14.9071	\$19.5607
6.1	\$12.7000	\$16.7000	7.1	\$14.9429	\$19.5643
6.2	\$12.7500	\$16.7250	7.2	\$14.9786	\$19.5679
6.3	\$12.8000	\$16.7500	7.3	\$15.0143	\$19.5714
6.4	\$12.8500	\$16.7750	7.4	\$15.0500	\$19.5750
6.5	\$12.9000	\$16.8000	7.5	\$15.0857	\$19.5786
6.6	\$12.9500	\$16.8250	7.6	\$15.1214	\$19.5821
6.7	\$13.0000	\$16.8500	7.7	\$15.1571	\$19.5857
6.8	\$13.0500	\$16.8750	7.8	\$15.1929	\$19.5893
6.9	\$13.1000	\$16.9000	7.9	\$15.2286	\$19.5929
7.0	\$13.1500	\$16.9250	8.0	\$15.2643	\$19.5964

As the supplier's manufacturing cost increases, the e-tailer needs to raise the retail price to maintain a certain level of profitability. However, an increase in retail price further inhibits customer demand and eventually leads to a gradual decline in the earnings of the e-tailer, as shown in Figure 3. Whether the e-tailer sells green or normal products, the benefits show an evident downward trend. Specifically, the manufacturing cost of these products increases from \$7.0 and \$6.0 to \$8.0 and \$7.0, respectively, and the profits of the e-tailer decrease from \$781.5364 and \$552.7813 to \$659.6231 and \$472.7813, respectively. With the increase in the manufacturing cost at the same time, the margins earned by the supplier from green and normal products gradually decline from \$1215.7 and \$1105.6 to \$1026.1 and \$945.6, respectively. Obviously, increasing the manufacturing cost of the supplier has a negative impact on both the e-tailer and supplier. $\pi_e^g > \pi_e^n$ and $\pi_s^g > \pi_s^n$ also hold true in this case.

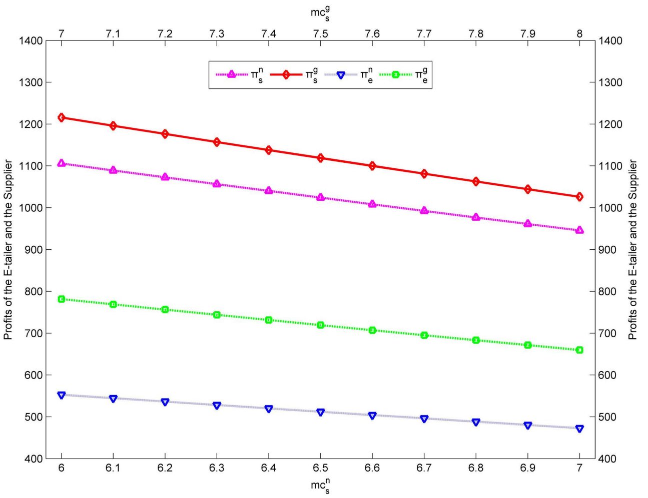

FIGURE 3. Influence of manufacturing cost on the profits of the e-tailer and supplier.

D. INFLUENCE OF GREEN INNOVATION FACTOR ON THE E-TAILER AND SUPPLIER

The green innovation factor is mainly used to measure the sensitivity of green products' green innovation to the supplier's resources. Table 6 shows that the wholesale prices of green products, as determined by the supplier, gradually decrease with an increasing green innovation factor. Obviously, an opposite relationship is observed between the green innovation factor and wholesale price of green products, which has a negative impact on retail prices. Meanwhile, the green innovation factor has no impact on retail prices of normal products. For example, as the green innovation factor increases from 33 to 43, the wholesale and retail prices of green products decrease from \$15.1180 and \$19.8770 to \$14.5557 and \$19.0336, respectively, whereas the wholesale and retail prices of normal products remain unchanged at \$12.6500 and \$16.6750, respectively. $w_s^g > w_s^n$ and $p_e^g > p_e^n$ always hold in the entire change process of the green innovation factor.

