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Pricing Strategies for Competitive Water Supply Chains under Different Power Structures: An Application to the South-to-North Water Diversion Project in China

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Abstract: Under two different power structures, where the supplier and the distributor, respectively, are modeled as the leader, this paper studies water pricing strategies in two competing water resources supply chains. We assume that each water supply chain consists of a risk-neutral water supplier and a risk-neutral water distributor. We build different decision models for two competitive water resources supply chains, derive the optimal decision strategies for the water supply chain members, and analyze how competition intensity affects these decisions. Analytical results show that when the supplier is the leader, its water wholesale price is always higher than that when the distributor serves as the leader. On the other hand, the retail price and the two supply chains' channel profits depend on the competition intensity, but are independent of the power structure. To illustrate the proposed models, we apply them to examine the water pricing strategies in the South-to-North Water Diversion Project in China. The results showed significant insights into the pricing strategies of water resources in different routes of this massive water diversion project.

Keywords: competitive supply chain; power structure; pricing strategy; South-to-North Water Diversion Project

1. Introduction

In many markets, an exclusive retailer is selected when a new product comes into the market [1]. That is, the retailer is the exclusive agency only doing the business of product retailing for an upstream supplier. There is an exclusive channel in many retail industries, such as gas, fast food, and gasoline. In many countries and regions, such as China, Japan, Korea, Europe, and the United States, this kind of exclusive channel seems to be very common in parts distribution systems [2]. Competition may exist in a common market if two distributors and two suppliers form two competitive supply chain systems. It is generally believed that the competition occurs between the two supply chains instead of in a traditional company in many retail industries [3].

Furthermore, economic globalization, growing population, and increasing demands for natural resources have created severe environmental challenges [4]. Many countries worldwide are becoming increasingly more intensely competitive for natural resources. Water resources are one typical competition issue faced by many countries. As a result of water shortage, regional competition is becoming increasingly fierce. Recently, a study by McKenzie found that the global water gap is expected to reach 40% by 2030 [5]. This shortfall will affect countries all over the world, including in Australia, Africa, and Asia. According to a study group, the risk of water shortage in Asia is especially troublesome because of its immense population and rapid economic growth. Water shortage will affect agricultural production and people's livelihood, and thus the search for reliable water sources and inter-basin water transfer projects has begun in some countries, for example, the California Water Conservancy Project, the Verdun Water Diversion Project in France, the Lesotho Highlands Water Conservancy Project in southern Africa, and the South-to-North Water Diversion Project (SNWDP) in China [6].

A new water transfer project may cause an increment in profits for water supply chains. Through cooperation between water supply chain members, such as in pricing strategy, contract choice, and order quantity, the performance of the supply chain system is improved. However, under fierce competition, water resource cooperation becomes more difficult. Water resource competition affects decision strategies adopted by the members. Thus, two fundamental questions need to be answered to investigate the effects of competition. How do competing water supply chain members price in different power structures? How do competition intensity and pricing strategy affect profits of the competing members?

In this study, we take the two water routes as competing water supply chains. Each supply chain has a water supplier and a water distributor, and they are risk-neutral. The two suppliers provide alternative water resources and maximize their profits in a decentralized structure that has two alternatives. One structure is formed by an upstream water supplier as the leader and a downstream water distributor as the follower. The other has an opposite structure consisting of a downstream water distributor as the leader and an upstream water supplier as the follower. The pricing decisions of the competing water supply chains are different under different power structures. In addition, this study investigates the effects of competition intensity between two alternative water sources.

Therefore, our study contributes to the growing body of research on water transfer projects and differs from previous studies in the following ways.

(1) We build different decision models for two competing water resources supply chains, derive optimal decision strategies for the members, and analyze how competition intensity affects these decisions.
(2) Under different power structures, we analyze the impacts of competition intensity and pricing strategy on the performance of competing water supply chain members and the whole system.

