Green Operations Management of Interbasin Water Transfer Project: An Extended Framework of Joint Pricing and Inventory Management

Huimin Wang,1 Liuyu Xue,1 Jianhui Peng,2 Gaofeng Liu,1 and Zhisong Chen3

1Business School, Hohai University, Jiangning District, Nanjing 211100, China
2School of Finance and Business, Shanghai Normal University, 100 Guilin Road, Xuhui District, Shanghai 200234, China
3Business School, Nanjing Normal University, Qixia District, Nanjing 210023, China

Correspondence should be addressed to Zhisong Chen; zhisongchen@gmail.com

Received 4 January 2022; Accepted 15 February 2022; Published 19 March 2022

Academic Editor: Giulio E. Cantarella

Copyright © 2022 Huimin Wang et al. This is an open access article distributed under the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

To achieve sustainable operations management of an interbasin water transfer (IBWT) project, we proposed and analyzed decentralized and coordination decision models of water-green-degree (WGD) efforts for the IBWT project, based on the thinking of green supply chain within an extended framework of joint pricing and inventory management. Subsequently, detailed numerical and sensitivity analyses are carried out, which is followed by theoretical and practical insights. The following can be drawn from the research: (1) the IBWT project would achieve better operational performance through making WGD efforts and implementing green supply chain management. (2) Coordination strategy outperforms the decentralized one in terms of the operational performance in the management of IBWT green supply chain. (3) A revenue and cost sharing contract based on Nash bargaining could help promote coordination of the IBWT green supply chain.

1. Introduction

With the global climate change, uneven distribution of water, and widespread global water abuse, the world may face a water shortage crisis by 2030, and the global water deficit may reach as high as 40% [1]. In order to cope with the crisis of water shortage, countries all over the world have constructed and carried out some interbasin water transfer (IBWT) projects, e.g., the South-to-North Water Diversion (SNWD) Project in China [2, 3]. Besides, many governments have issued various regulations/policies regarding efficient utilization and conservation of water resources to mitigate this water crisis, such as the regulation concerning ‘implementation of the most stringent water resources management system’ [4], the advice on ‘promotion of water-saving management contract and development of water-saving service industry’ [5], the notice on ‘construction plan of water-saving society in the 14th five-year plan’ [6], and the water quota system including 105 water quotas in agriculture, industry, construction, and service areas issued and established by the ministry of water resources [7], etc.

In this context, how to achieve efficient utilization and conservation of water resources and realize sustainable operations management in the IBWT projects is the key issue we should pay attention to. In the long term, since the IBWT projects often involve densely populated regions with high risk of water pollution and water abuse, it is still a severe challenge to achieve the sustainable management of the “clear water corridor.” Specifically, it is still a steep challenge to improve water resources utilization efficiency and maintain the water quality and water environment to a green standard in the water source as well as the water diversion line, etc. [8]. Furthermore, the coordination and cooperation among multiple operators can effectively facilitate the water green degree (WGD) of the IBWT project. WGD is a synthetic green degree of water quality, water environment, and water utilization, which is very essential and important for the sustainable and successful operations management of
IBWT project [9]. WGD is positively correlated with the level of water quality maintenance, the extent of water environment protection, and the rate of intensive and efficient water utilization. Furthermore, WGD effort represents the investment level in terms of personnel and funds to maintain WGD for the IBWT project [9].

However, there is often a lack of effective coordination and cooperation mechanism among multiple operators involved in the IBWT project, which may lead to the inefficiency of WGD improvement. Besides, random water demand is affected not only by random disturbance, but also by water price and WGD effort. Thus, the making of optimal decisions in pricing, inventory, and WGD effort in order to improve environmental and economic advantages is of vital importance in the sustainable operations and production management of IBWT projects. Furthermore, since the water demand depends on water price and WGD effort, an extended framework of joint pricing and inventory management (JPIM) is introduced to characterize the research problem. The extended framework of JPIM is developed based on the traditional theory and method of JPIM [10]. Different from traditional JPIM, under an extended framework of JPIM, the decision-makers cannot only make joint optimal decisions on their water prices and inventories, but also make decisions on their WGD efforts in the sustainable operations management of the IBWT projects.

Bearing both environmental and economic benefits in mind, green supply chain (GSC) management provides an optimal theory, method, and technology to solve the above research issues. IBWT green supply chain (IBWT-GSC) is a functional network structure mode that comprehensively considers the water quality maintenance, water environment protection, and intensive and economical utilization of water resources in the whole IBWT project [8, 9]. In the IBWT-GSC, internal supplier, external suppliers, and water distributors jointly transfer and deliver water resources to consumers through main channel, water-intakes, and branch channels through the control of information flow, water flow, capital flow, and business flow to pursue strategic objectives of WGD enhancement, operations management coordination, and operational performance improvement [8, 9]. With regard to IBWT-GSC management, the following issues need to be taken into serious consideration: (i) what is the value of GSC for improving the operational performance of IBWT project? Would the IBWT operators have economic incentive to implement GSC management? (ii) What operational decisions of WGD efforts should the GSC and its stakeholders make under different operational strategies? (iii) What operational strategies should the GSC and its stakeholders adopt to enhance their operational performance? With the assistance of game-theoretical decision models followed by in-depth analyses, these research questions will be further investigated in this research. Supply chain management theories, methodologies, and strategies have been widely used to explore the operational decision and strategy-making for the IBWT project (specifically, SNWD project) management under different scenarios. For instance, [11] investigated the optimum pricing for a supply chain in the SNWD project. The coordination mechanism between supplier and customer in the SNWD supply chain was examined based on a revenue-sharing contract [12]. Reference [13] applied an asymmetric Nash bargaining model to investigate the SNWD supply chain. Reference [14] developed a two-stage water inventory model with updated inflow projections in an IBWT project. Reference [15] analyzed a two-tier pricing and distribution schemes for the SNWD supply chain. Reference [16] inspected the competition intensity of water supply chain under two kinds of contracts. Reference [17] examined the power structure of competitive water supply chains. The optimum pricing and purchasing tactics under competition water supply chains with three kinds of contracts are evaluated by [18]. In order to maximize social welfare, potential subsidy policies and operational tactics for the IBWT green supply chain are investigated by [8, 19]. Reference [9] investigated the IBWT-GSC coordination with partial backlogging under random precipitation. Reference [20] explored the joint pricing and inventory management in the IBWT supply chain. The results of these studies show that coordination decision mode is better than decentralized decision mode, and the government’s conditional subsidy policy helps maximize social welfare and minimize the financial budget.

In summary, the existing literature mainly focuses on the operational decisions/tactics/performance and key influence factors in the operational management of the IBWT supply chain and fails to tackle the following important issues concerning sustainable management in the IBWT supply chain: (i) the economic incentives of making WGD efforts and implementing green supply chain management for the IBWT project; (ii) the joint operational decision-making in pricing, inventory, and WGD and the equivalent operational tactics/performance for the IBWT-GSC considering the loss of water delivery; (iii) the key impact factors for the operational decisions/tactics/results in the IBWT-GSC. These issues will be tackled and explored via game-theoretical decision models. Our research intends to investigate the impact of joint operational decision-making on pricing, inventory, and WGD and the equivalent operational strategies/outcomes in the sustainable operations management of IBWT project considering the loss of water delivery under an extended framework of joint pricing-inventory management.

