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Optimal Pricing and Coordination Schemes for the Eastern Route of the South-to-North Water Diversion Supply Chain System in China

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Abstract

The Eastern Route of the South-to-North Water Diversion (SNWD-ER) project in China is a highly complex interbasin water-diversion system, which is constructed to pump, store, and supply water to support the rational water redistribution in China. This article presents the optimization modeling approach for the pricing and coordinating schemes of SNWD-ER project, and discusses the analysis results and their policy implications on the pricing and coordinating mechanisms in the SNWD-ER water-resource supply chain. For the government, formulating reasonable retail price upper bound is important to control the water resource wholesale price and retail price. Besides, various water-saving mechanisms can increase the price elasticity of water demand and affect the wholesale and retail prices. For the corporations, increasing the water resource production capacity and its supply will decrease the wholesale and retail prices. Furthermore, keeping enough initial water resource inventory by enhancing the rainfall using rate, and using 'free supply sources'-rainfall, or even some flooding sources can effectively decrease the wholesale and retail prices. Finally, for the end-users, enhancing the rainfall using rate can effectively decrease the wholesale and retail prices and reduce the energy consumption, which is good for the sustainable development and a low-carbon economy.

Keywords

South-to-north water diversion, eastern route, optimal pricing, coordinating schemes, supply chain

Introduction

Due to the global climate change and continuous population increase, the water-resource shortage has become a major concern and challenge for many societies and the United Nations. The shortage of water resources has caused a bottleneck for the development of the economy and society, and created the interruption to production activities and people's daily lives. To solve and relieve the water-shortage problem, several large-scale interbasin water-transfer (IBWT) projects were implemented or are implementing in the world, such as the California State Water Project, Central Valley Project, and Central Arizona Project in the United States; the Quebec Water Transfer Project in Canada; the Snowy Mountains Scheme in Australia; the West-to-East Water Transfer Project in Pakistan; the Durance-Verdun Water Transfer Project in France; the Tajo-Segura North-to-South Water Transfer

Project in Spain; and the Lesotho Highlands Water Project in Lesotho and South Africa (Wang, Ouyang, et al. 2009; Yang 2003).

South-to-North Water Diversion (SNWD) Project, a world-scale strategic water resource engineering and construction critical to the sustainable development of China's economy, is an important initiative to solve the water-shortage problem in northern China. This project is divided into the eastern route, western route, and middle route, each of which can transfer water resources separately from the Yangtze River linking Yangtze River, Huaihe River, Yellow River, and Haihe River to formulate a huge connected water provision system. SNWD will create a nationwide water-supply system with "4 horizontal & 3 vertical" (see Ministry of Water Resources 2003). Routes of SNWD project are shown in figure 1.

On the basis of the North water-transfer project in Jiangsu Province, the eastern route of SNWD project is constructed and extended with a total investment of 65 billion Yuan (USD10 billion). In the eastern route engineering project, water resources are transferred from the Yangtze River to supplement water resources of Tianjin, the eastern North China Plain, and Shandong Peninsula. The eastern route is combined with the Yellow River Diversion Project and the middle route of SNWD to solve the water-shortage problem in more than twenty-five cities. Hongzehu Lake, Luomahu Lake, Nansihu Lake, and Dongpinghu Lake are linked together by Beijing-Hangzhou Grand Canal and its parallel river channels. There are thirteen pumping stations in the water-transfer system with the maximum

