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A DUAL-CHANNEL SUPPLY CHAIN MODEL UNDER PRICE AND WARRANTY COMPETITION

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Abstract. *Many industries use dual distribution channels to offer and distribute products, including electronics, appliances and apparel. This research develops a dual-channel supply chain including a manufacturer direct channel and a retail channel. If customers incur higher price or lower warranty length, they will shift to another channel, i.e., the substitute effect. In the retail channel, the manufacturer determines the optimal wholesale price and the warranty length, whereas the retailer determines the optimal retail price. In the direct channel, the manufacturer determines the optimal price and warranty length to provide to end customers. The current study adopts a non-cooperative and cooperative equilibrium to solve the problem described above and discusses how to use profit sharing mechanisms to achieve a positive situation in the cooperative game. The study concludes with a computational analysis that leads to various managerial insights. These results should be a useful reference for managerial decision-making.*
Keywords: Dual-channel, Substitute effect, Pricing, Warranty length, Internet

1. **Introduction.** A supply chain encompasses all the facilities, functions and activities involved in producing and delivering a product or service, from suppliers to customers. Supply chain management coordinates all activities to provide customers with prompt and reliable service of high-quality products at least cost. Research has investigated the issues of supply chain management for a long time. Recently, Su [1] and Chou [2] considered the topic of inventory control to reduce total cost or satisfy variable customer service levels. Tominaga et al. [3] discussed the effects of inventory control on bullwhip in the supply chain. Zhang et al. [4] investigated knowledge sharing in supply chain management. Grunder [5] dealt with lot sizing, delivery and scheduling problems in a single-stage supply chain. Tsao [6] simultaneously determined pricing, inventory and payment decisions.

Traditional selling systems have changed dramatically with customer use of the Internet. Manufacturers use both traditional retail stores and the Internet to sell their products. Such a system is called a two-echelon dual-channel distribution system, or more generally, a multi-channel distribution system. A review of the literature on distribution channels reveals several important economic reasons for serving various customer segments through different channels. Moriarty and Moran [7] pointed out that dual or multi-channel systems would become the dominant design for computer industries in the 1990s. However, not only computer industries, but also electronics, appliances, sporting goods and apparel, have begun to sell directly to customers over the Internet. When commercial organizations began using the Internet in 1991, it effectively broke the barriers of time and space for traditional sales models and distribution channels. Thus, the amount of money generated through e-commerce has increased every year since. These results have instigated many industries to construct Internet sales systems (Kacen et al. [8]).

Internet and traditional retail channels are parallel channels, as they both have substitute and complementary functions (Peterson et al. [9]). Gayer and Shy [10] also pointed out that, while the market is not fully covered, the channels are complementary. Chiang et al. [11], and Chiang and Monahan [12] considered a dual-channel supply chain, which contains a traditional retail store and an Internet-based direct channel. To achieve supply chain flexibility, companies are increasingly using new sales channels alongside traditional retail channels.

Unlike a single channel system for making pricing and warranty length decisions, a dual-channel supply chain can cause problems for the manufacturer. When customers in a dual-channel supply chain incur an increased price or a shorter warranty length, they will shift to another channel, i.e., the substitute effect. Consider the substitute effect between these two channels when developing a dual-channel supply chain model is essential. Thus, how to determine optimal pricing and warranty-length is a challenge for the manufacturer.

Retail channel pricing differs from direct channel pricing in that pricing can influence customer desire to purchase. For the same class of products on the market, a lower price typically enhances sales volume, but decreases profit units. The price of a product should not be so high that it dissuades consumers from purchasing it. Therefore, producers must use product pricing as a competitive tool in their marketing strategies. Fruchter and Taipiero [13] determined an optimal pricing policy for a manufacturer with both retail and Internet channels. Cattani et al. [14] developed pricing strategies for a manufacturer adding a direct channel that competes with the traditional channel.

Consumers can predict product quality based on warranty length. A warranty is the assurance that the manufacturer provides after evaluating the strength and durability of its product. An adequate warranty policy enhances consumer purchase willingness and increases overall performance of the sales channel. Manufacturer warranty for customers exists in current business, such as for computers, communication and consumer electronic products (3C products). Warranty is an important factor for marketing products because a better warranty policy typically signals higher product quality and provides greater customer assurance (Wu et al. [15]). Customers can predict product quality based on the warranty the producer provides after evaluating the strength of the product (Boulding and Kirmani [16]). Blischke and Murthy [17] demonstrated two important functions of warranty, protection and promotion. For protection, warranty not only reduces the risk of customer purchase, but also protects producers from unreasonable customer expectations. For promotion, warranty is a marketing tool to differentiate it from competitors (Padmanabhan [18]). An adequate warranty policy enhances customer purchase willingness. Therefore, warranty policy is an important decision for a manufacturer.