The remainder of the paper is structured as follows. The theoretical modelling assumptions and notations within a generic IBWT green supply chain (IBWT-GSC) will be first presented in section 3.1, and various game-theoretical models with and without WGD effort considerations under joint pricing and inventory management (JPIM) are proposed, analyzed and compared in section 3.2, the numerical and in-depth sensitivity analyses of these models followed by a comparison of their results are displayed in section 4; Section 4.1 provides the managerial suggestions; in the last section, some theoretical and practical contributions of the research are concluded.
2. Modelling Notations and Assumptions

A generic IBWT-GSC usually consists of a vertical green supply chain (v-GSC) and a horizontal green supply chain (h-GSC). In the h-GSC, there are an internal and an external supplier, and they make up a joint supplier through a well-managed cooperation mechanism. In the v-GSC, the IBWT joint supplier transfers water via the main channel and distributes water to multiple water distributors via water-intakes, and each distributor supplies water to the end consumers in her service area. In the IBWT-GSC, the internal and the external suppliers jointly decide the wholesale price within h-GSC, IBWT supplier determines the WGD efforts and wholesale prices, and distributors decide their retail prices and ordering quantities within v-GSC.

Water distributors are indexed as \( i = 1, 2, \ldots, n \). Presume that the internal supplier covers \( m \) distributors, and the remaining \( n - m \) distributors are supported by the external supplier. Based on this, the parameters/variables that will be used in the models are defined in Table 1.

The relationship between \( q_i \) and \( . \) is \( q_i = Q_i \prod_{k=1}^{i} (1 - \delta_k) \), and \( TC_i(Q_i) \) represents the total cost for supplying the original pumping quantity \( Q_i \), which is \( TC_i(Q_i) = Q_i \sum_{k=1}^{i} [c_{k} \prod_{j=0}^{k-1} (1 - \delta_j)] \); hereinto, \( \delta_0 = 0 \). Therefore, the total cost of transferring water of the \( i \)-th water-intake is \( TC_i(q_i) = \sum_{k=1}^{i} [c_{k} \prod_{j=0}^{k-1} (1 - \delta_j)] / \prod_{k=1}^{i} (1 - \delta_k)q_i \).

Define \( C_i = \sum_{k=1}^{i} [c_{k} \prod_{j=0}^{k-1} (1 - \delta_j)] / \prod_{k=1}^{i} (1 - \delta_k) \); then \( TC_i(q_i) = C_i q_i \).

Following [21–23], the \( i \)-th distributor’s water demand is \( d_i(p_i, g_i, x_i) \), and \( d_i(p_i, g_i, x_i) = y_i(p_i, g_i)x_i \). Hereinto, \( y_i(p_i, g_i) = a_ip_i^{h_i}g_i^{e_i} \). \( x_i \) is a random disturbance defined in the range \([A, B]\) with \( B > A > 0 \). The probability density function (PDF) and cumulative distribution function (CDF) of \( x_i \) are \( f_i(x_i) \) and \( F_i(x_i) \), and \( \mu_i \) and \( \sigma_i \) represent the mean value and standard deviation of \( x_i \). According to [24–26], \( z_i = q_i / y_i(p_i, g_i) \) is defined as \( i \)-th distributor’s “water stock factor,” and let \( z = \{z_1, z_2, \ldots, z_n\} \). Therefore, the purchase quantity function of water for the \( i \)-th water-intake is \( q_i = y_i(p_i, g_i)z_i \). The distribution of \( x_i \) meets the condition of the IGFR (Increasing Generalized Failure Rate): \( dh(x_i)/dx_i > 0 \), where \( h_i(x_i) \equiv x_i f_i(x_i) / 1 - F_i(x_i) \), which indicates that there is a unique solution to the maximal expected problem. It was demonstrated that normal distribution and exponential distribution also meet the IGFR condition [26–28].

According to the aforementioned modelling assumptions and notations, the profit functions of the IBWT supplier, the \( i \)-th water-intake of supplier, and the \( i \)-th water-intake of the supply chain with partial accumulating can be drawn, respectively, as follows:

\[
\Pi_D (p_i, z_i) = p_i y_i (p_i, g_i) E \left[ \min \{z_i, x_i\} \right] - (w_i + c_d) y_i (p_i, g_i) z_i
\]
\[
\Pi_S (w_i, g_i) = (w_i - C_i) y_i (p_i, g_i) z_i - \frac{1}{2} \kappa g_i^2 - c_f_i
\]
\[
\Pi_{SC} (p_i, z_i, g_i) = p_i y_i (p_i, g_i) E \left[ \min \{z_i, x_i\} \right] - (C_i + c_d) y_i (p_i, g_i) z_i - \frac{1}{2} \kappa g_i^2 - c_f_i.
\]

3. Game-Theoretical Decision Models

Based on the modelling notations and assumptions, various game-theoretical decision models with and without WGD effort under JIPM for the IBWT supply chain considering water loss are proposed, analyzed, and compared. In Section 3.1, we developed two game-theoretical decision models with WGD effort for the IBWT-GSC (including a decentralized decision model with WGD effort, and a coordination decision model with WGD effort). In Section 3.2, we developed and analyzed two game-theoretical decision models without WGD effort for the IBWT-GSC. Section 3.3.1 and 3.1.2, respectively. Table 2 provides a framework of the game-theoretical decision models developed and analyzed in Section 3.
3.1. Game-Theoretical Decision Models with WGD Effort

(1 > θ > 0, κ > 0). Under the scenario with WGD effort, the impact coefficient of WGD effort on the anticipated demand 1 > θ > 0, and the cost coefficient of the WGD effort κ > 0. Two different decision-making models, decentralized and coordination, will be developed and explored.

3.1.1. Decentralized Decision Model with WGD Effort. In a decentralized decision-making scenario, the sequence of decision is described as follows: two suppliers—the internal and the external suppliers—will first use Nash Bargaining game approach to bargain over the wholesale price within IBWT horizontal supply chain before agreeing on coordinating operations [29–31]; then, the IBWT supplier determines the WGD effort; next, the distributors simultaneously determine their retail prices; and finally, the distributors simultaneously determine their stock factor. The decentralized decision model for the IBWT-GSC under an extended framework of JPIM can be summarized as

\[
\begin{align*}
\max_w \Omega(w) &= \left[ \Pi_{NSS}^d(w_i^d, g_i^d, q_i^d, w) \right]^\tau \left[ \Pi_{ES}^d(w_i^d, g_i^d, q_i^d, w) \right]^{1-\tau} \\
\Pi_{NSS}^d(w_i^d, g_i^d, q_i^d, w) &= \Pi_{ES}^d(w_i^d, g_i^d, q_i^d, w)
\end{align*}
\]

subject to

\[
\begin{align*}
&\Pi_{NS}^d(w_i, g_i, p_i^d(w_i), z_i) \\
&\Pi_{E}^d(w_i, g_i, p_i^d(w_i), z_i) \\
&\Pi_{D_i}^d(p_i, z_i)
\end{align*}
\]

Table 1: Parameters/variables settings.