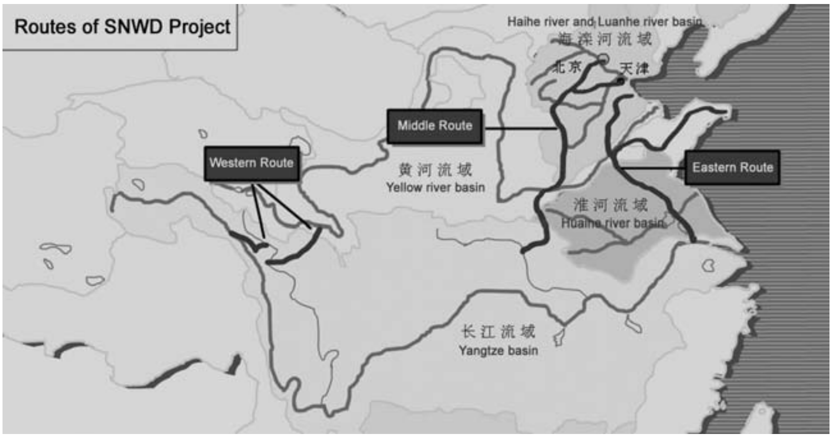

Figure 1 Routes of South-to-North Water Diversion Project

lift at 65 meters. In the north of Dongpinghu Lake, the water transferring is divided into two routes: water flows 1,156 kilometers through the Yellow River to Tianjin; while water flows 701 kilometers through Yellow river-Qingdao Diversion channel to city of Jinan, Yantai, and Weihai in the other route. The Eastern Route of SNWD (SNWD-ER) system is composed of four main lakes, pumping stations, sluice gate stations, regulation-storage reservoirs, several small lakes in Northern China, and several rivers, such as Mangdaohe River, Liyunhe River, Sanyanghe River, Tonghe River, Huaishuhe River, and Zhongyunhe River. Total storage capacity of all the lakes or reservoirs for the SNWD-ER system is almost eight billion cubic meters (m^3), which provide enough regulation-storage capacity for the northern needs. Routes of SNWD-ER project are depicted in figure 2.

We introduce the SNWD project background in this section. In the following sections, literature regarding water-resources regulation and allocation are reviewed, and methodologies for solving the optimal pricing and coordination problem for SNWD-ER supply chain are discussed. Then, a SNWD-ER water-resource supply chain mapping model is developed, the optimization model formulation and solutions discussed and analyzed, and the policy implications provided. Finally, conclusions and policy suggestions are made.

Literature Review

In the literature, we found that most of the interbasin water-transfer (IBWT) projects are managed in an integrated mode by a central management organization under the supervision of government. For example, the California State Water Project in the United States is operated by California Department of Water Resources; the Central Valley Project in the United States is operated by the US Bureau of Reclamation; the Central Arizona Project in the United States is operated and managed by the semi-government organization Soil and Water Conservation Society (SWCS); Snowy Mountains Scheme in Australia is centrally managed by Murray Darling Basin Commission; and the West-to-East Water Transfer Project in Pakistan is controlled by Hydropower Development Bureau (Wang, Ouyang, et al. 2009; Yang 2003). However, an integrated management mode controlled by central management is the lack of economic incentives for the participants to implement the decisions.

Supply chain management is an advanced management concept that focuses on achieving global optimization for all supply chain members. Pareto improvement is sought for the participants in the supply chain through integrated management with coordination mechanism, considering both the group rationality and individual rationality. Therefore, modeling the operations of IBWT project as a water-resource supply chain is an innovative way to study and develop economic incentives that can be built into a mechanism for the integrated management of IBWT projects.