This research develops a dual-channel supply chain, including a manufacturer direct channel and a retail channel. Figure 1 illustrates the dual-retailer channel supply chain. In the retail channel, the manufacturer provides a wholesale price (W_R) to a retailer and a warranty length (L_R) to customers. The retailer provides a retail price (P_R) to customers. In the direct channel, the manufacturer provides a selling price (P_I) and a warranty length (L_I) to customers. This study deals with cooperative and non-cooperative games by determining the optimal price and warranty length for a product, thus maximizing profit in the dual-channel supply chain and discusses using profit sharing mechanisms to achieve a positive situation in the cooperative game. This research presents numerical examples to illustrate the solution procedure and discusses the impact of various system parameters. We conclude with a computational analysis that leads to variety of managerial insights.

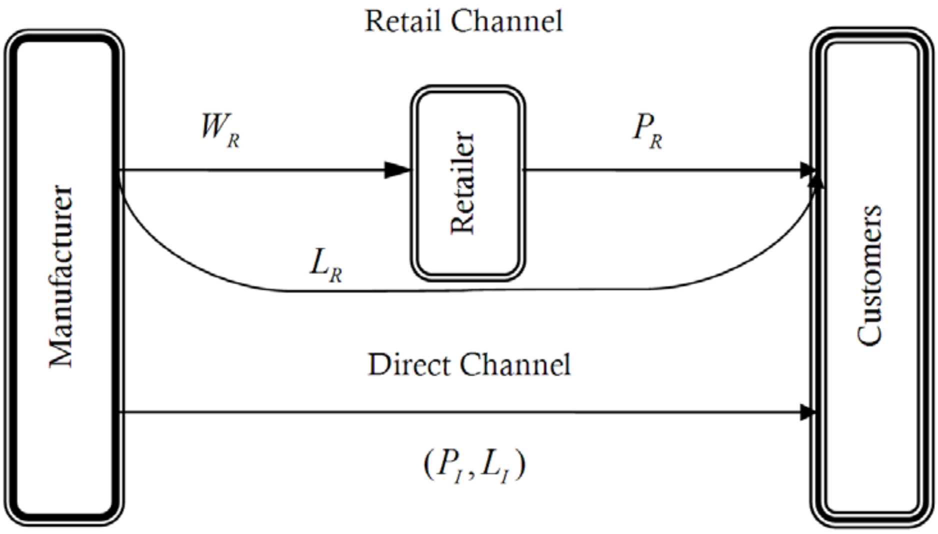

FIGURE 1. The dual-retailer channel supply chain

2. **Model Formulation.** The following notations are used through this paper.

NOTATION	
W_R:	wholesale price
λ_R:	fixed rate of retail channel
P_R:	retail price
λ_I:	fixed rate of direct channel
P_I:	price in direct channel
C_I:	product cost of direct channel
L_R:	warranty length in retail channel
C_R:	product cost of retail channel
L_I:	warranty length in direct channel
C_M:	defective cost per unit
D_R:	demand for retail channel
D_W:	demand for direct channel
$\prod_{M1}$:	manufacturer performance in Retail channel
$\prod_{M2}$:	manufacturer performance in Direct channel
$\prod_R$:	retailer performance in Retail channel

The mathematical model in this paper is developed under the following assumptions.

1. The manufacturer has a retail channel and a direct channel for selling its products. In retail channel, the manufacturer sells products to the retailer and then the retailer sells products to end customers. In direct channel, the manufacturer directly sells products to end customers from Internet.
2. The expected number of returned products from customers is (refer to Wu et al. [19]), $M(w) = (L\lambda)^\beta$, where λ is the failure rate, L is the warranty length and β is the shape parameter in the Weibull distribution. Then, the defective cost is $C_M \cdot M(w) = C_M(L\lambda)^\beta$.
3. Product cost is larger than defective cost for both channel, $C_I > C_M$, $C_R > C_M$.

4. The demand function of the retail channel is $D_R = a_1 - b_1 P_R + c_1 L_R + b_1' P_I - c_1' L_I$ and the demand function of the direct channel is $D_W = a_2 - b_2 P_I + c_2 L_I + b_2' P_R - c_2' L_R$, where $b_1' < b_1$ and $c_1' < c_1$. When the price of a channel declines, the substitute effect causes its demand to rise and the demand of the other channel to fall. When the warranty length of a channel increases, the substitute effect causes its demand to rise and the demand of the other channel to fall.

Manufacturer's profits in the retail channel and direct channel can be expressed as follows.

Manufacturer's profit in the retail channel:

$$\prod\nolimits_{M1}(W_R, L_R) = (W_R - C_R)D_R - (L_R\lambda_R)^\beta C_M; \tag{1}$$

Manufacturer's profit in the direct channel:

$$\prod\nolimits_{M2}(P_I, L_I) = (P_I - C_I)D_W - (L_I\lambda_I)^\beta C_M. \tag{2}$$

Retailer's profit can be expressed as follows.

$$\prod\nolimits_{R}(P_R) = (P_R - W_R)D_R. \tag{3}$$

3. Optimal Solution.

This study deals with cooperative and con-cooperative games by determining the optimal price and warranty length for a product, thus maximizing profit in the dual-channel supply chain. In the non-cooperative game, these decisions are made to maximize each party's profit; in the cooperative game, decisions are made to maximize channel profits.