Given that the green innovation factor is only related to green products, it does not affect the profits of the e-tailer and supplier with normal products, as shown in Figure 4, where these profits are maintained at \$552.7813 and \$1105.6, respectively. In contrast, these profits decrease along with an increasing green innovation factor, indicating a negative correlation between the green innovation factor and the profits of the e-tailer and supplier selling green products. For example, when the green innovation factor increases from 33 to 43, the profits of the e-tailer and supplier decrease from \$823.7741 and \$1248.1 to \$713.6102 and \$1161.7, respectively. The profits of the e-tailer and supplier always satisfy $\pi_e^g > \pi_e^n$ and $\pi_s^g > \pi_s^n$.

TABLE 6. Influence of green innovation factor on wholesale and retail prices.

g	w_s^n	p_e^n	w_s^g	p_e^g
33	\$12.6500	\$16.6750	\$15.1180	\$19.8770
34	\$12.6500	\$16.6750	\$15.0423	\$19.7635
35	\$12.6500	\$16.6750	\$14.9722	\$19.6583
36	\$12.6500	\$16.6750	\$14.9071	\$19.5607
37	\$12.6500	\$16.6750	\$14.8466	\$19.4698
38	\$12.6500	\$16.6750	\$14.7900	\$19.3850
39	\$12.6500	\$16.6750	\$14.7371	\$19.3056
40	\$12.6500	\$16.6750	\$14.6875	\$19.2312
41	\$12.6500	\$16.6750	\$14.6409	\$19.1614
42	\$12.6500	\$16.6750	\$14.5971	\$19.0956
43	\$12.6500	\$16.6750	\$14.5557	\$19.0336

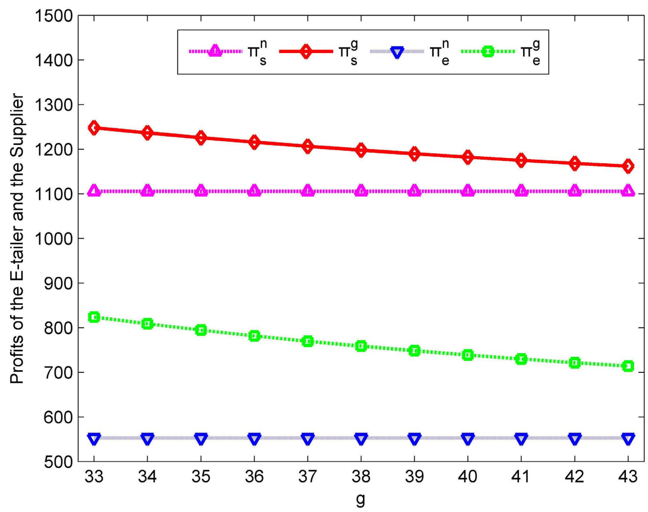

FIGURE 4. Influence of green innovation factor on the profits of the e-tailer and supplier.

E. INFLUENCE FACTOR ANALYSIS OF GREEN DEGREE

Before providing green products to the e-tailer, the supplier must invest additional resources in advance to carry out green transformation and innovation. With the goal of maximizing profit, the green degree is an important decision for the supplier's green products. In this study, the environmental factors that affect the green degree of green products mainly include the green elasticity coefficient, distribution cost, manufacturing cost, and green innovation factor.

The influence of the green elasticity coefficient on the green degree of green products is shown in Figure 5. With an increasing green elasticity coefficient, the green degree of green products shows an obvious upward trend. An increase in the green elasticity coefficient indicates that customer demand for green products in the market has increased. Such an increase in customer demand will increase the profits of both the e-tailer and supplier from green products, and encourage the latter to invest more resources in green transformation and innovation to improve the green degree of their green products. For example, when the green elasticity coefficient increases from 35 to 40, the green degree of green products increases from 3.6025 to 4.3929.