| Parameters/Variables | Definitions |
|----------------------|-------------|
| c_{di}               | The cost of supplying water to \(i^{th}\) distributor from \(i^{th}\) water-intake. |
| c_{ki}               | The cost of transferring water to \(k^{th}\) water-intake from \((k-1)^{th}\) water-intake in the horizontal supply chain. |
| \(\delta_k\)         | The water loss rate from \((k-1)^{th}\) to \(k^{th}\) water-intake in the horizontal supply chain, and \(\delta_k \in (0, 1)\). |
| Q_i                  | The original pumping quantity from water source to the \(i^{th}\) water-intake. |
| g_i                  | The ordering amount of \(i^{th}\) water-intake. |
| c_{fi}               | The fixed cost of water supply for the \(i^{th}\) water-intake. |
| c_{fe}               | The total fixed cost of the IBWT supplier is \(c_f = c_{fi} + c_{fe} = \sum_{i=1}^{n} c_{fi}\). |
| \(\tau\)             | The wholesale price of water from internal to external supplier. |
| \(\zeta\)            | The cost coefficient of the WGD effort. |
| \(\kappa\)           | The internal supplier’s bargaining power, \(\kappa \in (0, 1)\). |
| \(\lambda_i\)        | The \(i^{th}\) water-intake’s bargaining power, \(\lambda_i \in (0, 1)\). |
| \(a_i\)              | The possible maximum quantity of the water demand. |
| \(b_i\)              | The price-elasticity of water demand, and satisfies \(b > 1\). |
| \(\theta_i\)         | The impact coefficient of WGD effort, and satisfies \(0 < \theta < 1\). |
| \(y_i(p_i, g_i)\)    | The \(i^{th}\) distributor’s ”water stock factor”, then \(z = [z_1, z_2, \ldots, z_n]\). |
| \(z_i\)              | A random disturbance defined in the range \([A, B]\) with \(B > A > 0\). |
| \(d_i(p_i, g_i, x_i)\) | The \(i^{th}\) distributor’s water demand, \(d_i(p_i, g_i, x_i) = y_i(p_i, g_i)x_i\). |
| \(\mu_i\)            | The mean value of \(x_i\). |
| \(\sigma_i\)         | The standard deviation of \(x_i\). |
| \(f_i(x_i)\)         | The probability density function (PDF) of \(x_i\). |
| \(F_i(x_i)\)         | The cumulative distribution function (CDF) of \(x_i\). |
| \(h_i(x_i)\)         | \(h_i(x_i) = x_iF_i(x_i)/1 - F_i(x_i)\). |
| \(i = 1, 2, \ldots, n, k = 1, 2, \ldots, n\). |
Table 2: Framework of game-theoretical decision models.

| Section | Game-theoretical decision models | Theories/Methods |
|---------|----------------------------------|------------------|
| 3.1     | Game-theoretical decision models with WGD effort | SG and RSC and NB |
| 3.1.1   | Decentralized decision model with WGD effort | SG and NB |
| 3.1.2   | Coordination decision model with WGD effort | RSC and NB |
| 3.2     | Game-theoretical decision models without WGD effort | SG and RSC and NB |

Notation: RSC: Revenue Sharing Contract; SG: Stackelberg Game; NB: Nash Bargaining.

The first objective function represents internal supplier and external supplier bargains over the wholesale price under an asymmetric Nash bargaining framework. The second equation represents the total profit constraints for the internal and external suppliers. The variables and objective function in the third and fourth lines indicate IBWT supplier’s decision on his wholesale prices and WGD efforts to maximize his profit. By solving this decentralized decision model, we can derive the equilibrium wholesale price $w^d_i$ and the equilibrium WGD effort $q^d_i$ for the internal supplier, $g_i$, and the equilibrium stock factor $z^d_i$, the equilibrium retail price $p^d_i$, and the equilibrium purchasing amount $q^d_i$ for the internal supplier, and the bargaining wholesale price $w^d_i$. Moreover, we can calculate the profits of the internal supplier, external supplier, IBWT supplier, the IBWT supply chain, which are represented, respectively, by $\Pi_{NS}^d$, $\Pi_{ES}^d$, $\Pi_{SI}^d$, $\Pi_{WI}^d$, and $\Pi_{SC}^d$ (the detailed analysis results are shown in Table 3).

3.1.2. Coordination Decision Model with WGD Effort. In the coordination decision-making scenario, the sequence of decision is as follows: a bargain over the wholesale price of water in IBWT horizontal supply chain occurs between the internal and external suppliers by utilizing a Nash Bargaining game in the first place before agreeing on collaborated operations; then, the IBWT supplier should determine the WGD effort $q_i$ and provide a contract about revenue sharing to distributors under which the water distributors are charged a lower wholesale price $w_i$ by IBWT supplier; then, the contract can be either chosen to be accepted or rejected by the water distributors; finally, if the distributors need to recognize the terms of the contract, they will order amount $q_i$ with IBWT supplier and determine their resale prices $p_i$ and stock factors $z_i$. Finishing sales, a proportion $(1 - \phi_i)$ of their net revenues will be shared with IBWT supplier, where $\phi_i$ represents the water distributors of the revenue maintenance rate, $\phi_i \in (0, 1)$. $T_i = (1 - \phi_i) p_i \gamma_i (p_i, \phi) E [\min(z_i, x_i)]$ represents the revenue of the internal supplier with IBWT supplier. Therefore, $\Pi_{NS}^d (p_i, z_i) = \Pi_{DS} (p_i, z_i) - T_i$, and $\Pi_{ES}^d (w_i, g_i) = \sum_{i=1}^{n} \Pi_{ES}^d (w_i, g_i) = \sum_{i=1}^{n} \Pi_{ES}^d (w_i, g_i) + T_i$, represent the profit of the internal supplier and IBWT supplier. The coordination decision model for IBWT green supply chain under an extended framework of JIPIM can be formulated as

\[
\begin{align*}
\text{max} & \quad \Omega (w) = |\Pi_{NS}^d (w_i^d, g_i^d, q_i^d, w)|^{1-r} |\Pi_{ES}^d (w_i^d, g_i^d, q_i^d, w)|^{1-l} \\
\text{s.t.} & \quad \int_{N} (w_i, g_i^d, q_i^d, w) + \int_{E} (w_i, g_i^d, q_i^d, w) = \int_{s} (w_i, g_i^d, q_i^d) \\
& \quad w_i^d, g_i^d, q_i^d, \int_{N} (w_i, g_i^d, q_i^d, w), \int_{E} (w_i, g_i^d, q_i^d, w) \text{ and } \int_{s} (w_i, g_i^d, q_i^d) \\
& \quad \text{are derived from solving the following problem} \\
& \quad \max \pi_i (\phi_i) = [\int_{r_i} (\phi_i) - \int_{s_i} (\phi_i)]^{1-r} [\int_{D_i} (\phi_i) - \int_{D_i^c} (\phi_i)]^{1-l} \\
& \quad \text{s.t.} \quad \int_{r_i} (\phi_i) + \int_{r_i^c} (\phi_i) = \int_{s_i} (\phi_i) \\
& \quad \text{are derived from solving the following problem} \\
& \quad \max_{p, z} \int_{r_i} (p_i, z_i) \max_{p, z, \phi_i} \int_{s_i} (p_i, z_i) \\
\end{align*}
\]
Table 3: Analytical results of IBWT green supply chain with WGD effort (1 > θ > 0, κ > 0).