3.1. Non-cooperative game.

The retailer wants to determine the optimal retail price P_R^* to maximize his profit. Since $\frac{d^2\prod_R}{d^2P_R} = -2b_1 < 0$, the second order condition is satisfied. We can obtain the optimal retail price P_R^* by solving $\frac{\partial\prod_R}{\partial P_R} = a_1 - c_1'L_I + c_1L_R + b_1'P_I - 2b_1P_R + b_1W_R = 0$:

$$P_R^* = \frac{a_1 - c_1'L_I + c_1L_R + b_1'P_I + b_1W_R}{2b_1}. \tag{4}$$

In the retail channel, the manufacturer wants to determine the optimal wholesale price W_R^* and warranty length L_R^* to maximize his profit. Substituting Equation (4) into Equation (1), we use the Hessian Matrix to check the concavity of the model:

$$\frac{\partial^2\prod_{M1}}{\partial W_R^2} = -b_1 < 0, \tag{5}$$

$$\frac{\partial^2\prod_{M1}}{\partial L_R^2} = (1-\beta)\beta C_M\lambda_R^2(L_R\lambda_R)^{-2+\beta} < 0, \tag{6}$$

$$\frac{\partial^2\prod_{M1}}{\partial W_R^2}\cdot\frac{\partial^2\prod_{M1}}{\partial L_R^2} - \left(\frac{\partial^2\prod_{M1}}{\partial W_R\partial L_R}\right)^2 = -\frac{c_1^2}{4} - b_1(1-\beta)C_M\lambda_R^2(L_R\lambda_R)^{-2+\beta} > 0. \tag{7}$$

From $\beta > 1$ and $b_1 > c_1 > 0$, Equations (5)-(7) imply that $\prod_{M1}$ is a concave function of W_R and L_R. Then we can obtain the optimal wholesale price W_R^* and warranty length L_R^* by solving $\frac{\partial\prod_{M1}}{\partial W_R} = 0$ and $\frac{\partial\prod_{M1}}{\partial L_R} = 0$:

$$W_R^* = \frac{a_1 + b_1C_R - c_1'L_I + c_1L_R + b_1'P_I}{2b_1}, \tag{8}$$

$$L_R^* = \left(\frac{(-\frac{1}{2}c_1C_R + \frac{c_1W_R}{2})\lambda_R^{-\beta}}{\beta C_M}\right)^{\frac{1}{-1+\beta}}. \tag{9}$$

In the direct channel, the manufacturer determines the optimal price P_I^* and warranty length L_I^* to maximize his profit. Substituting Equation (4) into Equation (2), we use the Hessian Matrix to check the concavity of the model:

$$\frac{\partial^2 \prod_{M2}}{\partial P_I^2} = -2b_2 < 0, \tag{10}$$

$$\frac{\partial^2 \prod_{M2}}{\partial L_I^2} = (1-\beta)\beta C_M \lambda_R^2 (L_I\lambda_R)^{-2+\beta}, \tag{11}$$

$$\frac{\partial^2 \prod_{M2}}{\partial P_I^2}\cdot\frac{\partial^2 \prod_{M2}}{\partial L_I^2} - \left(\frac{\partial^2 \prod_{M2}}{\partial P_I \partial L_I}\right)^2 = -c_2^2 - 2b_2(1-\beta)\beta C_M \lambda_R^2 (L_I\lambda_R)^{-2+\beta} > 0. \tag{12}$$

From $\beta > 1$ and $b_2 > c_2 > 0$, Equations (10)-(12) imply that $\prod_{M2}$ is a concave function of W_R and L_R. Then, we can obtain the optimal wholesale price P_I^* and warranty length L_I^* by solving $\frac{\partial \prod_{M_2}}{\partial P_I} = 0$ and $\frac{\partial \prod_{M2}}{\partial L_R} = 0$:

$$P_I^* = \frac{a_2 + b_2 C_I + c_2 L_I - c_2' L_R + b_2' P_R}{2b_2}, \tag{13}$$

$$L_I^* = \left(\frac{(-c_2 C_I + c_2 P_I)\lambda_I^{-\beta}}{\beta C_M}\right)^{\frac{1}{-1+\beta}}. \tag{14}$$

3.2. **Cooperative game.** In the cooperative game, the optimal prices (P_R^*, P_I^*) and warranty lengths (L_R^*, L_I^*) are determined from the channel's perspective. This means these decisions are made to maximize channel profits. Channel profits are defined as the sum of the retailer's profit and the manufacturer's profit.

$$\prod\nolimits_C (P_R, L_R, P_I, L_I) = \prod\nolimits_{M1}(W_R, L_R) + \prod\nolimits_{M2}(P_I, L_I) + \prod\nolimits_R (P_R). \tag{15}$$