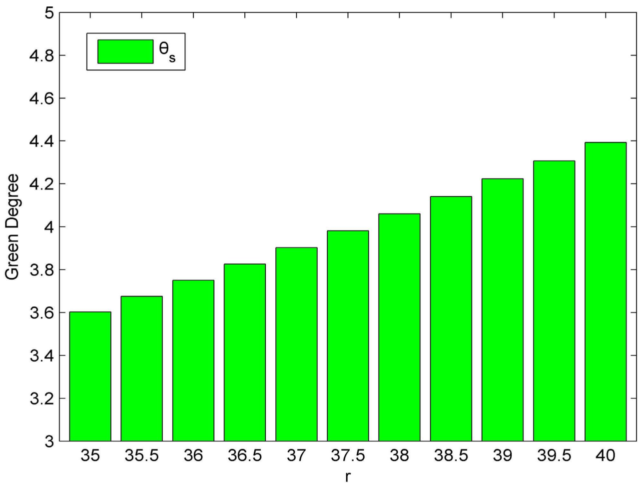

FIGURE 5. **Influence of green elasticity coefficient on green degree.**

As the distribution cost increases, the green degree of green products shows the opposite trend, as shown in Figure 6. As the distribution cost of the e-tailer increases, the retail price of green products correspondingly increases, and customer demand in the market will be restrained, thereby reducing both the income of the supplier and the resources invested in green transformation and innovation. These trends gradually reduce the green degree of the green products. When the distribution cost increases from \$0.10 to \$0.70, the green degree of the green products decreases from 4.6071 to 4.3929.

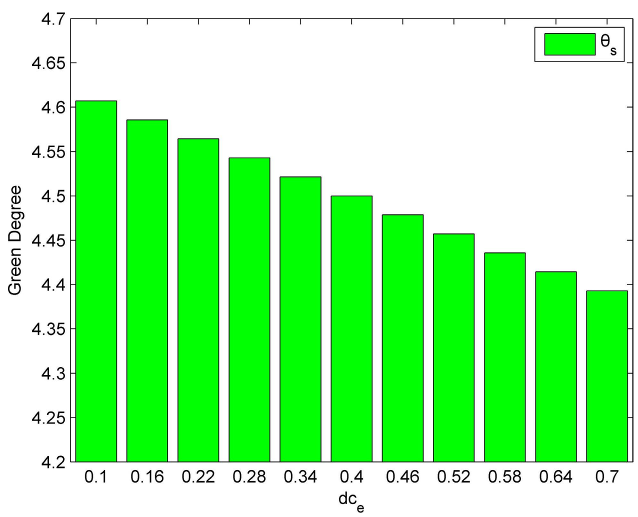

FIGURE 6. **Influence of distribution cost on green degree.**

With increasing manufacturing cost, the green degree of green products provided by the supplier gradually decreases, as shown in Table 7. As the manufacturing cost of green products increases from \$7.1 to \$8.0, the green degree of green products determined by the supplier, decreases from 4.3571 to 4.0357, thereby highlighting a negative correlation between manufacturing cost and green degree.

TABLE 7. **Impact of manuafacturing cost on green degree.**

mc_s^g	7.1	7.2	7.3	7.4	7.5
θ_s	4.3571	4.3214	4.2857	4.2500	4.2143
mc_s^g	7.6	7.7	7.8	7.9	8.0
θ_s	4.1786	4.1429	4.1071	4.0714	4.0357