| Scenario | Decentralized decision | Coordination decision |
|----------|------------------------|-----------------------|
| | | $u_f^d = b C_i + c_q / b - 1$ | $u_f^c = \psi_i C_i - (1 - \psi_i) x_q$ |
| | | $p_f^d = b / b - 1 p_f^c$ | $p_f^c = (b / b - 1) \{ (C_i + c_d) x_i / z_i^c - \Lambda (x_i^c) \}$ |
| | | $q_f^d = (b - 1 / b)^{\theta \omega (2 - \theta)} [\theta (C_i + c_d) x_i (b - 1) \kappa]^{3 - \theta (2 - \theta)}$ | $q_f^c = [\theta (C_i + c_d) x_i (p_f^c)^\theta / (b - 1) \kappa]^{1 / 2 - \theta}$ |
| | | $w^* = r \Pi_{SS}^f - \sum_{n=1}^n \Pi_{SS}^f / \sum_{n=1}^n \Pi_{SS}^f$ | $w_i = r \Pi_{SS}^c - \sum_{n=1}^n \Pi_{SS}^c / \sum_{n=1}^n \Pi_{SS}^c$ |
| $\Pi_{SS}^f$ | $\Pi_{SS}^f = \sum_{n=1}^n \Pi_{SS}^f = \sum_{n=1}^n \left[ \{ (b - 1) \kappa / 2 \sqrt{2 \theta (C_i + c_f) / \kappa} \} (b - 1 / b)^{\theta \omega (2 - \theta)} [2 \theta (C_i + c_f) / (2 - \theta) \kappa]^{3 - \theta (2 - \theta)} - c_i \right]$ | $\Pi_{SS}^c = \sum_{n=1}^n \Pi_{SS}^c = \sum_{n=1}^n \left[ 2 \psi_i \{ (C_i + c_d) x_i / z_i^c - \Lambda (x_i^c) \} \right]$ |
| $\Pi_{SS}^d$ | $\Pi_{SS}^d = b c / (b - 1) \theta (b - 1 / b)^{\theta \omega (2 - \theta)} [2 \theta (C_i + c_f) / (2 - \theta) \kappa]^{3 - \theta (2 - \theta)}$ | $\Pi_{SS}^c = 2 \psi_i \{ (C_i + c_d) x_i / z_i^c - \Lambda (x_i^c) \}$ |
| $\Pi_{SS}^c$ | $\Pi_{SS}^c = \sum_{n=1}^n \Pi_{SS}^c = \sum_{n=1}^n \left[ (2 b - 1) \kappa / (b - 1) \theta - \kappa / 2 \sqrt{2 \theta (C_i + c_f) / \kappa} \} (b - 1 / b)^{\theta \omega (2 - \theta)} [2 \theta (C_i + c_f) / (2 - \theta) \kappa]^{3 - \theta (2 - \theta)} - c_i \right]$ | $\Pi_{SS}^c = \sum_{n=1}^n \Pi_{SS}^c = \sum_{n=1}^n \left[ (C_i + c_d) x_i / z_i^c - \Lambda (x_i^c) \right]$ |
| $\psi_i$ | $\Lambda_i (x_i^c) = \int_a^b (x_i^c - x_i) f_i (x_i) dx_i$ | $\psi_i = (b - 1) / \{ \psi_i C_i + \Lambda_i (x_i^c) \}$ |
the \( i \)-th water-intake of IBWT supplier and the \( j \)-th distributor bargaining over the revenue maintenance rate under an asymmetric Nash bargaining framework. The sixth equation represents the total profit constraints for the \( i \)-th water-intake of IBWT supplier and the \( j \)-th distributor. The variables and objective functions in the seventh, eighth, ninth, and tenth lines indicate the coordinated wholesale prices determined by making the decentralized decision of retail prices and stock factors consistent with the centralized decision of retail prices and stock factors. Hereinto, the objective functions in the ninth line represent the \( i \)-th distributor’s decision on his retail price and stock factor to maximize his profit. The objective functions in the tenth line represent the IBWT-GSC’s decision on his retail prices, stock factors, and WGD efforts to maximize his profit. Solving this coordination decision model, we can get the revenue keeping rate \( \phi_i^\ast \), the bargaining wholesale price \( w_c^i \), the equilibrium employment price \( w_f^i \) and the equilibrium WGD effort \( g_f^i \) in the \( i \)-th water-intake, the equilibrium retail price \( p_r^i \), the equilibrium stock factor \( z_i^r \) and the equilibrium purchasing amount \( q_f^i \) for the \( i \)-th water distributor. Moreover, the profits formulated among the internal supplier, external supplier, IBWT supplier, the \( i \)-th water distributor, and IBWT supply chain are, respectively, represented as \( \Pi_{NS}^i \), \( \Pi_{ES}^i \), \( \Pi_{SC}^i \), \( \Pi_{Di}^i \), and \( \Pi_{\Gamma SC}^i \) (the detailed analysis results are shown in Table 3).

3.2. Game-Theoretical Decision Models without WGD Effort

\( \theta = 0, \kappa = 0 \). Under the scenario without WGD effort, the impact coefficient of WGD effort on the anticipated demand \( \theta = 0 \), and the cost coefficient of the WGD effort \( \kappa = 0 \). Likewise, the same game-theoretical modelling methods employed in section 3.1, a decentralized decision-making model and a coordination decision-making model, are used for model formulation and analysis. The analytical results of equivalent modelling are illustrated in Table 4 for comparison.

4. Numerical and Sensitivity Analyses

Based on the public released information and historical operational data of eastern route of SNWD project [32, 33], a real-world case of eastern route of SNWD project in China is chosen to conduct numerical and sensitivity analyses in this section. In the eastern route of the SNWD project, there are six sections for the mainline of the project (\( n = 6 \)). Sections 1 \( \sim \) 2 are managed and operated by internal supplier (Jiangsu Water Source Company), and Sections 3 \( \sim \) 6 are managed and operated by external supplier (Shandong Mainline Company). Besides, there is one water distributor (regional branch companies) at the water intake of each section. The service area of the internal supplier has two water distributors (i.e., \( m = 2 \)) and the service region of the external supplier has four water distributors (i.e., \( n - m = 4 \)). The water consumers are water companies in service regions. The random factor \( x_i \) follows normal distribution, i.e., \( x_i \sim N(\mu_i, \sigma_i^2) \). \( A \) is set at 0 and \( B = 1000 \). The bargaining power of the internal supplier \( \tau \) is 0.6. The IBWT supplier’s bargaining power of coefficient \( \lambda_i \) is 0.6 in the \( i \)-th water-intake. The coefficient \( b \) representing the price-elasticity of the anticipated demand is 1.5. The impact coefficient of WGD effort on the anticipated demand \( \theta = 0.01 \). The coefficient \( \delta_i \) representing water loss rate from \( (i-1) \)-th to \( i \)-th water-intake is 11% in the horizontal supply chain. The coefficient \( c_{fi} \) representing the water delivering fixed cost of the IBWT supplier for the \( i \)-th water-intake is 20,000 CNY. The cost coefficient of the WGD effort \( \kappa = 10,000 \). The equivalent parameters values of costs, demand, and random factors are listed and shown in Table 5 (including the water transferred cost in the horizontal supply chain \( c_i \) from \( (i-1) \)-th to \( i \)-th water-intake, the water transferred cost from \( i \)-th water-intake to \( j \)-th distributor \( c_{ji} \), the potential maximum quantity of water demand \( a_i \), the mean value and standard deviation of random disturbance \( \mu_i, \sigma_i \)).