We use the Hessian Matrix to check the concavity of the model:

$$H(P_R, P_I, L_R, L_I) = \begin{bmatrix} \frac{\partial^2 \prod_C}{\partial^2 P_R} & \frac{\partial^2 \prod_C}{\partial P_R \partial P_I} & \frac{\partial^2 \prod_C}{\partial P_R \partial L_R} & \frac{\partial^2 \prod_C}{\partial P_R \partial L_I} \\ \frac{\partial^2 \prod_C}{\partial P_I \partial P_R} & \frac{\partial^2 \prod_C}{\partial^2 P_I} & \frac{\partial^2 \prod_C}{\partial P_I \partial L_R} & \frac{\partial^2 \prod_C}{\partial P_I \partial L_I} \\ \frac{\partial^2 \prod_C}{\partial L_R \partial P_R} & \frac{\partial^2 \prod_C}{\partial L_R \partial P_I} & \frac{\partial^2 \prod_C}{\partial^2 L_R} & \frac{\partial^2 \prod_C}{\partial L_R \partial L_I} \\ \frac{\partial^2 \prod_C}{\partial L_I \partial P_R} & \frac{\partial^2 \prod_C}{\partial L_I \partial P_I} & \frac{\partial^2 \prod_C}{\partial L_I \partial L_R} & \frac{\partial^2 \prod_C}{\partial^2 L_I} \end{bmatrix}, \tag{16}$$

$$[-2b_1] = -2b_1 < 0, \tag{17}$$

$$\begin{bmatrix} -2b_1 & b_1' + b_2' \\ b_1' + b_2' & -2b_2 \end{bmatrix} = 4b_1 b_2 - (b_1')^2 - 2b_1' b_2' - (b_2')^2 > 0, \tag{18}$$

$$\begin{bmatrix} -2b_1 & b_1' + b_2' & c_1 \\ b_1' + b_2' & -2b_2 & -c_2' \\ c_1 & -c_2' & (1-\beta)\beta C_M \lambda_R^\beta L_R^{-2+\beta} \end{bmatrix} \tag{19}$$

$$= c_2'(-b_1' c_1 - b_2' c_1 - 2b_1 c_2') + c_1(2b_2 c_1 + b_1' c_2' + b_2' c_2') + (1-\beta)\beta\big(4b_1 b_2 - (b_1' + b_2')^2\big) C_M L_I^{-2+\beta}\lambda_R^\beta < 0,$$

$$\begin{bmatrix} -2b_1 & b_1'+b_2' & c_1 & -c_1' \\ b_1'+b_2' & -2b_2 & -c_2' & c_2 \\ c_1 & -c_2' & (1-\beta)\beta C_M \lambda_R^{\beta} L_I^{-2+\beta} & 0 \\ -c_1' & c_2 & 0 & (1-\beta)\beta C_M \lambda_I^{\beta} L_I^{-2+\beta} \end{bmatrix}$$

$$\begin{aligned} &= (1-\beta)C_M L_I^{-2+\beta}\lambda_I^{\beta}(c_2'(-b_1'c_1 - b_2'c_1 + 2b_1c_2') \\ &\quad + c_1(2b_2c_1 - b_1'c_2' - b_2'c_2') + (1-\beta)\beta(4b_1b_2 - (b_1'+b_2')^2)C_M L_R^{-2+\beta}\lambda_R^{\beta}) \\ &\quad + c_1'(-c_2'(c_1c_2 - c_1'c_2') - (1-\beta)\beta(b_1'c_2 + b_2'c_2 - 2b_2c_1')C_M L_R^{-2+\beta}\lambda_R^{\beta}) \\ &\quad + c_2(c_1(c_1c_2 - c_1'c_2') - (1-\beta)\beta(-2b_1c_2 + b_1'c_1' + b_2'c_1')C_M L_R^{-2+\beta}\lambda_R^{\beta}) > 0. \end{aligned} \tag{20}$$

Because $\beta > 1$ and $b_1 > c_1$, $b_2 > c_2$, Equations (17)-(20) imply that $\prod_C$ is a concave function of P_R, L_R, P_I and L_I. From Winston [20], this means an existing solution of $\frac{\partial \Pi_C}{\partial P_R} = 0$, $\frac{\partial \Pi_C}{\partial L_R} = 0$, $\frac{\partial \Pi_C}{\partial P_I} = 0$ and $\frac{\partial \Pi_C}{\partial L_I} = 0$. They are

$$P_R^* = \frac{a_1 - b_2'C_I + b_1C_R - c_1'L_I + c_1L_R + b_1'P_I + b_2'P_I}{2b_1}, \tag{21}$$

$$L_R^* = \left(\frac{(c_2'C_I - c_1C_R - c_2'P_I + c_1P_R)\lambda_R^{-\beta}}{\beta C_M}\right)^{\frac{1}{-1+\beta}}, \tag{22}$$

$$P_I^* = \frac{a_2 + b_2C_I - b_1'C_R + c_2L_I - c_2'L_R + b_1'P_R - b_2'P_R}{2b_2}, \tag{23}$$

$$L_I^* = \left(\frac{(-c_2C_I + c_1'C_R + c_2P_I - c_1'P_R)\lambda_I^{-\beta}}{\beta C_M}\right)^{\frac{1}{-1+\beta}}. \tag{24}$$

4. **Computational Analysis.**

4.1. **Numerical example.** We consider a case and summarize the values of parameters in Table 1.