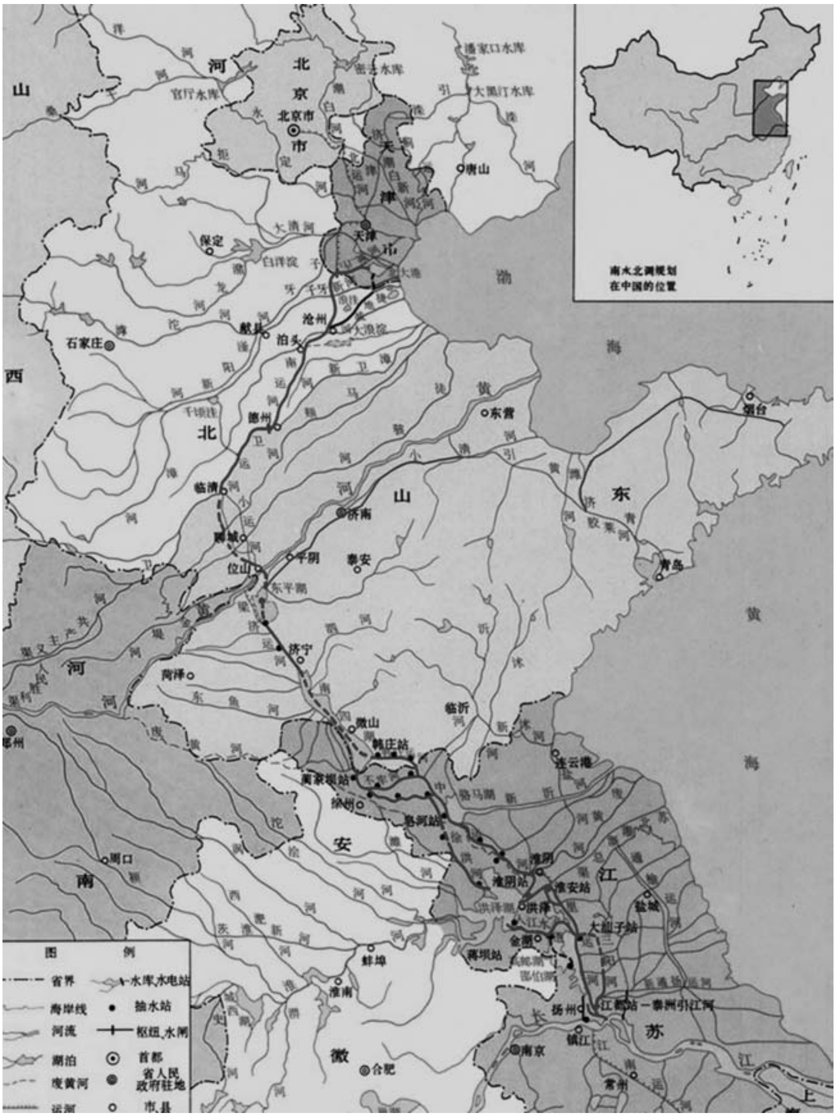

Figure 2 Routes of South-to-North Water Diversion Project

Besides, most of the water-resource pricing methods for IBWT project are traditional cost-based accounting methods. These pricing methods are based on historical costs that only reflect the actual money spent for water resources and are not adequate for the future pricing decisionmaking. Also, the traditional pricing methods only take into account cost reclaiming, ignoring the relationship between water supply-demand and its price. On the contrary, based on the supply chain management principle, an optimal and coordinated pricing method is developed in this article by considering the relationship between the water price and supply-demand change. The pricing method can support the future pricing decision and profit coordination in the water supply chain.

As the supply chain theory evolved, many scholars have applied the supply chain principles to the optimal allocation and scheduling of interbasin water resources. Due to the characteristics of planning and collaboration in water-resources allocation and scheduling, and also owing to the nature of overall coordination and benefit maximization in supply chain management, Wang et al. (2004) and Wang and Hu (2005) argued that it is feasible and suitable to manage the operations of the SNWD project as a supply chain. Since then, much research regarding the optimal allocation and scheduling of interbasin water resources in SNWD project has been done. Wang, Zhang, and Yang (2008) built a principal-agent contract model and pricing model for the SNWD supply chain; Zhu et al. (2005) and Zhu (2007, 2008a, 2008b) designed the water-resources supply chain structure for the eastern route of SNWD, analyzed the bullwhip effect, and built the water-resources allocation model and inventory management model; Zhang, Wang, and Wang (2004, 2005) built the multistage coordination model for the SNWD supply chain; Hou, Wang and Qiu(2008), Hou, Wang, Qiu et al. (2008) and Hou et al.(2009) built minimum commitment and flexibility contracts, vendor-managed inventory (VMI) coordination model and the SRSS model for the SNWD supply chain; and Zhang, Wang, and Yang (2008) also built a pricing model for the SNWD supply chain.

However, past research with a supply chain focus simply studied interbasin water-resources allocation without taking into account other issues such as rainfall, capacity constraints, and price control of the government. Furthermore, these research studies on water-resource supply chain system treated suppliers and multidistributors with similar characteristics.

In contrast to the past research studies, this research focuses on the joint production-allocation optimization of water supply chain system with one supplier and two distributors. The two distributors possess different characteristics in this study in that one is a local distributor without free supply sources, while the other is an external distributor with free supply sources.