The rest of this paper is organized as follows. Section 2 presents the literature review. Section 3 introduces the problem description and hypotheses. In Section 4, we build different decision models for two competing water resources supply chains, and derive optimal decision strategies for the members. Section 5 presents the numerical analysis and pricing decisions of supply chain enterprises under different power structures. We summarize the research in Section 6. All proofs of the propositions are included in Appendix A.

2. Literature Review

Based on the methods and procedures for literature review described by [7,8], we systematically review the relevant studies and summarize the critical viewpoints in this section. A review of the literature shows three relevant areas including operational decisions of competitive supply chains, water resources supply chain management, and water pricing and decision strategies in the South-to-North Water Diversion Project.

2.1. Operational Decisions of Competitive Supply Chains

One stream of previous studies has mainly focused on the operational decisions in competitive supply chains. In 1983, McGuire and Staelin [9] first proposed a model to examine competition among supply chains. Moorth [10] compared the performance of the supply chain members with assumptions on various control modes and found that a decentralized structure became the equilibrium of chain-to-chain management. Under various competitive conditions on price and service, Ai et al. [11]

investigated the performance of both electronic and traditional supply chains, and designed a coordination mechanism. They found that the transfer payment contracts increased as the ordered quantity increased, while they decreased as the service level increased. Ha and Tong [12] studied a linear pricing contract and analyzed investment effect on competition in the supply chain. Through a dual brand replacement, Zhang et al. [13] built a competitive model, analyzed the replacement level of inventory, and investigated the expected profits on supply chain members.

Additionally, in two competitive supply chains, Shou et al. [14] designed two types of contracts to effectively cope with supply risks, and illustrated the effects of risks on supply chains. They found that supply chain coordination was the power structure strategy under competition and consumers could benefit from the coordination. Anderson and Bao [15] analyzed the problem of chain-to-chain structures and found that different operating decisions were made with different structural modes in supply chains. Considering that demand is affected by the retail price of the product and the inventory, Xu and Sun [16] analyzed the competition within each strand of the supply chain coordination regarding the contract design. Chen and Zhang [17] studied the effects of Nash game and Stackelberg game between two competing supply chains of customer returns. Xiao et al. [18] examined the chain-to-chain coordination and found that a more competitive environment could stimulate the productivity of supply chain members. In studying competition of a number of chains, Zhao et al. [19] estimated the competition form and designed a profit sharing contract and a quantity discount contract. Their results showed that the quantity discount contract realized a Pareto improvement in the performance of the supply chain system.

Furthermore, regarding supply chain management under both decentralized and centralized structures directly selling products through two retail channels, Xiao et al. [20] analyzed chain-to-chain contracts in terms of price and lead time. Naser and Khojasteh [21] built a price competition model in an uncertain demand environment wherein each supply chain contained a risk-neutral manufacturer and two risk-averse retailers, and studied the supply chain strategies under the leadership of either the manufacturer or the retailers. Under demand uncertainty and with longitudinal structural constraints, Zhao et al. [22] studied the chain-to-chain competition of fixed price contracts, and analyzed the effects of fixed prices and competition intensity on contract selection. Using an experiment, Choi and Messinger [23] analyzed the role of fairness in competing supply chains, and the results showed that fairness plays an important role in supply chain management. Chen et al. [24] explored the pricing policies and green strategies in a duopoly green supply chain with vertical and horizontal competition. However, these studies do not consider supply chain competition, particularly in water resources management, nor do they examine the pricing decisions of water supply chain members under different power structures or with competition intensity.

2.2. Water Resource Supply Chain Management

A second stream has focused on supply chain management and water resources research. In India, the water supply network in small- and medium-sized towns is insufficient to fulfill the needs of the whole population, and Angueletou-Marteau et al. [25] dealt with the water supply methods providing access to water in these towns in the peri-urban territories of Mumbai. They found the complementary forms of water supply fill the gaps left because of the failure of municipal services. In Gweru, Kusena and Beckedahl [26] evaluated the effective water capacity, satisfied the needs of local residents, and resolved the negative impacts of the supply chain. Neil and Barry [27] developed arguments for more effective procurements leading to real cost reduction and for service enhancement on a sustainable basis. They proposed to acquire major capital goods and associated services to improve the relationships with contractors, suppliers, and supply chains.