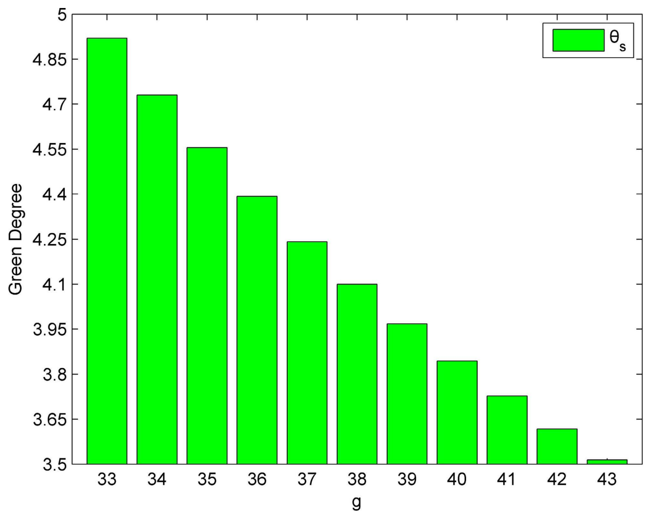

FIGURE 7. **Influence of green innovation factor on green degree.**

As shown in Figure 7, as the green innovation factor gradually increases, the green degree of the green products decreases. An increase in the green innovation factor implies that the supplier should invest more resources to obtain the same green transformation and innovation results as before. Therefore, when the amount of resources invested in green transformation and innovation remains stable, an increase in the green innovation factor will reduce the green degree. Specifically, when the green innovation factor increases from 33 to 43, the green degree of green products decreases from 4.9200 to 3.5143.

VI. CONCLUSION

As many people go shopping on the Internet and increasingly focus on a low-carbon lifestyle, this study constructs four operational models of the e-tailer and supplier. The first two models involve the e-tailer and supplier with normal products, whereas the last two models involve the e-tailer and supplier who provide products with green factors. The optimal decisions of the e-tailer and supplier across different operational conditions are also analyzed.

This study evaluates the impacts of environmental factors on the e-tailer and supplier, and finds that both the e-tailer and supplier should provide green products to the market to earn margins, which are higher than those obtained from providing normal products. Although green products have higher wholesale and retail prices than normal products, both the e-tailer and the supplier can earn more profit by paying additional costs to procure green products. Given concerns about environmental protection, many consumers willingly purchase green products despite their high prices. This study also analyzes the optimal green degree of green products and the optimal wholesale and retail prices of the supplier and e-tailer; and evaluates the influences of other operational parameters on the e-tailer, supplier and green degree of green products. These results are valuable for e-tailers and suppliers of green products when formulating tactical decisions to maximize their margins in e-commerce.

APPENDIX

A. PROOF OF PROPOSITION 1

It can be obtained from equation (23) minuses equation (10), as follows:

$$\begin{aligned}
w_s^g - w_s^n &= \frac{2g(a-bdc_e)+(2gb-r^2)mc_s^g}{4gb-r^2} - \frac{a+b(mc_s^n-dc_e)}{2b} \\
&= \frac{1}{2b(4gb-r^2)}\{2b[2g(a-bdc_e) + (2gb-r^2)mc_s^g] - (4gb-r^2) \times [a+b(mc_s^n-dc_e)]\} \\
&= \frac{1}{2b(4gb-r^2)}[4gb(a-bdc_e) + 2b(2gb-r^2)mc_s^g - (4gb-r^2)a - b(4gb-r^2)(mc_s^n-dc_e)] \\
&= \frac{1}{2b(4gb-r^2)}[4gba-4gb^2dc_e + 2b(2gb-r^2)mc_s^g - 4gba + r^2a - b(4gb-r^2)mc_s^n + b(4gb-r^2)dc_e] \\
&= \frac{1}{2b(4gb-r^2)}\{[b(4gb-r^2)-4gb^2]dc_e + 2b(2gb-r^2)mc_s^g - b(4gb-r^2)mc_s^n + r^2a\} \\
&= \frac{1}{2b(4gb-r^2)}\{[-r^2b]dc_e + 2b(2gb-r^2)mc_s^g - b(4gb-r^2)mc_s^n + r^2a\} \\
&= \frac{1}{2b(4gb-r^2)}[r^2a - r^2bdc_e + 2b(2gb-r^2)mc_s^g - b(4gb-r^2)mc_s^n] \\
&> \frac{1}{2b(4gb-r^2)}[r^2a - r^2bdc_e + 2b(2gb-r^2)mc_s^g - b(4gb-r^2)mc_s^g]
\end{aligned}$$