Methodologies

Water resources are special products with the characteristics of both the public goods and the private goods, which are noncompetitive and nonexclusive, namely quasi-public goods. Therefore, the management of an IBWT project is different from managing a commercial product. A hybrid management approach with both the governmental control and proper market operation is required for the management of an IBWT project.

The production and distribution of an interbasin water-transfer project can be modeled as a water supply chain optimization problem, and the core issue of the water supply chain optimization problem is to design a profit coordination scheme for all agents to achieve the global optimal for all supply chain members. This article first looks at SNWD-ER as a centrally controlled supply chain, then discusses the nature and results of the quadratic programming method that built the optimal pricing model for the supply chain to develop the corresponding optimal pricing schemes, and then applies the revenue-sharing contract theory to build the coordinating model for the SNWD-ER supply chain to obtain the corresponding coordination schemes.

Quadratic programming is a mathematical optimization model that minimizes or maximizes a quadratic function of several variables subject to linear constraints on several variables. As the water demand is dependent on the water price and the price upper-bound is set by the government, the SNWD-ER supply chain can be modeled as a classic quadratic programming problem with a quadratic objective function.

A revenue-sharing contract is a type of supply chain contract in which the producer charges lower wholesale price to the retailer in exchange of a fraction of retail revenue (Cachon and Lariviere 2005). Supply chain coordination problems are usually able to achieve coordination via a proper revenue-sharing contract. In SNWD-ER case, it is feasible for the supplier and distributors to sign a revenue-sharing contract under the guidance of the government. Therefore, the revenue-sharing contract to obtain the coordination schemes for the SNWD-ER supply chain is investigated.

Eastern Route of SNWD Water Resources Supply Chain

Through a supply chain analysis of SNWD-ER system, a SNWD-ER water-resource supply chain is presented in figure 3 including the Jiangsu and Shandong subsystems. The Jiangsu subsystem mainly includes Hongzehu Lake, Luomahu Lake, Nansihu Lake, and corresponding lakes, pumping stations, sluice gate stations, and regulation-storage reservoirs. The main operations agents are Jiangsu supplier and Jiangsu distributor. The Shandong subsystem mainly includes Dongpinghu Lake, Qianqinwa, Dalangdian, Beidagang, and corresponding lakes, pumping stations, sluice gate stations, and regulation-storage reservoirs, and the main operations agents are Shandong supplier and Shandong distributor. In figure 3, the Jiangsu supplier is the Supplier (S), the Jiangsu distributor is the local distributor (LD), and the Shandong supplier and Shandong distributor are combined as the external distributor (ED). The difference between the local distributor and the external distributor is that the water-diversion cost of the local distributor is lower than that of the external distributor and the external distributor has an

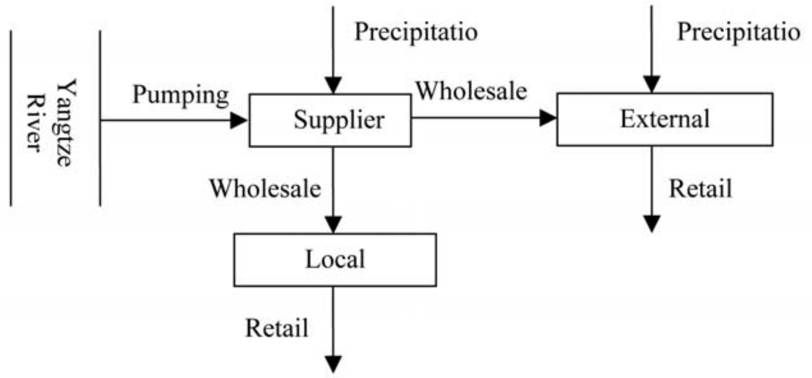

Figure 3 SNWD-ER Water Resources Supply Chain

external rainfall as a free water supply source while the local distributor doesn't.