In addition, Saif and Almansoori [28] examined the optimal capacity at the water infrastructure in a certain planning horizon. The results showed that increasing carbon tax led to a cost increase of the supply chain. Guerra et al. [29] and Ozawa et al. [30] established a framework that integrated water management, and design and planning of the shale gas supply chain. Kogan and Tapiero [31] addressed the economic efficiency of water production and distribution in a vertical supply chain consisting of a water supplier and a consumer (municipality). The study showed that when the supply variance depends on the supply mean, the effect of uncertainty depends on the intensity of the conflict between the municipality and the water supplier. Castillo et al. [32] pointed out Brazil's uneven spatial distribution of water resources among regions, and showed the scarce water footprint and the interregional virtual water flows in 27 states in Brazil. Saif and Almansoori [33] built an integer linear program model, and analyzed the water transfer in a water supply chain. They studied the water shortage, effective water capacity, and costs in water resources supply chains. They also analyzed the optimal transfer ability of the cycle, water productivity, water distribution capacity, and so on. However, they did not analyze the operational management of water resources supply chains, nor did they consider the effects of competition on the decisions of the water resources supply chain system.

2.3. Water Pricing and Decision Strategies in SNWDP

A third stream has mainly focused on water resource pricing in the Eastern and Middle Routes of SNWDP. Moncue [34] studied the pricing of water resources in arid regions, while Liu [35] pointed out that the Eastern Route is the most effective way to solve the water shortage in northern China. Garcia-valinas [36] studied water pricing from the perspectives of efficiency and fairness, while Wang and Hu [37] noted that it is feasible and relevant to incorporate supply chain management into the operation and management of SNWDP. Zhu [38] introduced supply chains into the optimal allocation and scheduling of water resources and proposed water management using supply chains. Wang et al. [39] established a principal–agent contract model and a pricing model for the SNWDP supply chain. Zhang et al. [40] studied a discriminatory pricing model using simulations of different markets in the Eastern Route. Similarly, Yang [41] adopted the supply chain pricing model and studied the single-cycle pricing strategy in secondary supply chains in a stochastic demand condition. Chen and Wang [42] combined the Eastern Route with the engineering practice of water resources supply chain system, established a quasi-market using a Newsvendor optimizing production model, and put forward the corresponding policy suggestions regarding the eastern water supply chain system. Wang et al. [43] studied the optimization of pricing and proposed an optimized coordination scheme in the Eastern Route supply chain. Chen et al. [44] studied the pricing mechanism of the SNWDP in a stable environment.

Additionally, based on the Eastern Route, Du et al. [45] studied the selection of two-part pricing contracts and wholesale pricing contracts. To reduce power costs and meet water demand, Zhuan et al. [46] proposed the operational optimization of three pumping stations and pointed out two main aspects of cost-effectiveness, including the time interval of high electricity price and the period of low electricity price, as well as the operation modes of high energy efficiency. Regarding scheduling issues, Zhuan et al. [47] studied the optimal operation of the Eastern Route and found that demand shifting was the main reason for high levels of demand at a given pump head. Overall, these studies examined water pricing by considering either route of the SNWDP, while they did did not consider the competition between the two routes. Furthermore, they did not study how different power structures and competition intensity affect the pricing decisions.

3. Problem Description and Hypotheses

This study analyzes two competing water supply chains, and each supply chain has a supplier and a distributor of water resources. Assume the members are risk-neutral, the two suppliers are homogenous but alternative water sources, and quantity competition exists between the two distributors with a decentralized market structure. The decentralized structure has two alternatives. One is formed by an upstream water supplier as the leader and a downstream water distributor as the follower. The other structure is consisted of a downstream water distributor as the leader and an upstream water supplier as the follower. Both chains are risk-neutral and the members behave in a manner of rational economic actors. Other costs for the suppliers and distributors are assumed to be zero for simplicity.