4.1. Numerical Analysis. Tables 6 and 7 compare and summarize the operational decisions/profits for all the game-theoretical decision models under decentralized/coordination decision scenario with WGD effort, respectively. Besides, Tables 8 and 9 compare and summarize the operational decisions/profits for all the game-theoretical decision-making models under decentralized/coordination decision setting without WGD effort, respectively. For these tables, \( \phi_i^\ast \) is the revenue maintenance rate of the \( i \)-th distributor, \( w^j_c \) is the wholesale price from supplier to \( i \)-th distributor, \( w_s \) is the wholesale price from internal to external supplier, \( p^\ast_r \) is the retail price from the \( i \)-th distributor to consumers, \( q^\ast_r \) is the \( i \)-th distributor’s water ordering quantity, \( z^\ast_i \) is the \( i \)-th distributor’s water stock factor, \( g^\ast_r \) is the WGD effort for the \( i \)-th water-intake, and \( \Pi_{NS}^i, \Pi_{ES}^i, \Pi_{SC}^i, \Pi_{Di}^i, \Pi_{\Gamma SC}^i \) are profits for the \( i \)-th distributor, internal supplier, external supplier, IBWT supplier, and IBWT-GSC. The asterisk (*) in the superscript/subscript represents four different decision scenarios: \( d \) under the decentralized decision with WGD effort, \( c \) under the coordination decision with WGD effort, \( d' \) under the decentralized decision without WGD effort, and \( c' \) under the coordination decision without WGD effort. The main findings can be summarized and discussed as follows:

(i) By comparing the numerical analysis results, the following results can be drawn afterwards between decentralized decision scenario with WGD effort (Table 6) and coordination decision scenario with WGD effort (Table 7): (i) under decentralized decision setting, we find that the water resources’ wholesale prices (1.31–10.32) are higher than those under coordination decision setting (0.25–1.99). (ii) Under decentralized decision-making setting, the water resources’ retail prices (4.38–34.43) are higher than those under coordination decision-making setting (1.46–11.48). (iii) Under coordination decision setting, the water stock factors are the same as those under decentralized decision setting (104.92–367.22). (iv) Under decentralized decision setting, the WGD efforts (0.93–4.23) are lower than those under coordination decision setting (1.65–4.53). (v) Under decentralized decision setting,
Table 4: Analytical results of IBWT green supply chain without WGD effort ($\theta = 0, \kappa = 0$).

| Scenario | Decentralized decision | Coordination decision |
|----------|------------------------|-----------------------|
| $w_i^d$  | $w_i^d = bC_i + c_a/b - 1$ | $w_i^d = \phi_i^{cd} - (1 - \phi_i^{cd})$ |
| $P_i^d$  | $P_i^d = b(b - 1)\phi_i^{cd}$ | $P_i^d = (C_i + c_a)\phi_i^{cd} - \Lambda(z_i^d)$ |
| $z_i^d$  | $F_i(z_i^d) = F_i(z_i)$ | $F_i(z_i) = 1/b + ((1 - \Lambda(z_i)/b)z_i)$ |
| $q_i^d$  | $q_i^d = y_i(p_i)z_i - a_i(p_i)^{b_i}z_i^b$ | $q_i^d = \phi_i^{cd} = a_i(p_i)^{b_i}z_i^b$ |
| $w_i^d$  | $w_i^d = 1/\sum_{i=1}^n \phi_i^{cd}(r\Pi_{NS}^d - \sum_{i=1}^n \Pi_{NS}^d_i)$ | $w_i^d = 1/\sum_{i=1}^n q_i^d(r\Pi_S^d - \sum_{i=1}^n \Pi_S^d_i)$ |
| $\Pi_{NS}^d$ | $\Pi_{NS}^d = \Pi_{NS}^d_i = \Pi_{NS}^d$ | $\Pi_{NS}^d = \Pi_{NS}^d_i = \Pi_{NS}^d$ |
| $\Pi_{ES}^d$ | $\Pi_{ES}^d = (1 - \tau)\Pi_{ES}^d_i$ | $\Pi_{ES}^d = (1 - \tau)\Pi_{ES}^d_i$ |
| $\Pi_{S}^d$ | $\Pi_{S}^d_i = \sum_{i=1}^n \Pi_{ES}^d_i = \sum_{i=1}^n [1 - (1 - \phi_i^{cd})(\Pi_{ES}^d_i + c_f_i) - c_f_i]$ | $\Pi_{S}^d_i = \sum_{i=1}^n \Pi_{ES}^d_i = \sum_{i=1}^n [1 - \phi_i^{cd}\Pi_{ES}^d_i + \phi_i^{cd}c_f_i]$ |
| $\Pi_{D}^d$ | $\Pi_{D}^d_i = (b - 1)b^{b_i-1}(\Pi_{ES}^d_i + c_f_i)$ | $\Pi_{D}^d_i = \phi_i^{cd}(\Pi_{ES}^d_i + c_f_i)$ |
| $\Pi_{SC}^d$ | $\Pi_{SC}^d_i = \sum_{i=1}^n \Pi_{D}^d_i = \sum_{i=1}^n [(1 - \phi_i^{cd})(\Pi_{ES}^d_i + c_f_i) - c_f_i]$ | $\Pi_{SC}^d_i = \sum_{i=1}^n \Pi_{D}^d_i = \sum_{i=1}^n [(1 - \phi_i^{cd})\Pi_{ES}^d_i + \phi_i^{cd}c_f_i]$ |

Note: $\Lambda_i(z_i) = \int_{x_i}^{z_i} (z_i - x_i)f_i(x)dx_i$

Table 5: List of parameters.

| Water-intake $i$ | Mainline water transfer cost $c_i$ | Branch-line water transfer cost $c_{di}$ | Potential maximum water demand quantity $a_i$ | Mean value of random factor $\mu_i$ | Standard deviation of random factor $\sigma_i$ |
|-----------------|-----------------------------------|---------------------------------|--------------------------------|---------------------------|-----------------------------|
| 1               | 0.36                              | 0.05                            | 50,000                            | 100                        | 10                          |
| 2               | 0.27                              | 0.07                            | 100,000                           | 150                        | 15                          |
| 3               | 0.10                              | 0.12                            | 150,000                           | 200                        | 20                          |
| 4               | 0.16                              | 0.16                            | 200,000                           | 250                        | 25                          |
| 5               | 0.45                              | 0.29                            | 250,000                           | 300                        | 30                          |
| 6               | 0.90                              | 0.40                            | 300,000                           | 350                        | 35                          |

Table 6: Numerical analysis results of decentralized decision scenario with WGD effort.

| $i$ | $w_i^d$ | $P_i^d$ | $z_i^d$ | $q_i^d$ | $q_i^d$ | $\Pi_{D}^d_i$ | $\Pi_{S}^d_i$ |
|-----|---------|---------|---------|---------|---------|---------------|---------------|
| 1   | 1.31    | 4.38    | 104.92  | 0.93    | 571,966  | 1,559,731     | 13,840,921    |
| 2   | 2.41    | 7.98    | 157.38  | 1.69    | 702,213  | 3,487,999     | 8,304,553     |
| 3   | 3.13    | 10.44   | 209.84  | 2.58    | 941,432  | 6,122,429     | 10,753,599    |
| 4   | 4.11    | 13.71   | 262.30  | 3.42    | 1,046,235| 8,931,458     | 14,444,163    |
| 5   | 6.35    | 21.34   | 314.76  | 3.94    | 4,209,338| 12,469,216    | 9,629,442     |
| 6   | 10.32   | 34.43   | 367.22  | 4.53    | 5,443,990| 10,357,006    | 11,690,056    |

Note: $w_d = 1.99$

Table 7: Numerical analysis results of coordination decision scenario with WGD effort.

| $i$ | $\psi_i$ | $w_i$ | $P_i$ | $z_i$ | $q_i$ | $q_i$ | $\Pi_{D}^d_i$ | $\Pi_{S}^d_i$ |
|-----|----------|-------|-------|-------|-------|-------|---------------|---------------|
| 1   | 0.6665   | 0.25  | 1.46  | 104.92| 1.65  | 2,989,218| 1,811,020     | 24,073,605    |
| 2   | 0.6674   | 0.48  | 2.66  | 157.38| 2.46  | 3,662,523| 4,046,973     | 14,444,163    |
| 3   | 0.6681   | 0.60  | 3.48  | 209.84| 3.26  | 4,903,293| 7,100,872     | 9,629,442     |
| 4   | 0.6686   | 0.79  | 4.57  | 262.30| 3.94  | 5,443,990| 10,357,006    | 11,690,056    |
| 5   | 0.6688   | 1.19  | 7.11  | 314.76| 4.32  | 4,209,338| 12,469,216    | 5,536,368     |
| 6   | 0.6690   | 1.99  | 11.48 | 367.22| 4.53  | 2,876,128| 13,751,853    | 73,610,546    |