In formulating the SNWD-ER water-resource supply chain optimization problem, the following assumptions are made:

1. This research considers only the regulation-storage capacities of lakes but not river networks, for the regulation-storage capacities of river networks are lower than lakes.
2. The complex conditions among the lakes are simplified as a single river channel and lakes and corresponding ranges are simplified as a lake system, all these sub-systems are formulated as a cascade tandem structure.
3. Water diversion cost increases with the water transferring distance due to the longer distance and higher terrain further to the North.
4. The lead time of water diversion is not considered because the river channel is always kept at a certain water level to guarantee the tranferring of water.
5. We combine the water conveyance loss, evaporation and runoff with the initial water storage of the lake as the original water supply sources. The rainfall of the supplier and the external distributor is a free external water supply source while the water diversion from the Yangtze River is an expensive water supply source.
6. This research does not consider extreme flood or drought disaster conditions, that is, the water system can effectively control the disaster by flood forecasting, drought early warning and appropriate capacity regulation to recover the system to its normal state.
7. The demand of water is related to the rainfall, that is, end-users are able to use some of the rainfall, combined with the water resources supplied by distributors, to satisfy the total demand.
8. Water resources are defined as a quasi-public product, whose end retail price is strictly controlled by the government; therefore, there is an upper bound for the retail price at the end-user market.

Models and Solutions

This article intends to show the analysis results and their policy implications toward the optimal pricing and coordination schemes rather than the detail of the mathematical programming systems. Therefore, in the following analysis, only the key aspects of the quadratic programming models/revenue-sharing contract model and their results are introduced. A complete mathematical modeling system is available from the authors.

There are currently three agents defined in the SNWD-ER supply chain model, including one supplier and two distributors, and they respectively make decisions on pricing to maximize their own profits under a decentralized decision mode. Generally, a decentralized decision mode without incentive mechanisms is able to achieve equilibrium price policy for all the agents. However, that the equilibrium price policy is not optimal for all the agents has been proved and is commonly recognized in the academic world (Lee and Whang 1999). Therefore, this study attempts to find the optimal pricing policy under a hybrid decision mode with the coordination between the centralized supplier and the decentralized distributors. This approach, in contrast to the decentralized decision mode, is able to achieve the optimal pricing and profit improvement for the water-resource supply chain.

We assume that the relationship between water demand and water price obeys classic economy assumptions, that is, water demand decreases as precipitation increases, and water demand decreases as the retail price increases. Here, the local and external demands are assumed to be linear functions of retail prices to be maximized as the following.

Water Demand = Water Market Scale—Available Precipitation—
Price Elasticity * Retail Price

The profits of the supplier, the local distributor (LD), and the external distributor (ED) can be formulated as three quadratic programs that maximize the profits of three agents.

The sequence of the optimal supply chain analysis is as follows. First, the supply chain decides the retail price under a centralized decision mode. Then, the LD and ED simultaneously decide the retail price with a revenue-sharing contract under a decentralized decision mode. Finally, according to the contract coordination theory, to achieve coordination of supply chain, it is necessary to let supply chain optimal local retail price equals to LD's optimal retail price under revenue sharing contract; meanwhile, it is necessary to let supply chain optimal external retail price equals to ED's optimal retail price under revenue sharing contract, and then, we can get the coordinated wholesale prices for the supplier.

Local Distributor's and External Distributors' Optimal Retail Pricing under the Centralized Supply Chain Decision

Following the assumptions above, the optimization problem for the SNWD-ER supply chain is as follows:

Maximize Profit of centralized Supply Chain
= – Cost * Pumping quantity + (Local retail price – Local marginal cost) * Local demand + External retail price * External demand – External marginal cost * (External demand – External storage – External available precipitation)

Subject to

Local demand + External demand ≤ Maximal supply capacity
0 ≤ Local retail price ≤ Local retail price upper bound
0 ≤ External retail price ≤ External retail price upper-bound

We solve the first-order necessary conditions and second-order sufficient conditions of the KKT points of the problem, and get the optimal retail prices under the centralized decision.

In the centralized decision mode, when all the retail price upper-bound (RPUB) constraints are not active, and the supply capacity constraint is also not active, we can define the optimal retail price under this condition as the *regular optimal retail price*. This optimal retail price is related to the local demand, local rainfall, local cost, and system cost, or related to the external demand, external rainfall, external cost, and system cost.