And due to

$$\begin{aligned}
&\frac{1}{2b(4gb-r^2)}[r^2a - r^2bdc_e + 2b(2gb-r^2)mc_s^g - b(4gb-r^2)mc_s^g] \\
&= \frac{1}{2b(4gb-r^2)}\{r^2a - r^2bdc_e + [2b(2gb-r^2) - b(4gb-r^2)]mc_s^g\} \\
&= \frac{1}{2b(4gb-r^2)}\{r^2a - r^2bdc_e + b[2(2gb-r^2) - (4gb-r^2)]mc_s^g\} \\
&= \frac{1}{2b(4gb-r^2)}\{r^2a - r^2bdc_e + b[4gb-2r^2-4gb+r^2)]mc_s^g\} \\
&= \frac{r^2a - r^2bdc_e - r^2bmc_s^g}{2b(4gb-r^2)} \\
&= \frac{r^2[a-bdc_e-bmc_s^g]}{2b(4gb-r^2)} \\
&= \frac{r^2[a-b(mc_s^g+dc_e)]}{2b(4gb-r^2)}
\end{aligned}$$

with $a-b(mc_s^g+dc_e) > a-b(w_s^g+dc_e) > a-bp_e^g > 0$ and equation (20), then $\frac{r^2[a-b(mc_s^g+dc_e)]}{2b(4gb-r^2)} > 0$, and $w_s^g > w_s^n$.

B. PROOF OF PROPOSITION 2

The result of equation (26) minuses equation (11) is,

$$\begin{aligned}
p_e^g - p_e^n &= \frac{3ga+(gb-r^2)(mc_s^g+dc_e)}{4gb-r^2} - \frac{3a+b(mc_s^n+dc_e)}{4b} \\
&= \frac{1}{4b(4gb-r^2)}\{4b[3ga+(gb-r^2)(mc_s^g+dc_e)] - (4gb-r^2)[3a+b(mc_s^n+dc_e)]\} \\
&= \frac{1}{4b(4gb-r^2)}[12gba+4b(gb-r^2) \times (mc_s^g+dc_e) - 3a(4gb-r^2) - b(4gb-r^2)(mc_s^n+dc_e)] \\
&= \frac{1}{4b(4gb-r^2)}[3r^2a+4b(gb-r^2)mc_s^g + 4b(gb-r^2)dc_e - b(4gb-r^2)mc_s^n - b(4gb-r^2)dc_e] \\
&= \frac{1}{4b(4gb-r^2)}\{3r^2a+4b(gb-r^2)mc_s^g - b(4gb-r^2)mc_s^n - [4b(gb-r^2) - b(4gb-r^2)]dc_e\} \\
&= \frac{1}{4b(4gb-r^2)}[3r^2a-3r^2bdc_e + 4b(gb-r^2)mc_s^g - b(4gb-r^2)mc_s^n] \\
&> \frac{1}{4b(4gb-r^2)}[3r^2a-3r^2bdc_e + 4b(gb-r^2)mc_s^g - b(4gb-r^2)mc_s^g]
\end{aligned}$$

And,

$$\frac{1}{4b(4gb-r^2)}[3r^2a-3r^2bdc_e+4b(gb-r^2)mc_s^g - b(4gb-r^2)mc_s^g]$$
$$=\frac{1}{4b(4gb-r^2)}\{3r^2a-3r^2bdc_e + [4b(gb-r^2)-b(4gb-r^2)]mc_s^g\}$$
$$=\frac{1}{4b(4gb-r^2)}\{3r^2(a-bdc_e) + b[4(gb-r^2)-(4gb-r^2)]mc_s^g\}$$
$$=\frac{1}{4b(4gb-r^2)}\{3r^2(a-bdc_e) + b[4gb-4r^2-4gb+r^2]mc_s^g\}$$
$$=\frac{3r^2(a-bdc_e)-3r^2bmc_s^g}{4b(4gb-r^2)}$$
$$=\frac{3r^2[a-b(mc_s^g+dc_e)]}{4b(4gb-r^2)}$$

Though $a-b(mc_s^g+dc_e) > a-b(w_s^g+dc_e) > a-bp_e^g > 0$ and equation (20), then $\frac{3r^2[a-b(mc_s^n+dc_e)]}{4b(4gb-r^2)} > 0$, and $p_e^g > p_e^n$.