The inverse demand function of the water distributors [48] can be expressed as follows:

$$p_i = a_i - q_i - bq_j, j = 3 - i, i = 1, 2 \tag{1}$$

The corresponding demand function can be derived as follows:

$$q_i = \frac{a_i - ba_j - p_i + bp_j}{1 - b^2}, j = 3 - i, i = 1, 2 \tag{2}$$

where a_i is the maximum willingness to pay (WTP) of consumers to purchase water in the end market. Because consumers' cognition of water resources is different, a_i is hypothesized to be a random variable, and $E(a_i) = \delta_i$. b is the competition intensity between the two alternative water supply chains. p_i is the retail water price from source i, and q_i is the water demand for source i.

4. Decision Models for Water Resources Supply Chains under Different Power Structures

4.1. The Supplier as the Leader

When two water supply chain competitors adopt a decentralized longitudinal structure, the supplier acts as a leader and the distributor as a follower. To maximize the profits, the suppliers offer a wholesale water price w_i. Then, the distributors set the retail water price to maximize their profits. According to the authors of [10,11], the profit function can be solved, and we can get the expressions for the profit function and expected profit function of the supply chain members.

In this regard, the profit function of the distributors is as follows:

$$R_{imm} = \frac{(p_i - w_i)(a_i - ba_j - p_i + bp_j)}{1 - b^2} \tag{3}$$

The expected profit function of the distributors is the following:

$$E(R_{imm}) = \frac{(p_i - w_i)(\delta_i - b\delta_j - p_i + bp_j)}{1 - b^2} \tag{4}$$

The profit function of the suppliers is the following:

$$M_{imm} = \frac{w_i(a_i - ba_j - p_i + bp_j)}{1 - b^2} \tag{5}$$

The expected profit function of the suppliers is the following:

$$E(M_{imm}) = \frac{w_i(\delta_i - b\delta_j - p_i + bp_j)}{1 - b^2} \tag{6}$$

Proposition 1. *When the suppliers are the leaders in two competitive water supply chains, the best retail price of the distributors is* $p_i{}^* = \frac{2(b^2-3)A_i}{(2b^2-b-4)(2b^2+b-4)(b^2-4)}$, *and the optimal wholesale price of the suppliers is* $w_i{}^* = \frac{A_i}{4b^4-17b^2+16}$ *to realize their maximum profits, respectively, where* $A_i = 2\delta_i b^4 + \delta_j b^3 - 9\delta_i b^2 - 2\delta_j b + 8\delta_i$.

Proof. See Appendix A.

Proposition 1 shows that when the suppliers are the leaders and the distributors are the followers, the supply chain members can get the optimal decision strategy. The wholesale price of the suppliers can be expressed as a function of the competition intensity and market size. In the same way, the retail price of the distributors can also be expressed as a function of the competition intensity and market size.

In this case, the expected profits of the water suppliers and distributors are, respectively, the following:

$$E(M_i)^* = \frac{\left(2-b^2\right)^2 {A_i}^2}{(1-b^2)(4-b^2)(2b^2-b-4)^2(2b^2+b-4)^2} \tag{7}$$

$$E(R_i)^* = \frac{\left(b^2-2\right)^2 {A_i}^2}{(1-b^2)(b^2-4)^2(2b^2-b-4)^2(2b^2+b-4)^2} \tag{8}$$

The expected profit of the water supply chain system is as follows:

$$E(T_i)^* = \frac{2\left(2-b^2\right)\left(3-b^2\right) {A_i}^2}{(1-b^2)(2b^2-b-4)^2(2b^2+b-4)^2(b^2-4)^2} \tag{9}$$

4.2. The Distributor as the Leader

The two water supply chain competitors adopt a decentralized longitudinal structure with the distributors as the leaders and the suppliers as the followers. To maximize the profits, the distributors make their retail price. Then, the suppliers set the wholesale price to maximize their profits. To solve this problem, the retail price can be considered as the value added to the wholesale price.