When all the RPUB constraints are not active, but the supply capacity constraint is active, we can define the optimal retail price under this condition as the *interactive optimal retail price*. This optimal retail price is not only related to the local demand, local rainfall, and local cost, but also related to the external demand, external rainfall, external cost, and supply capacity.

When part of the RPUB constraints are not active and part of the RPUB constraints are active, and the supply capacity constraint is active, we can define the optimal retail price under this condition as the *mixed optimal retail price*. This optimal retail price is not only related to the local demand, local rainfall, local cost, and local RPUB, but also related to the external demand, external rainfall, external cost, external RPUB, and supply capacity.

Local Distributor's and External Distributors' Optimal Retail Pricing under the Decentralized Supply Chain Decision with Revenue-Sharing Contract

To achieve the coordination of SNWD-ER supply chain, it is necessary to set the optimal retail price under the decentralized decision equal to that under the centralized decision. However, this coordination condition leads to 'zero profit' for the supplier, which is not acceptable to the supplier. Therefore, we introduce a revenue sharing contract to achieve the coordination for the supply chain members.

Under the revenue sharing contract, the LD's and ED's optimization problems are as follows:

Maximize Local Distributor's Profit under Revenue-Sharing Contract
= (1 – Local revenue sharing rate) ∗ Local retail price ∗ Local demand – (Local wholesale price + Local marginal cost) ∗ Local demand
Subject to
0 ≤ Local retail price ≤ Local retail price upper bound
Maximize External Distributor's Profit under Revenue-Sharing Contract
= (1 – External revenue sharing rate) ∗ External retail price ∗ External Demand – (External wholesale price + External marginal cost) ∗ (External demand – Original storage – Available precipitation)
Subject to
0 ≤ External retail price ≤ External RPUB
Where 0 ≤ Revenue sharing rate ≤ 1

We can solve the first-order necessary conditions and second-order sufficient conditions of the KKT points of the problem, and then get the optimal retail prices under the revenue sharing contract.

Supplier's Coordinated Wholesale Pricing for the Supply Chain Coordination

To achieve the coordination, we must set the retail price such that the price under the decentralized decision equal to that under the centralized decision, and we can get the coordinated wholesale price.

In the decentralized decision mode, when part of the RPUB constraints are not active and part of the RPUB constraints are active, and the supply capacity constraint is active, we can respectively define the equilibrium retail price and wholesale price under this condition as the *bound reaction equilibrium wholesale price*. These equilibrium prices are related to the local demand, local rainfall, local cost, and local RPUB; or related to the external demand, external rainfall, external cost, and external RPUB.

In the supply chain coordinating mode, when the RPUB constraints are not active, and the supply capacity constraint is also not active, we can define the coordinating wholesale price under this condition as the *regular coordinating price*. This wholesale price is related to the local revenue sharing rate, local cost, and system cost, or related to the external revenue sharing rate, external cost, and system cost.

When the RPUB constraints are not active, and the supply capacity constraint is active, we can define the coordinating wholesale price under this condition as the *interactive coordinating price*. This wholesale price is not only related to the local demand, local rainfall, local cost, and local revenue sharing rate, but also related to the external demand, external rainfall, external cost, external revenue sharing rate, and supply capacity.

When part of the RPUB constraints are not active and part of the RPUB constraints are active, and the supply capacity constraint is active, we can define the coordinating wholesale price under this condition as the *mixed coordinating price*. This wholesale price is not only related to the local demand, local rainfall, local cost, local RPUB, and local revenue-sharing rate, but also related to the external demand, external rainfall, external cost, external RPUB, external revenue sharing rate, and supply capacity.

It should be noted that by combining the centralized supply chain decision and decentralized supply chain decision with a revenue-sharing contract, it is shown that optimal retail pricing and coordinated wholesale pricing schemes for SNWD-ER supply chain follows the rules in table 1.

Discussions and Policy Implications

A good water-pricing mechanism should be designed according to the principle of fairness, reclaimable cost, and the relationship between demand and supply.