TABLE 1. Values of parameters

Base parametric for illustrative examples	
Retail channel Market space	$a_1 = 2000$
Direct channel Market space	$a_2 = 1700$
Price parameter	$b_1 = b_2 = 6$, $b_1' = b_2' = 4$
Warranty length parameter	$c_1 = c_2 = 4$, $c_1' = c_2' = 2$
Product life cycle	$\beta = 2$
Product cost for retail channel (per unit)	$C_R = 200$
Product cost for direct channel (per unit)	$C_I = 170$
Defective cost (per unit)	$C_M = 150$
Product failure rate	$\lambda_R = \lambda_I = 0.3$

Using the solution procedures described above to solve the problem, the results of the model are as Table 2.

In a retail channel, the optimal retail price is 499.965, the optimal wholesale price is 399.967, and the optimal warranty length is 14.8131. In a direct channel, the optimal price is 402.326 and the optimal warranty length is 34.4186. The total channel profit in the non-cooperative game is 484852.9; the total channel profit in the cooperative game is 568662. The channel profit in the cooperative game is greater than that in the non-cooperative game. In the retail channel, it is interesting to discuss the profit distribution

TABLE 2. Results of the model

Non-Cooperative Games		Cooperative Games	
$P_R = 499.965$	$L_R = 14.8131$	$P_R = 584.231$	$L_R = 28.4615$
$P_I = 402.326$	$L_I = 34.4186$	$P_I = 554.231$	$L_I = 28.4615$
$W_R = 399.976$			
$\prod_{M1} = 117009$	$\prod_R = 59985.9$		
$\prod_{M2} = 307858$			
$\prod_R + \prod_{M1} + \prod_{M2} = 484852.9$		$\prod_C = 568662$	

between retailer and manufacturer. Table 3 shows the profit distribution under various wholesale prices.

TABLE 3. Profit sharing in the retail channel

W_R	**367**	**400**	**430**	**460**	**506**
$\prod_R$	16933	141574	118520	95466.6	60117.3
$\prod_{M1}$	117397	142757	165810	188864	224213
$\prod_R + \prod_{M1}$	284331	284331	284331	284331	284331

4.2. **Sensitive analysis.** This section discusses the influence of parameters such as market base (a_1, a_2), price parameter (b_1, b_2) and warranty length parameter (c_1, c_2) on decisions and profits.

Let $W_R(N)$ be the wholesale price in the non-cooperative game and $W_R(C)$ be the wholesale price in the cooperative game, respectively. Other variables follow the same format. Figures 2-7 show that all the prices will increase as a_1 and a_2 increase; L_R and L_I will increase as a_1 and a_2 increase; the profits will increase as a_1 and a_2 increase. Because the market base increases, the price and warranty length will increase to earn more profit.

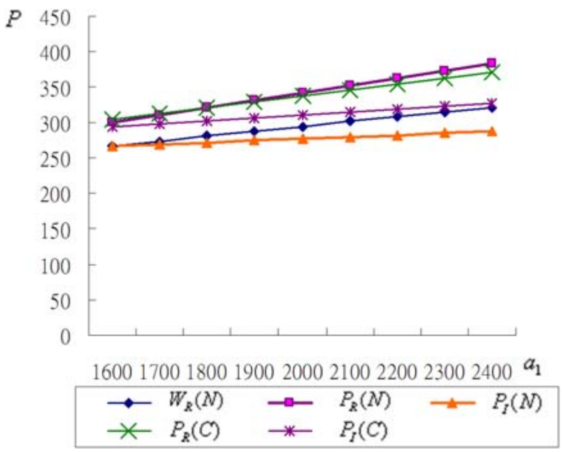

FIGURE 2. Effect of a_1 on price P

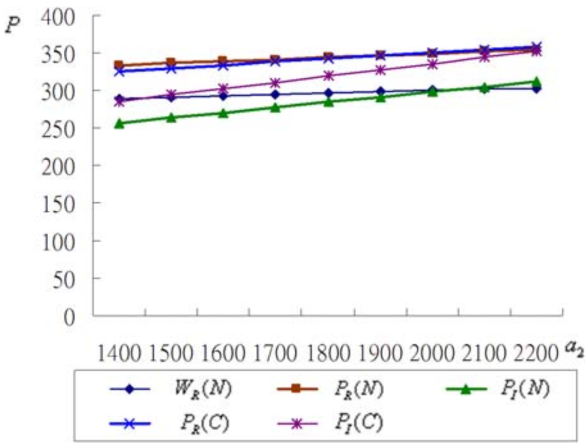

FIGURE 3. Effect of a_2 on price P

Figures 8-13 show that all the prices will decrease as b_1 and b_2 increase; L_R and L_I will decrease as b_1 and b_2 increase; the profits will decrease as b_1 and b_2 increase. When