At this point, the profit function of the suppliers is the following:

$$M_{irr} = \frac{w_i\left(a_i - ba_j - p_i + bp_j\right)}{1-b^2} \tag{10}$$

The expected profit function of the suppliers is the following:

$$E(M_{irr}) = \frac{w_i\left(\delta_i - b\delta_j - (w_i + \Delta w_i) + b\left(w_j + \Delta w_j\right)\right)}{1-b^2} \tag{11}$$

The profit function of the distributors is the following:

$$R_{irr} = \frac{(p_i - w_i)\left(a_i - ba_j - p_i + bp_j\right)}{1-b^2} \tag{12}$$

The expected profit function of the distributors is the following:

$$E(R_{irr}) = \frac{\Delta w_i\left(\delta_i - b\delta_j - (w_i + \Delta w_i) + b\left(w_j + \Delta w_j\right)\right)}{1-b^2} \tag{13}$$

Proposition 2. *When the distributors are the leaders in the two competing water supply chains, the best retail price of the distributors is* ${p_i}^* = \frac{2\left(b^2-3\right)A_i}{(2b^2-b-4)(2b^2+b-4)(b^2-4)}$ *, and the optimal wholesale price of the suppliers is* ${w_i}^* = \frac{\left(b^2-2\right)A_i}{(2b^2-b-4)(2b^2+b-4)(b^2-4)}$*, to realize their maximum profits, respectively, where* $A_i = 2\delta_i b^4 + \delta_j b^3 - 9\delta_i b^2 - 2\delta_j b + 8\delta_i$.

Proof. See Appendix A.

Proposition 2 shows that when the distributors are the leaders and the suppliers are the followers, the supply chain members can get the optimal decision strategy. The wholesale price of the suppliers can be expressed as a function of the competition intensity and market size. In the same way, the retail price of the distributors is also a function of the competition intensity and market size.

In this case, the expected profits of the suppliers and distributors are, respectively, the following:

$$E(M_i)^* = \frac{2\left(b^2-2\right)^2 {A_i}^2}{(1-b^2)(2b^2-b-4)^2(2b^2+b-4)^2(b^2-4)^2} \tag{14}$$

$$E(R_i)^* = \frac{2\left(2-b^2\right) {A_i}^2}{(1-b^2)(4-b^2)(2b^2-b-4)^2(2b^2+b-4)^2} \tag{15}$$

The expected profit of the water supply chain system is the following:

$$E(T_i)^* = \frac{\left(2-b^2\right) B_i}{(b^2-1)(2b^2-b-4)^2(2b^2+b-4)^2(b^2-4)^2} \tag{16}$$

where $B_i = \left({A_i}^2 + {A_j}^2\right)b^2 - 2{A_i}^2 - 4{A_j}^2$.

5. Numerical Analysis and Discussion

The numerical analysis helps us better understand the effects of competition intensity on the optimal strategies of the two water supply chains [45]. For the Eastern and Middle Routes of the SNWDP, each has a supplier and a distributor of water resources, and the water diverted from both routes arrives at the same location in northern China. The suppliers set different wholesale water prices and the distributors choose different retail prices under different power structures. To further simplify the calculations, we assume there are two maximum WTPs (for example, two consumers) in the market, with the first fixed (for one consumer) and the second variable or fixed (for the other consumer). The other parameters are shown in Table 1.

Table 1 shows that the competition intensity affects the parameters for the water resources supply chains regardless of the power structure. Whether the distributors or the suppliers are the leaders, the retail price of the two water supply chains is constant, and the expected profit of the second supply chain is also constant. In other words, within the two competing water supply chains, the supply chains' retail prices and expected profits are related to the competition intensity, but independent of the power structure.