C. PROOF OF PROPOSITION 3

Firstly, equation (28) minuses equation (12) is,

$$\pi_e^g-\pi_e^n = \frac{g^2b[a-b(mc_s^g+dc_e)]^2}{(4gb-r^2)^2} - \frac{[a-b(mc_s^n+dc_e)]^2}{16b} > \frac{g^2b[a-b(mc_s^g+dc_e)]^2}{(4gb-r^2)^2} - \frac{[a-b(mc_s^g+dc_e)]^2}{16b}$$

And,

$$\frac{g^2b[a-b(mc_s^g+dc_e)]^2}{(4gb-r^2)^2} - \frac{[a-b(mc_s^g+dc_e)]^2}{16b}$$
$$=[a-b(mc_s^g+dc_e)]^2[\frac{g^2b}{(4gb-r^2)^2}-\frac{1}{16b}]$$
$$=\frac{[a-b(mc_s^g+dc_e)]^2}{16b(4gb-r^2)^2} \times [16g^2b^2-(4gb-r^2)^2]$$
$$=\frac{[a-b(mc_s^g+dc_e)]^2}{16b(4gb-r^2)^2} \times [4gb+(4gb-r^2)][4gb-(4gb-r^2)]$$
$$=\frac{r^2(8gb-r^2)[a-b(mc_s^g+dc_e)]^2}{16b(4gb-r^2)^2}.$$

Due to $a-b(mc_s^g+dc_e) > a-b(w_s^g+dc_e) > a-bp_e^g > 0$ and equation (20), then $\frac{r^2(8gb-r^2)[a-b(mc_s^g+dc_e)]^2}{16b(4gb-r^2)^2} > 0$, and $\pi_e^g > \pi_e^n$

D. PROOF OF PROPOSITION 4

The difference of equation (29) and equation (13) is,

$$\pi_s^g-\pi_s^n = \frac{g[a-b(mc_s^g+dc_e)]^2}{2(4gb-r^2)} - \frac{[a-b(mc_s^n+dc_e)]^2}{8b} > \frac{g[a-b(mc_s^g+dc_e)]^2}{2(4gb-r^2)} - \frac{[a-b(mc_s^g+dc_e)]^2}{8b}.$$

And,

$$\frac{g[a-b(mc_s^g+dc_e)]^2}{2(4gb-r^2)} - \frac{[a-b(mc_s^g+dc_e)]^2}{8b}$$
$$=\frac{[a-b(mc_s^g+dc_e)]^2}{2}[\frac{g}{4gb-r^2}-\frac{1}{4b}]$$
$$=\frac{[a-b(mc_s^g+dc_e)]^2}{2}[\frac{1}{4b(4gb-r^2)}][4gb-(4gb-r^2)]$$
$$=\frac{r^2[a-b(mc_s^g+dc_e)]^2}{8b(4gb-r^2)}.$$

Because of $a-b(mc_s^g+dc_e) > a-b(w_s^g+dc_e) > a-bp_e^g > 0$ and equation (20), $\frac{r^2[a-b(mc_s^g+dc_e)]^2}{8b(4gb-r^2)} > 0$, then $\pi_s^g > \pi_s^n$

ACKNOWLEDGMENT

This work was supported by the Social Science Fund Project of Hebei Province, China, under Grant HB17GL044. The authors would like to thank the reviewers and the editors for their helpful comments and suggestions.

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