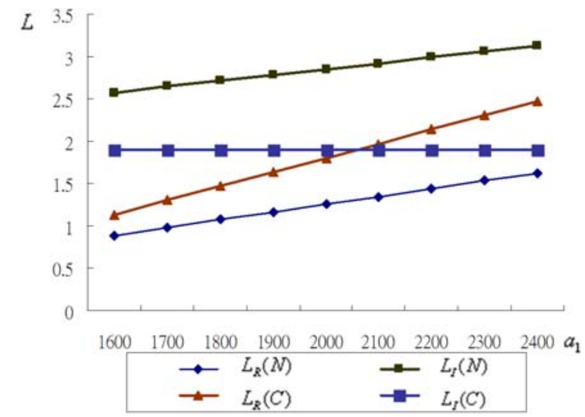

FIGURE 4. Effect of a_1 on length L

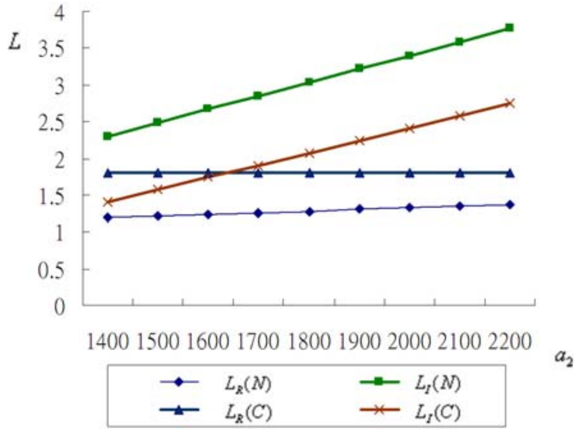

FIGURE 5. Effect of a_2 on length L

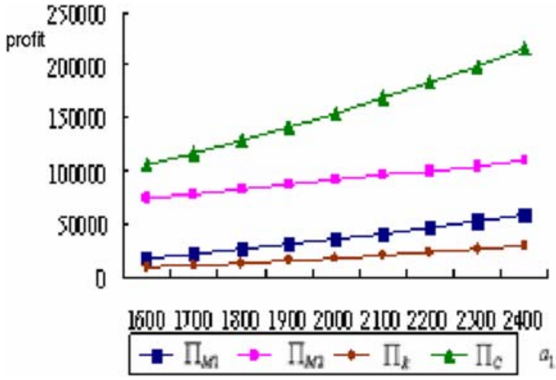

FIGURE 6. Effect of a_1 on profit $\prod$

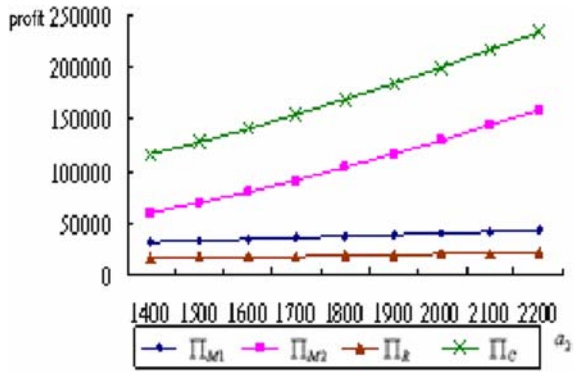

FIGURE 7. Effect of a_2 on profit $\prod$

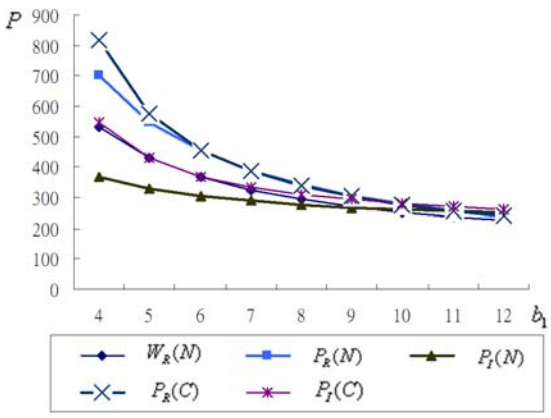

FIGURE 8. Effect of b_1 on price P

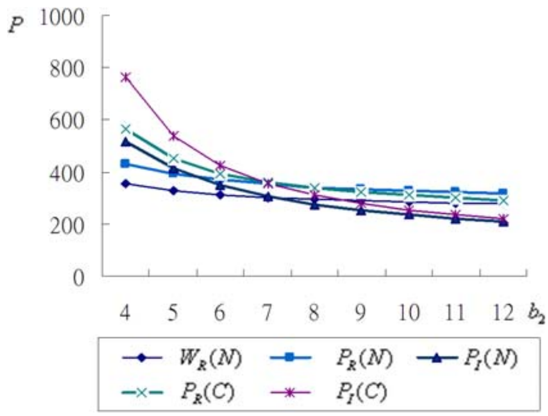

FIGURE 9. Effect of b_2 on price P

the price parameters increase, the prices are more sensitive to demand. The price and warranty length will decrease to reduce profit loss.

Figures 14-19 show that all the prices will increase as c_1 and c_2 increase; L_R and L_I will increase asc_1 and c_2 increase; the profits will increase as c_1 and c_2 increase. When the warranty length parameters increase, the warranty lengths are more sensitive to demand. The price and warranty length will increase to earn more profit.