If the suppliers are the leaders, when the second water supply chain's maximum price paid is less than or equal to the price of the first supply chain, the water suppliers' wholesale prices and water distributors' retail prices are affected by the competition intensity. When the second water supply chain's maximum price paid is higher than the first supply chain's maximum price, the water suppliers' wholesale prices and the distributors' retail prices decrease as the competition intensity increases. On the other hand, if the distributors are the leaders, when the second water supply chain's maximum price paid is less than or equal to that of the first supply chain, the suppliers' wholesale prices and the distributors' retail prices decrease as the competition intensity increases. When the second water supply chain's maximum price paid is higher than that of the first supply chain, the suppliers' wholesale prices and the distributors' retail prices also decrease as the competition intensity increases. Thus, both the wholesale prices and retail prices decrease as the competition intensity increases when one demand is fixed and regardless of the other demand.

Regarding the profit expectation of the water supply chains, if the suppliers are the leaders, when the maximum price paid in the second water supply chain is lower than the first supply chain's maximum price, the second supply chain's expected profit is always lower than that of the first supply chain. As the competition intensity increases, the second supply chain's profit gradually decreases, while the first supply chain's profit gradually increases. When the second water supply chain's maximum price paid is equal to the first supply chain's maximum price, the second supply chain's profit is always equal to that of the first supply chain, and the profits of both supply chains gradually decrease as the competition intensity increases. When the second water supply chain's maximum price paid is higher than the first supply chain's maximum price, the second supply chain's profit is always higher than that of the first supply chain. Meanwhile, as the competition intensity increases, the second supply chain's profit first decreases and then gradually increases, while the first supply chain's profit decreases.

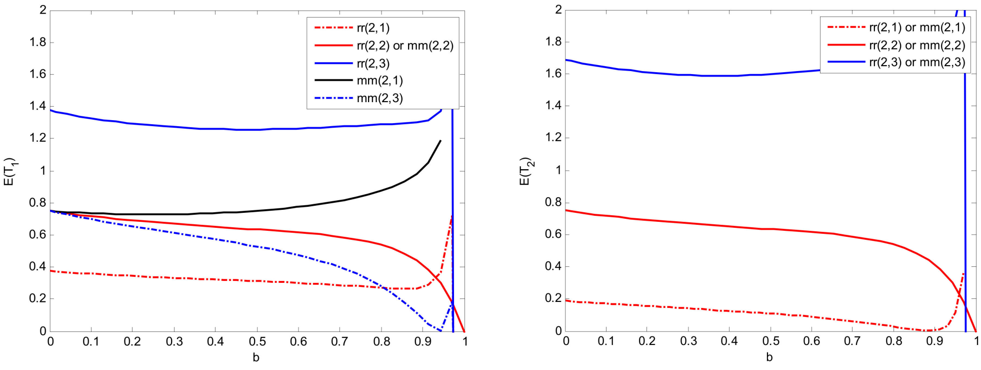
Table 1. The influence of competition intensity on the parameters of water resources supply chains under different power structures.