Note: $w_i = 0.67$

Table 8: Numerical analysis results of decentralized decision scenario without WGD effort.

| $i$ | $w_i^d$ | $P_i^d$ | $z_i^d$ | $q_i^d$ | $\Pi_{D}^d_i$ | $\Pi_{S}^d_i$ |
|-----|---------|---------|---------|---------|---------------|---------------|
| 1   | 1.31    | 4.38    | 104.92  | 1.65    | 572,407       | 1,560,935     | 13,951,627    |
| 2   | 2.41    | 7.98    | 157.38  | 2.46    | 698,529       | 3,469,702     | 8,370,976     |
| 3   | 3.13    | 10.44   | 209.84  | 3.26    | 932,553       | 6,064,688     | 7,307,996     |
| 4   | 4.11    | 13.71   | 262.30  | 3.94    | 1,033,439     | 8,822,225     | 11,607,274    |
| 5   | 6.35    | 21.34   | 314.76  | 4.32    | 798,324       | 5,580,651     | 5,580,651     |
| 6   | 10.32   | 34.43   | 367.22  | 4.53    | 545,207       | 11,690,056    | 56,166,507    |

Note: $w_i = 2.03$
the purchasing amounts of water resources (553,132–1,046,235) are smaller than those under coordination decision setting (2,876,128–5,443,990). (vi) Under decentralized decision setting, the profits of IBWT-GSC and its stakeholders (10,753,559–11,859,974) are lower than those under coordination decision setting (1,811,020–14,444,163). Overall, the coordination decision setting with WGD effort outperforms the decentralized decision setting with WGD effort regarding operational decisions/performance.

(2) By comparing the numerical analysis results, there are results drawn between decentralized decision setting without WGD effort (Table 8) and coordination decision setting without WGD effort (Table 9); (i) under decentralized decision setting, the water resources’ wholesale prices (1.31–10.32) are higher than those under coordination decision setting (0.25–1.99). (ii) Under decentralized decision setting, the water resources’ retail prices (4.38–34.43) are higher than those under coordination decision setting (1.46–11.48). (iii) Under coordination decision setting, the water stock factors are the same as those under decentralized decision setting (104.92–367.22). (iv) Under decentralized decision setting, the ordering amounts of water resources (545,207–1,033,439) are smaller than those under coordination decision setting (2,832,980–5,369,908). (v) Under decentralized decision setting, the profits of IBWT-GSC and its stakeholders (1,560,935–11,690,056) are smaller than those under coordination decision setting (1,809,884–14,430,428). In short, the coordination decision-making setting with WGD effort (2,876,128–5,443,990) are smaller than those under coordination decision-making setting with WGD effort (2,832,980–5,369,908) are smaller than those under coordination decision-making setting with WGD effort (2,876,128–5,443,990). (vi) Under coordination decision-making setting, the profits of IBWT-GSC and its stakeholders without WGD effort (1,809,884–14,430,428) are smaller than those under coordination decision-making setting (1,811,020–14,444,163). In a word, the coordination decision-making setting with WGD effort outperforms the coordination decision-making setting without WGD effort regarding operational decisions/performance.

In brief, the coordination decision scenario with WGD effort is the optimum operational strategy for the IBWT-GSC because it is superior to all the other decision scenarios.

4.2. Sensitivity Analysis. The sensitivity analysis will pay close attention to how changes in several pivotal parameters of the coordination decision-making model will affect the operational profits/decisions of the IBWT-GSC and its stakeholders under JPIM, because the coordination strategy is superior to the decentralized strategy concerning operational decisions/performance for the IBWT-GSC in all models.

These key parameters are as follows: (1) the cost coefficient of the WGD effort (κ), (2) the impact coefficient of WGD effort on the anticipated demand (θ), (3) the price-elasticity index of the anticipated demand (b), (4) the loss of water delivery rate (δ), (5) the trunkline water transfer cost (c_e), and (6) the branch-line water transfer cost (c_d). Table 10 lists the relevant increase scale and sensitivity range of each given parameter, and then the sensitivity analysis results of each parameter.
4.2.1. Cost Coefficient of the WGD Effort (κ). The sensitivity analysis results of cost coefficient of the WGD effort (κ) are shown in Figure 1. With the growth of the cost coefficient of the WGD effort (κ), the WGDs of all distributors decrease, the revenue maintenance rates of all distributors decrease, and the returns of the IBWT green supply chain and its stakeholders decrease.

4.2.2. Impact Coefficient of WGD Effort on the Anticipated Demand (θ). The results of sensitivity analysis of impact coefficient of WGD effort on the anticipated demand (θ) are shown in Figure 2. As the impact coefficient of WGD effort on the anticipated demand (θ) increases, the WGDs of all distributors increase, the revenue maintenance rates of all distributors increase, the profits of all distributors increase, the returns of suppliers cut down, and the return of the IBWT-GSC increases.

4.2.3. Price-Elasticity Index of the Anticipated Demand (b). In Figure 3, the sensitivity analysis results of the anticipated demand price-elasticity index (b) are shown. With the growth of the price-elasticity index of the anticipated demand (b), the WGDs of all distributors decrease, the revenue maintenance rates of all distributors decrease, and the profits of the IBWT-GSC and its stakeholders decrease.

4.2.4. Water delivery Loss Rate (δi). In Figure 4, the loss of water delivery rate sensitivity analyzing results (δi) are shown. As the loss rate of water delivery (δi) increases, the retail prices of all distributors increase, the WGDs of all distributors decrease, the revenue maintenance rates of all distributors decrease, and the returns of the IBWT-GSC and its stakeholders decrease.

4.2.5. Mainline Water Transfer Cost (ci). The results drawn from the trunkline water transfer cost (ci) sensitivity analyzing are shown in Figure 5. With the growth of trunkline water transfer cost (ci), the retail prices of all distributors increase, the WGDs of all distributors decrease, the revenue maintenance rates of all distributors decrease, and the returns of the IBWT-GSC and its stakeholders decrease.

4.2.6. Branch-Line Water Transfer Cost (cdi). In Figure 6, the results drawn from the branch-line water transfer cost (cdi) sensitivity analyzing are shown. With the growth of the branch-line water transferred cost (cdi), the retail prices of all distributors increase, the WGDs of all distributors decrease, the revenue maintenance rate of distributor 1 decreases, and the returns of the IBWT-GSC and its stakeholders decrease.

| Parameter                        | Original value | ± increment | Range          |
|----------------------------------|----------------|-------------|----------------|
| κ                                | 10,000         | 100         | [5,000, 15,000]|
| θ                                | 0.01           | 0.001       | [0.01, 0.1]    |
| b                                | 1.5            | 0.01        | [1.3, 2.3]     |
| δi                               | 11%            | 0.1%        | [5%, 15%]      |
| c1                               | 0.36           | 0.001       | [0.30, 0.40]   |
| cdi                              | 0.05           | 0.001       | [0.01, 0.10]   |

5. Theoretical and Practical Insights

This section summarizes the theoretical and practical insights that can be drawn from the analysis above.

5.1. Theoretical Insights. Different from the previous research of [8] with focus on the optimal/equilibrium decisions of subsidy intensity and water prices and green efforts for the IBWT supply chain under deterministic demand, and also different from the previous study of [20] with focus on the optimal/equilibrium decisions of water prices and inventories for the IBWT supply chain under stochastic demand, this research investigates the optimal/equilibrium operational decisions of green efforts, water prices, and inventories in the IBWT-GSC under the extended framework of JPIM. A novel and useful approach towards characterizing and exploring the effect and value of WGD efforts in the IBWT-GSC is developed via game-theoretical modelling and comparative analysis. The key contribution of this research provides a theoretical framework to investigate and understand the effect of green efforts and its economic value in the IBWT-GSC and propose the corresponding managerial insights to enhance the sustainable management and improve the operational performance for the IBWT-GSC.