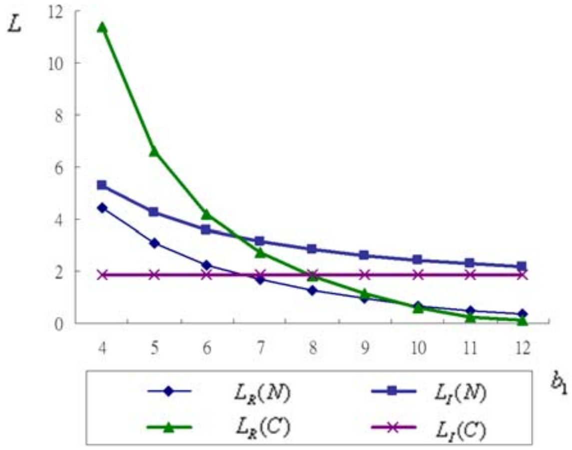

FIGURE 10. Effect of b_1 on length L

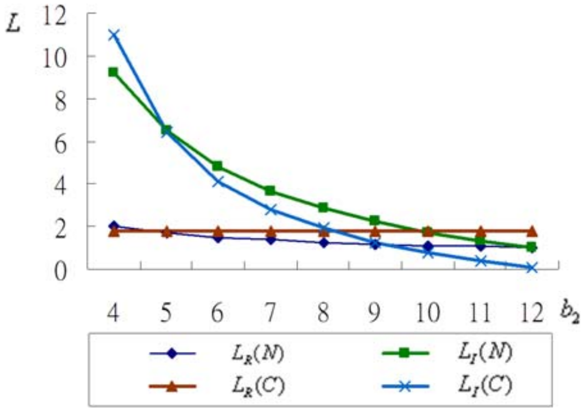

FIGURE 11. Effect of b_2 on length L

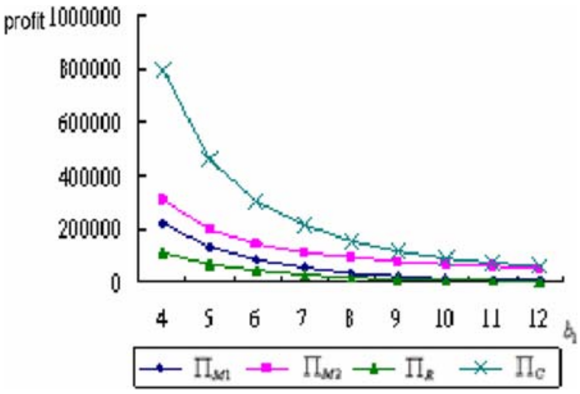

FIGURE 12. Effect of b_1 on profit $\prod$

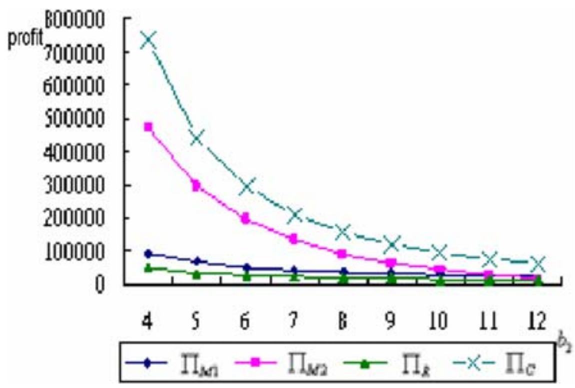

FIGURE 13. Effect of b_2 on profit $\prod$

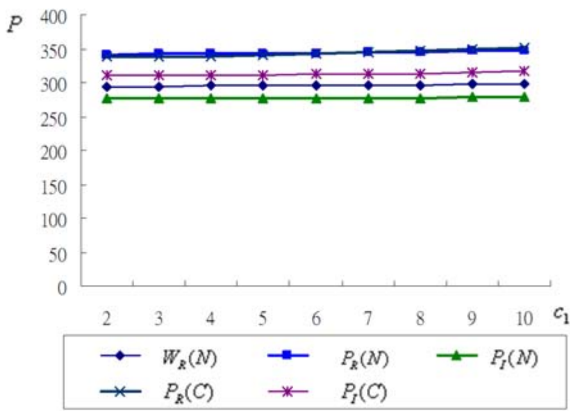

FIGURE 14. Effect of c_1 on price P

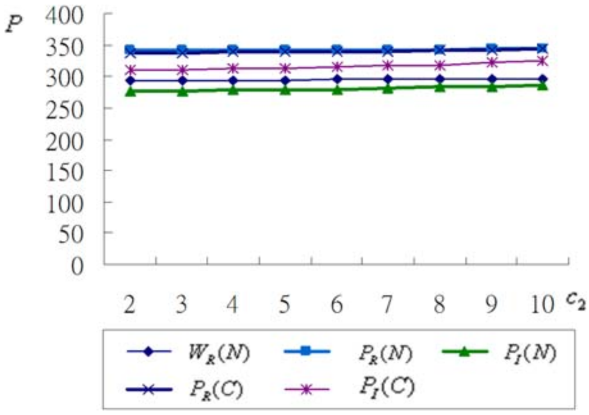

FIGURE 15. Effect of c_2 on price P

5. **Conclusion.** Previous studies on the dual-channel supply chain have focused on the issue of inventory and controlling costs, but have neglected the issue of pricing, warranty length and profit. This study considers the manufacturer wholesale price and warranty length decisions coupled with the retailer retail pricing decisions to maximize profits. Findings show that both the manufacturer and the retailer earn more profit in the co-operative game than in the non-cooperative game. This work also discusses how to use