Most of the IBWT projects are managed under the integrated management mode, and the water-pricing mechanism is controlled by the government. The existing water-pricing mechanism mainly include two pricing schemes: block rate pricing and seasonal pricing. However, the balance between supply and demand in the water-supply market is not sufficiently considered in the existing water-pricing mechanism; that is, governments control the prices, and market forces are not reflected enough. Moreover, as the supplier and distributors try to maximize their own interest, the global optimization of water-supply prices is sacrificed in the traditional integrated management mode.

Table 1 Optimal Retail Pricing and Coordinated Wholesale Pricing Schemes for SNWD-ER Supply Chain in China

Case	Conditions	Optimal Retail pricing policy	Coordinated Wholesale Pricing Policy
1	Both the local distributor's and the external distributor's RPUB constraints are not active, and the supply capacity constraint is also not active	Both local distributor's and external distributor's optimal retail price equal to regular optimal retail price.	Both the local distributor's and the external distributor's coordinating wholesale prices are regular coordinating price.
2	Both the local distributor's and the external distributor's RPUB constraints are not active, and the supply capacity constraint is active	Both local distributor's and external distributor's optimal retail price equal to interactive optimal retail price.	Both the local distributor's and the external distributor's coordinating wholesale prices are interactive coordinating price.
3	The local distributor's RPUB constraint is not active, and external distributor's RPUB constraint is active, and the supply capacity constraint is not active	Local distributor's optimal retail price equals to regular optimal retail price. External distributor's optimal retail price equals to upper bound.	The local distributor's coordinating wholesale price is regular coordinating price. The external distributor's coordinating whole price is no less than bound reaction equilibrium wholesale price.
4	The local distributor's RPUB constraint is not active, and external distributor's RPUB constraint is active, and the supply capacity constraint is active	Local distributor's optimal retail price equals to mixed optimal retail price. External distributor's optimal retail price equals to upper bound.	The local distributor's coordinating wholesale price is mixed coordinating price. The external distributor's coordinating whole price is no less than bound reaction equilibrium wholesale price.
5	The local distributor's RPUB constraint is active, and external distributor's RPUB constraint is not active, and the supply capacity constraint is not active	Local distributor's optimal retail price equals to upper bound. External distributor's optimal retail price equals to regular optimal retail price.	The local distributor's coordinating wholesale price is no less than bound reaction equilibrium wholesale price. The external distributor's coordinating wholesale price is regular coordinating price.
6	The local distributor's RPUB constraint is active, and external distributor's RPUB constraint is not active, and the supply capacity constraint is active	Local distributor's optimal retail price equals to upper bound. External distributor's optimal retail price equals to mixed optimal retail price.	The local distributor's coordinating wholesale price is no less than bound reaction equilibrium wholesale price. The external distributor's coordinating wholesale price is mixed coordinating price.
7	Both the local distributor's and the external distributor's RPUB constraints are active, and the supply capacity constraint is not active	Local distributor's optimal retail price equals to upper bound. External distributor's optimal retail price equals to upper bound.	The local distributor's coordinating wholesale price is no less than bound reaction equilibrium wholesale price. The external distributor's coordinating whole price is no less than bound reaction equilibrium wholesale price.

Under the centralized decision mode, a mixed pricing mechanism considering both market-pricing and price-upper-bound control for the optimal retail pricing is proposed in this study. Usually, the market-pricing is made based on the balance between supply and demand, while the price-upper-bound is set through the government public hearing or enterprise bargaining under the government's control and supervision. Market operations are reflected in the market pricing to achieve the maximization of the economic benefits for supply chain members, whereas government's control is reflected in the price-upper-bound to protect public interests. This type of pricing mechanism takes into account both the public interests and the market requirements, which is in accordance with the quasi-public goods' characteristics of water resources. If the price-upper-bound is not active, it shows that the market mechanism works very well. In contrast, if the price-upper-bound is active, it shows that the government's control is necessary when "market failure" occurs. On the premise of the supply chain global optimization, Pareto improvement and supply chain coordination are achieved by the wholesale pricing via the revenue sharing contracts with retailers.