			mm						***rr***					
δ_1	δ_2	b	w_1	w_2	p_1	p_2	T_1	T_2	w_1	w_2	p_1	p_2	T_1	T_2
2	1	0.1	0.99	0.47	1.48	0.71	0.74	0.17	0.49	0.24	1.48	0.71	0.36	0.17
		0.3	0.95	0.42	1.42	0.62	0.73	0.14	0.47	0.20	1.42	0.62	0.33	0.14
		0.5	0.91	0.34	1.33	0.50	0.75	0.11	0.42	0.16	1.33	0.50	0.31	0.11
		0.7	0.82	0.23	1.17	0.32	0.81	0.06	0.35	0.10	1.17	0.32	0.29	0.06
		0.9	0.61	−0.02	0.84	−0.03	1.01	0.00	0.23	−0.01	0.84	−0.03	0.28	0.00
	2	0.1	0.97	0.97	1.46	1.46	0.72	0.72	0.49	0.49	1.46	1.46	0.72	0.72
		0.3	0.91	0.91	1.36	1.36	0.69	0.69	0.45	0.45	1.36	1.36	0.69	0.69
		0.5	0.83	0.83	1.22	1.22	0.63	0.63	0.39	0.39	1.22	1.22	0.63	0.63
		0.7	0.70	0.70	1.00	1.00	0.59	0.59	0.30	0.30	1.00	1.00	0.59	0.59
		0.9	0.39	0.39	0.54	0.54	0.41	0.41	0.15	0.15	0.54	0.54	0.41	0.41
	3	0.1	0.96	1.47	1.44	2.21	0.70	1.64	0.47	0.74	1.44	2.21	1.33	1.64
		0.3	0.88	1.41	1.30	2.10	0.61	1.59	0.43	0.69	1.30	2.10	1.27	1.59
		0.5	0.76	1.32	1.12	1.94	0.53	1.60	0.35	0.62	1.12	1.94	1.25	1.60
		0.7	0.58	1.17	0.82	1.67	0.40	1.65	0.25	0.50	0.82	1.67	1.27	1.65
		0.9	0.17	0.81	0.24	1.11	0.08	1.76	0.06	0.30	0.24	1.11	1.30	1.76

mm: the suppliers as the leaders; *rr*: the distributors as the leaders; δ_1, δ_2: the expected maximum price paid by consumers to purchase water (willingness to pay) from the water supply chain 1 or 2; b: the competition intensity between the two alternative water supply chains; w_1,w_2: the wholesale price of supplier 1 or 2 (see their expressions in Propositions 1 and 2) p_1,p_2: the retail price of distributor 1 or 2 (see their expressions in Propositions 1 and 2); T_1,T_2: the expected profit of the water supply chain 1 or 2.

If the distributors are the leaders, when the maximum price paid in the second water supply chain is lower than that of the first supply chain, the second supply chain's profit is always lower than the first supply chain's profit. The profits of both supply chains gradually decrease as the competition intensity increases. When the second water supply chain's maximum price is paid equal to that of the first supply chain, the second supply chain's profit is always equal to the first supply chain's profit, and the profits of both supply chains decrease as the competition intensity increases. When the second water supply chain's maximum price paid is higher than the first supply chain's maximum price, the second supply chain's profit is always higher than the first supply chain's profit, and the profits of both supply chains increase as the competition intensity increases.

To better compare the changes of the expected profits and competition effects in the competing water supply chains, we present the expected profits of the two supply chains in Figure 1.



(**a**) (**b**)

Figure 1. The influence of competition intensity on the expected profits of the supply chains under different power structures (**a**) the first supply chain; (**b**) the second supply chain.

Figure 1 shows the maximum price paid by consumers affect profits of the two water supply chain. If the water suppliers are the leaders, the greater the expected price, the higher the supply chain's profit. If the distributors are the leaders, the greater the expected price, the more beneficial to the profit of the first supply chain. When the market size is the same, the profits of two water supply chains are equal. That is, their results are symmetric. A similar result is found for competition intensity affecting the profits of the two water supply chains. On the contrary, once the two water supply chains are facing markets with different sizes, the profits of the two water supply chains are different. As shown in Figure 1a,b when the market sizes for the two water supply chains are (2, 2), their profits are the same.

6. Conclusions

This study analyzes two competitive water supply chains. Each water supply chain has a risk-neutral supplier and a risk-neutral distributor. The two water diversion routes are considered two competing supply chains. The two suppliers are homogenous, but alternative water sources and a quantity of competition exists between the two distributors in a decentralized market. Under different power structures with either the suppliers or the distributors as the leaders, this study builds different decision models of two competing water resources supply chains. We also show the optimal decision strategies of supply chain members, and analyze how competition intensity affects these decisions. The Eastern and Middle Routes of the SNWDP are investigated with a numerical analysis conducted.