What follows are the theoretical insights that can be drawn from our research:

First, for both scenarios with and without WGD effort, under coordination setting, the IBWT-GSC and its stakeholders would offer lower retail prices, purchase larger quantities, and make more WGD efforts compared with those under decentralized setting, thus gaining more profits. Hence, a coordination strategy with WGD efforts is conducive to the operational improved performance of the IBWT-GSC and its stakeholders.

Second, for both the scenario with and without WGD effort, a revenue and cost sharing contract with Nash bargaining mechanism could contribute to the coordination of the IBWT-GSC and boost operational performance for all the IBWT-GSC members. Besides, the IBWT supplier could gain more profit, while the distributors could gain less under coordination strategy, due to the relatively stronger market power of the IBWT supplier.
Figure 1: Sensitivity analysis of cost coefficient of the WGD effort ($\kappa$).
Figure 2: Sensitivity analysis of impact coefficient of WGD effort on the anticipated demand ($\theta$).
Figure 3: Sensitivity analysis of price-elasticity index of the anticipated demand (b).
Figure 4: Sensitivity analysis of loss of water delivery rate ($\delta_i$).
Figure 5: Sensitivity analysis of mainline water transfer cost ($c_1$).
Figure 6: Sensitivity analysis of branch-line water transfer cost ($c_{d1}$).
Third, the IBWT-GSC and its stakeholders compared with those under the coordination strategy without WGD effort will send for additional water sources under the coordination strategy with WGD effort and could produce more profits. Hence, WGD efforts are conducive to the promotion of the operational performance for all the IBWT-GSC stakeholders.

Finally, reducing the water delivery loss rate as well as the operational costs (containing trunkline transfer cost, branch-line transfer cost, WGD effort’s cost) improves the operational performance for all the IBWT-GSC stakeholders. Also, a lower expected water demanding price-elasticity improves the operational performance for all the IBWT-GSC members. Besides, a higher impact coefficient of WGD effort on the anticipated demand helps promote the operational performance for the IBWT distributors but does not benefit to improve the operational performance for the IBWT suppliers; moreover, a higher impact coefficient of WGD effort on the anticipated demand also improves the operational performance for the IBWT-GSC.

In brief, the best operational strategy is the coordination strategy with WGD efforts for the IBWT-GSC because of outperforming all the other strategies.

5.2. Practical Insights. On May 14, 2021, President Xi Jinping pointed out that strengthening water conservation to better manage supply and demand in the high-quality follow-up development of China’s mega water diversion project must be paid attention to [34]. Obviously, the research on green supply chain management of IBWT project is consistent with the major strategic needs of the country regarding the sustainable management and high-quality development of water diversion project, which has great theoretical significance and application value.

According to the theory of sustainable management of supply chain and water environment science, management of the IBWT-GSC calls for comprehensive consideration of water resource efficiency, water quality maintenance, and water environment impact in the IBWT project. From the dual perspective of management innovation and technical improvement, systematically considering green source, green transfer, green storage, green transportation, green purification, green sales, and green utilization through the control of water flow, business flow, information flow, and capital flow in the IBWT project with multiple operators and engineering facilities, the IBWT-GSC management is committed to the realization of multiple strategic goals of rational and efficient utilization of water resources, minimum negative impact of water environment interaction, coordination and cooperation among multiple operators, and efficient operations of the IBWT-GSC. From the theoretical insights discussed above, we can draw the following practical insights:

The WGD effort represents the IBWT supply chain’s investment level of resources, funds, technology, and personnel in water quality maintenance, water resource conservation, water ecological restoration, water environment protection and governance, water disaster prevention and control, etc. Therefore, providing clean water resources, strengthening water environment management ability, and improving comprehensive utilization efficiency of water resources are conducive to enhancing not only environmental protection performance, but also economic performance. Combined with the modelling and numerical analyses results, it is found that there are strong economic incentives for the IBWT-GSC and its stakeholders to make WGD efforts and implement green supply chain management.

Moreover, coordination strategy with WGD efforts outperforms the other operational strategies regarding the operational decisions and outcomes, and it turned out to be the optimal operational strategy for the IBWT-GSC. To achieve coordination and cooperation in the IBWT-GSC, a revenue and cost sharing contract is proposed based on Nash bargaining mechanism for the IBWT-GSC management. Here is a detailed decision sequence: the internal suppliers first bargain the wholesale price of water resources with the external ones in IBWT G-SWT with an aim to carry out teamwork operations. Then, a revenue and cost sharing contract is offered by the IBWT supplier to the distributors through Nash bargaining mechanism. The IBWT supplier bargains with distributors over the revenue keeping rate; the distributors will then place orders with the IBWT supplier based on the optimal decisions of retail prices, stock factors, and WGD efforts of water resources under the centralized decision scenario; and finally, the distributors will share their net revenues with the IBWT supplier.

Finally, the IBWT-GSC and its stakeholders should work together to decrease the loss rate of water delivery, the cost of mainline and branch-line transfer, and the cost of WGD effort to improve their operational performance. Furthermore, the IBWT-GSC and its stakeholders should make efforts as to the WGD promotion and education to enhance water users’ environmental consciousness and environmental preference, which is beneficial to improve the environmental and economic performance for the IBWT-GSC.

Overall, WGD effort and management of green supply chain do good to the IBWT-GSC and its stakeholders. Furthermore, for the IBWT-GSC, the coordination strategy is the best operational strategy built on revenue and cost sharing agreement with Nash bargaining mechanism.

6. Conclusions

In order to cope with the challenges in water quality maintenance and water environment protection in the sustainable management of an IBWT project, this paper investigates the joint operational decisions of pricing, inventory, and WGD and relevant operational strategies/outcomes of IBWT-GSC considering water loss from the perspective of green supply chain management. We proposed, analyzed, and summarized centralized, decentralized, and coordination decision-making models in the IBWT-GSC taking the water loss into account through game-theoretic research methods. Besides, for comparison purposes, the analytical results for the three types of decision-making models in the IBWT-GSC are also presented and summarized. On this basis, numerical and sensitivity...
analyses are carried out for each model. Finally, the theoretical and practical insights are drawn at the end of this work. From the research results, we know that (1) WGD efforts and green supply chain management are conducive to promote the operational performance of the IBWT-GSC and its stakeholders. (2) Coordination strategy outperforms the decentralized one regarding the operational decisions/performance in the IBWT-GSC management. (3) A revenue and cost sharing contract based on Nash bargaining mechanism would benefit the IBWT-GSC management and promote the operational performance. (4) The operational performance of the IBWT-GSC could be improved by reducing the water loss rate and operational costs (containing trunkline transfer cost, branch-line transfer cost, the WGD efforts' cost). (5) A lower price-elasticity is conducive to improve of the operational performance of the IBWT-GSC and its stakeholders. (6) A higher impact coefficient of WGD effort on the anticipated demand promotes operational performance of the IBWT-GSC and its stakeholders.

As to theoretical contribution, for the IBWT-GSC, joint operational decisions of pricing, inventory, and water green degree and the equivalent operational strategies are explored via the game-theoretical decisions modelling approach, which has further complemented the theories, applications, and methodologies in the sustainable operations management. In terms of practical contributions, the numerical analyzing results offer IBWT operators with more sound guidelines in making sustainable operational decisions and strategies.