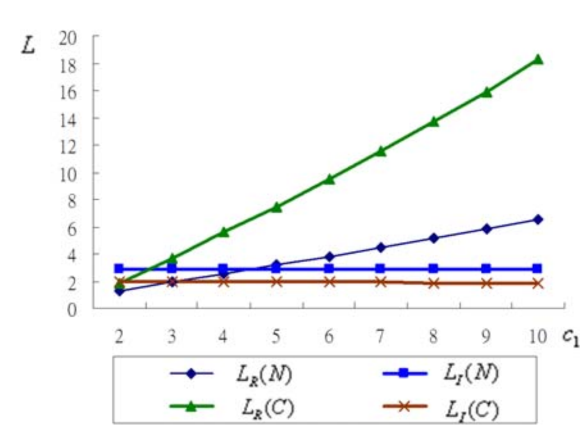

FIGURE 16. Effect of c_1 on length L

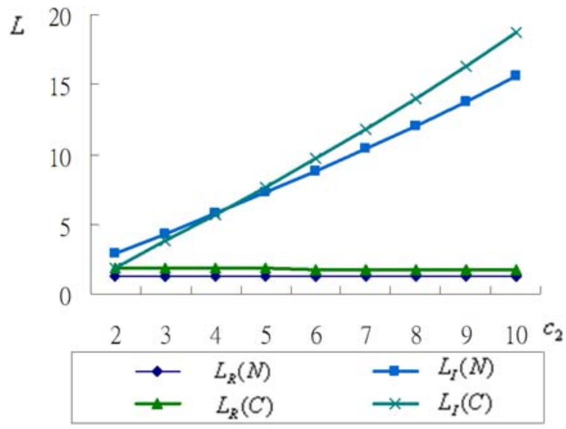

FIGURE 17. Effect of c_2 on length L

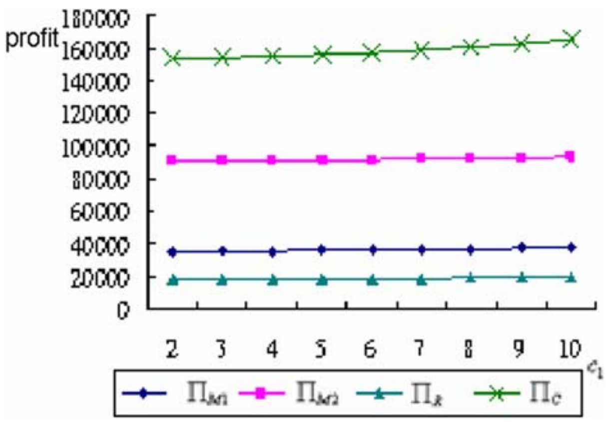

FIGURE 18. Effect of c_1 on profit $\prod$

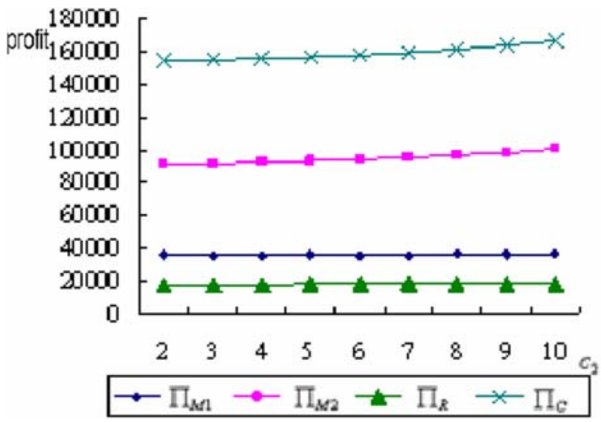

FIGURE 19. Effect of c_2 on profit $\prod$

profit sharing mechanisms to achieve a positive situation in the cooperative game. Numerical examples and analysis illustrate the solution procedure and discuss the impact of various system parameters. This paper deals with pricing and warranty decisions from the perspective of profit, to be used as an add-in optimizer in an ERP system. The model utilizes the nonlinear program to solve the pricing and warranty problem. Thereby, the model and solution procedure developed in this paper can be embedded into an ERP system to determine pricing and warranty decisions.

This paper utilizes a calculus-based optimization approach to solve pricing and warranty decisions in a two-echelon, dual-channel supply chain and adopts non-cooperative and cooperative equilibrium to solve the problem. The solution approach can be applied to any multivariable nonlinear programming problem. This paper also discusses how to use profit sharing mechanisms for coordination. This is useful for managers to coordinate their channel partners to earn more profit. The management insights from numerical analysis are a useful reference for decision-making.

One limitation of this research is the deterministic demand. Future research may consider a stochastic demand. This means that the demand is uncertain and that shortages may occur. Goods such as medicine, volatile liquids, and foodstuffs can deteriorate during normal storage periods. This paper does not consider the characteristics of deteriorating items. Further research can extend this paper to consider other situations, such as stochastic demand or deteriorating items.

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