Seven optimal pricing and coordination schemes from the modeling analysis are presented in table 1. The policy implications regarding these schemes are further discussed below.

1. In the condition when both the local distributor's and the external distributor's RPUB constraints are not active, and the supply capacity constraint is active or not active, the market operations are efficient. The optimal retail prices of two distributors should be set by the law of supply and demand, and the coordinating wholesale prices should be set according to the revenue sharing contract. The government's control is not necessary in this condition.
2. The local distributor's RPUB constraint is not active, and the external distributor's RPUB constraint is active, and the supply capacity constraint is active or not active. In these conditions, part of the market operations are efficient, while others are not, and part of the "market failure" phenomenon appears. Therefore, the optimal local retail price should be set according to the law of supply and demand, and the external optimal retail price should be set at the price-upper-bound. Besides, the local coordinating wholesale price should be set according to the revenue sharing contract, and the external coordinating wholesale price should not be lower than the bound reaction

equilibrium wholesale price. The government's control is necessary in this condition.

3. When the local distributor's RPUB constraint is active, and the external distributor's RPUB constraint is not active, and the supply capacity constraint is active or not active, part of the market operations are efficient, while the others are not, and part of the "market failure" phenomenon appears. Then, the external optimal retail price should be set according to the law of supply and demand, and the local optimal retail price should be set at the price-upper-bound; besides, the external coordinating wholesale price should be set at the revenue sharing contract, and the local coordinating wholesale price should be no lower than the bound reaction equilibrium wholesale price. The government's control is necessary in this condition.
4. When both the local distributor's and the external distributor's RPUB constraints are active, and the supply capacity constraint is not active, the market operations are not efficient and the "market failure" phenomenon appears. Then, the optimal retail prices of both the local and the external distributors should be set at the price-upper-bound. Besides, both of the coordinating wholesale prices should not be lower than the bound reaction equilibrium wholesale price. The government's control is necessary in this condition.

Conclusions

The SNWD-ER project in China is a highly complex interbasin water-diversion system coordinating multi-sources, multi-objects, and multi-projects to pump, store, and supply water to support the rational water redistribution to North China. The project is close to its completion and is at the stage to make proper water allocation and pricing policies.

This article has studied the optimal pricing and coordination problems for the SNWD-ER project based on a supply chain model, utilizing the supply chain contract-coordination theory and the quadratic programming modeling approach. The analysis looks at seven different conditions and their respective optimal retail pricing and coordinating wholesale pricing schemes. The analysis provides a sound theoretic support to the pricing policy decision for the future operation of the SNWD-ER supply chain.

In this modeling analysis, it is also found that for the government, formulating reasonable RPUB is important to control the water-resource wholesale price and retail price. Besides, water-resource saving society development, water-resource saving technology, and other saving mechanism can increase the price elasticity of the water-resource demand and affect the wholesale and retail prices. For the corporations, increasing the water-resource production capacity and its supply will decrease the wholesale and retail prices. Furthermore, keeping enough initial water-resource inventory by using "free supply sources" such as rainfall, runoff, and even some flooding sources, and enhancing the rainfall using rate can effectively decrease the wholesale and retail prices. Finally, for the end-user, enhancing the rainfall using rate can effectively decrease the wholesale and retail prices and reduce the energy consumption, which is good for the sustainable development and a low-carbon economy.

This article has contributed to the IBWT literature in the following aspects:

1. IBWT system is analyzed as a water-resource supply chain, applying supply chain management principles. The supply chain management theory can be extended to the quasi-public goods study, in this case, the water resources.
2. A new optimal and coordinating pricing mechanism for IBWT project is developed, considering both the market operations and the government control.
3. Under the integrated management mode for IBWT system, a coordinating mechanism via revenue sharing contract can be designed to provide economical incentives to the supplier and the retail operators during the implementation of a centralized decision mode.

Certainly, there are still many research works can be done in the future. For example, what will be the optimal production-allocation model if the rainfall is random presenting a certain kind of probability distribution? Can the problem be extended to the multi-period scenario? And are there better ways to coordinate the economic benefits among the supply chain members?

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