Data Availability
The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest
The authors declare that they have no conflicts of interest to this work.

Acknowledgments
This work was supported by the Humanities and Social Science Youth Fund of Ministry of Education of P.R. China (Grant nos. 21YJC790017 and 17YJC790202), National Natural Science Foundation of China (Grant no. 71603125), China Scholarship Council (Grant no. 201706865020), and Young Leading Talent Program of Nanjing Normal University.

Supplementary Materials
Sensitivity Analysis Results of Key Parameters. (Supplementary Materials)

References
[1] World Water Assessment Programme, The United Nations World Water Development Report 2015: Water for a Sustainable World, UNESCO (United Nations Educational, Scientific and Cultural Organization, Paris, 2015.
[2] L. Yang, Foreign Projects of Water Diversions, China Water and Power Press, Beijing, China, 2003.
[3] G. Wang, Q. Ouyang, Y. Zhang, J. Wei, and Z. Ren, World’s Water Diversions Project, Science Press, Beijing, China, 2009.
[4] China State Council, “State council’s opinion on implementing the most stringent water resources management system,” 2012, http://www.gov.cn/zwgk/2012-02/16/content_2067664.htm.
[5] China National Development and Reform Commission, “The Advice on promoting Water-Conservation Management Contract and Promoting the Development of Water-Conservation Service Industry,” 2016, http://hzs.ndrc.gov.cn/newswxw/201608/t20160804_814054.html.
[6] China National Development and Reform Commission, “The Notice on construction Plan of Water-Saving Society in the 14th Five-Year Plan,” 2021, http://ggisb.mwr.gov.cn/zwgk/g/jh/202111/t20211109_1550644.html.
[7] National Office of Water Conservation, “The Ministry of Water Resources Issued 105 National Water Quotas and Basically Established a Water Quota System,” 2021, http://ggisb.mwr.gov.cn/zwgk/bzde/slbqy/202112/t20211214_1555041.html.
[8] Z. Chen and L. Pei, “inter-basin water transfer green supply chain equilibrium and coordination under social welfare maximization,” Sustainability, vol. 10, no. 4, p. 1229, 2018.
[9] Z. Chen and H. Wang, “inter-basin water transfer green supply chain coordination with partial backlogging under random precipitation,” Journal of Water & Climate Change, vol. 12, 2020.
[10] X. Chen and D. Simchi-Levi, “Pricing and inventory management,” in The Oxford Handbook of Pricing Management, O. Ozer and R. Phillips, Eds., Oxford University Press, Oxford, UK, pp. 784–822, 2012.
[11] H. Wang, Z. Chen, and S.-I. Ivan Su, “Optimal pricing and coordination schemes for the eastern route of the South-to-North water diversion supply chain system in China,” Transportation Journal, vol. 51, no. 4, pp. 487–505, 2012.
[12] Z. Chen and H. Wang, “Optimization and coordination of South-to-North Water diversion supply chain with strategic customer behavior,” Water Science and Engineering, vol. 5, no. 4, pp. 464–477, 2012.
[13] Z. Chen and H. Wang, “Asymmetric Nash bargaining model for the eastern route of South-to-North Water diversion supply chain cooperative operations,” Journal of the Chinese Institute of Industrial Engineers, vol. 29, no. 6, pp. 365–374, 2012.
[14] Y. Xu, L. Wang, Z. Chen, S. Shan, and G. Xia, “Optimization and adjustment policy of two-echelon reservoir inventory management with forecast updates,” Computers & Industrial Engineering, vol. 63, no. 4, pp. 892–900, 2012.
[15] Z. Chen, H. Wang, and X. Qi, “Pricing and water resource allocation scheme for the South-to-North water diversion project in China,” Water Resources Management, vol. 27, no. 5, pp. 1457–1472, 2013.
[16] W. Du, Y. Fan, and X. Tang, “Two-part pricing contracts under competition: the South-to-North Water Transfer Project supply chain system in China,” International Journal of Water Resources Development, vol. 32, no. 6, pp. 895–911, 2016.
[17] W. Du, Y. Fan, and L. Yan, “Pricing strategies for competitive water supply chains under different power structures: an application to the South-to-North water diversion project in China,” Sustainability, vol. 10, no. 8, pp. 1–13, 2018.
[18] W. Du, Y. Fan, X. Liu, S. C. Park, and X. Tang, “A game-based production operation model for water resource management:
an analysis of the South-to-North Water Transfer Project in China,” *Journal of Cleaner Production*, vol. 228, pp. 1482–1493, 2019.

[19] Z. Chen, S. I. Su, and H. Wang, “inter-basin water transfer supply chain equilibrium and coordination: a social welfare maximization perspective,” *Water Resources Management*, vol. 33, 2019.

[20] X. Chen and Z. Chen, “Joint pricing and inventory management of interbasin water transfer supply chain,” *Complexity*, vol. 2020, Article ID 3954084, 2020.

[21] C. W. Howe and F. P. Linaweaver, “The impact of price on residential water demand and its relation to system design and price structure,” *Water Resources Research*, vol. 3, no. 1, pp. 13–32, 1967.

[22] K. Schoengold, D. L. Sunding, and G. Moreno, “Price elasticity reconsidered: panel estimation of an agricultural water demand function,” *Water Resources Research*, vol. 42, no. 9, Article ID W09411, 2006.

[23] L. Wang, L. Fang, and K. W. Hipel, “Basin-wide cooperative water resources allocation,” *European Journal of Operational Research*, vol. 190, no. 3, pp. 798–817, 2008.

[24] N. C. Petruzzii and M. Dada, “Pricing and the newsvendor problem: a review with extensions,” *Operations Research*, vol. 47, no. 2, pp. 183–194, 1999.

[25] Y. Wang, “Joint pricing-production decisions in supply chains of complementary products with uncertain demand,” *Operations Research*, vol. 54, no. 6, pp. 1110–1127, 2006.

[26] Y. Wang, L. Jiang, and Z.-J. Shen, “Channel performance under consignment contract with revenue sharing,” *Management Science*, vol. 50, no. 1, pp. 34–47, 2004.

[27] M. A. Lariviere and E. L. Porteus, “Selling to the newsvendor: an analysis of price-only contracts,” *Manufacturing & Service Operations Management*, vol. 3, no. 4, pp. 293–305, 2001.

[28] M. A. Lariviere, “A note on probability distributions with increasing generalized failure rates,” *Operations Research*, vol. 54, no. 3, pp. 602–604, 2006.

[29] J. F. Nash, “The bargaining problem,” *Econometrica*, vol. 18, no. 2, pp. 155–162, 1950.

[30] E. Kalai and M. Smorodinsky, “Other solutions to nash’s bargaining problem,” *Econometrica*, vol. 43, no. 3, pp. 513–518, 1975.

[31] A. Muthoo, *Bargaining Theory with Applications*, Cambridge University Press, Cambridge, MA, USA, 1999.

[32] National Development and Reform Commission (Ndrc), “Notice on the Water Supply price Policy for the First Phase of the East Line of the South-To-North Water Diversion Project,” 2014, https://www.ndrc.gov.cn/xxgk/zcfb/tz/201401/t20140121_964023.html?code=&state=123.

[33] State Council of China, “Regulations on the Administration of Water Supply and Consumption for the South-To-North Water Transfer Project,” 2014, http://www.gov.cn/zhengce/2014-02/28/content_2625853.htm.

[34] Huaxia, “Xi Focus: Xi convenes symposium on follow-up development of China’s mega water diversion project,” 2021, http://www.xinhuanet.com/english/2021-05/14/c_139946207_2.htm.