The findings suggest that the competition between the supply chains influences the optimal decisions. The suppliers' pricing decisions are more likely to change as the competition intensity increases. A comparison of the effects of competition intensity under different power structures shows the water suppliers' wholesale prices and the distributors' retail prices change as the competition intensity changes. In addition, the price affects profits of the supply chains. When the second water supply chain's maximum price paid is less than or equal to the first supply chain's maximum price, the greater the expected price, the higher the supply chain's profit, regardless of the leaders.

Different power structures do not always affect the distributors' marketing behaviors. For the two competing water supply chains, the retail price and expected profit of the second supply chain depend on the competition intensity, but are independent of the power structure. If the suppliers are the leaders, the wholesale price of the water resource suppliers is always higher than that when the distributors are the leaders. However, the retail price of the distributors is constant regardless of the leaders.

Our research expands the studies of [15,45], and our findings provide significant insights. Consistent with the model building under competition [15], this research incorporates varying power structures and member performance as affected by competition intensity in the South-to-North Water Diversion Project. Similarly, this research extends the scope of the work of [45] from Eastern Route to two routes, and develops the pricing strategies for competing supply chains as well as the profit determination. By enriching the theoretical analysis of competitive supply chain management, this study provides guidance for the operation of competing enterprises under varying power structures and for government policy design.

This study applies a generalized competitive supply chain model to the analysis of water allocation in two routes of SNWDP. The developed model can be helpful for other future research on competing markets with power differences. The limitation of our research is the assumptions of risk-neutral supply chain members and each supply chain consisting of one supplier and one distributor. Future research can examine the structural models with multiple supply chains incorporating risk-averse water suppliers and distributors.

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Appendix A

Proof of Proposition 1. To solve the problem using reverse induction, we first solve for the distributor's retail price, then solve for the wholesale price according to the supplier's profit. It is easy to get the following equation by taking the second derivative of Equation (4).

$$\frac{\partial^2 E(R_{imm})}{\partial {p_i}^2} = \frac{-2}{1-b^2} < 0 \tag{A1}$$

Thus we can know that the expected profit function of the distributor is a strict concave function of the retail price. In this way, firstly, we can obtain the implicit retail price function of the wholesale price according to the first-order optimization condition of the distributor's retail price. Secondly, we substitute the function expression of the retail price into the supplier's expected profit function, solve its first and second derivatives with respect to the wholesale price, and get the optimal wholesale price. Finally, we substitute the wholesale price into the retail price function, and get the optimal retail price.

Thus, Proposition 1 is proven.

Proof of Proposition 2. To solve the problem using reverse induction, we first solve for the supplier's wholesale price, then solve for the retail price according to the distributor's profit. It is easy to get the following equation by take the second derivative of Equation (11).

$$\frac{\partial^2 E(M_{idd})}{\partial {w_i}^2} = \frac{-2}{1-b^2} < 0 \tag{A2}$$

Equation (A2) shows the expected profit function of the supplier is a strict concave function of the wholesale price. The first-order optimal condition can be obtained as follows:

$$w_i = \frac{\left(-2+b^2\right)\delta_i + b\delta_j + \left(2-b^2\right)\Delta w_i - b\Delta w_j}{b^2-4} \tag{A3}$$

Substitute Equation (14) into Equation (13), and the distributors' function of the wholesale price is obtained from the first-order optimal condition.

$$\Delta {w_i}^* = \frac{A_i}{4b^4-17b^2+16} \tag{A4}$$

Thus, the optimal wholesale price of suppliers and the optimal retail price of distributors are, respectively, the following:

$${w_i}^* = \frac{\left(b^2-2\right)A_i}{(2b^2-b-4)(2b^2+b-4)(b^2-4)} \tag{A5}$$

$${p_i}^* = {w_i}^* + \Delta {w_i}^* = \frac{2\left(b^2-3\right)A_i}{(2b^2-b-4)(2b^2+b-4)(b^2-4)} \tag{A6}$$

Thus, Proposition 2 is proven.

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