How does water-saving service contribute to the sustainability of supply chain? A game-theoretical modelling study

Zhisong Chen, Feng Chen, Rong Yu and Jianhui Peng

ABSTRACT

Currently, water-saving service (WSS) providers are devoted to providing high-water-consumption (HWC) supply chains with comprehensive water-saving solutions. In this context, the decentralized and cooperative decision models for HWC supply chain under the benchmark scenario without WSS, and the decentralized, hybrid and cooperative decision models for the three-tier WSS supply chain under the scenario with WSS are developed and analyzed, the corresponding numerical and sensitivity analyses for all models are conducted and compared, and finally, the managerial insights are summarized. The research results indicate that: (1) introducing WSS could effectively increase the profits, social welfare and consumer surplus for the HWC supply chain; (2) a cooperative strategy could effectively increase the profits, social welfare and consumer surplus and is the best strategy for the three-tier WSS supply chain; (3) the hybrid strategy (partial cooperative strategy) could effectively increase the profits, social welfare and consumer surplus and is the second-best strategy for the three-tier WSS supply chain; (4) reducing the costs of water saving could effectively enhance water consumption reduction, increase the profits, social welfare and consumer surplus for the three-tier WSS supply chain.

Key words | cooperation, high water consumption (HWC), supply chain, water-saving effort (WSE), water-saving service (WSS)

Zhisong Chen
Business School, Nanjing Normal University,
Qixia District,
Nanjing 210023,
China
and
Stern School of Business,
New York University, 44 West Fourth Street,
New York, NY 10012,
USA

Feng Chen
Rong Yu (corresponding author)
School of Management Science and Engineering,
Nanjing University of Finance and Economics,
Nanjing 210023,
China
E-mail: *yurong@nufe.edu.cn*

Rong Yu
College of Economics and Management, Nanjing
University of Aeronautics and Astronautics,
Nanjing 211106,
China

Jianhui Peng
School of Finance and Business, Shanghai Normal
University,
100 Guilin Road, Xuhui District,
Shanghai 200234,
China

HIGHLIGHTS

- The value of water saving service for the sustainability of supply chain is investigated.
- The operational strategies for the water saving service supply chain are explored.
- The cooperative strategy is the best strategy for the water saving service supply chain.
- The partial cooperative strategy is the second-best strategy for the water saving service supply chain.

INTRODUCTION

In the context of global climate change, water resources are becoming increasingly scarce, especially with the rapid development of modern industries. The 'World Water Resources Development Report' pointed out that the current problem of global water abuse is formidable, and the global water deficit is estimated to reach as high as 40% by 2030, based on current water use ratio (United Nations World Water Assessment Programme (WWAP) 2015). In many developing countries, the extensive development mode has caused a serious waste of water resources. As sustainable development relies, more and more, on the capacity of water resources, various water resources saving/conservation plans and schemes for industrial users, agricultural users and municipal users have been launched in many developed and developing countries of the world. In China, the regulation 'Implementing the Most Stringent Water Resources Management

doi: 10.2166/ws.2020.112

System' was issued by China State Council in 2012 (China State Council 2012). The regulation stipulates that the development of industries and cities be contingent on their water resources capacity, as is required in the nation's endeavor to build a water-saving/conservation society. Besides, the guideline for 'Promoting Water-saving Management Contract and Promoting the Development of Water-saving Service Industry' was issued by China National Development and Reform Commission (NDRC) in 2016 (NDRC 2016). Under the water-saving management contract, water-saving service (WSS) providers raise capitals, integrate advanced technologies, provide comprehensive water-saving services and solutions for their customers, and the customers share their water-saving benefits with their WSS providers. Furthermore, 'National Water-saving Action Plan' was jointly issued by NDRC and Ministry of Water Resources in 2019 (NDRC & Ministry of Water Resources 2019). This plan puts forward the water-saving objectives and key actions during 2020–2035, aiming to promote water conservation in agriculture, industry, towns and other fields, improve water resource utilization efficiency, and promote high-quality development. With these policies in the background, high-water-consumption (HWC) manufacturers would have external incentive to seek WSS in order to reduce the cost of water input and increase the benefit of water-saving practices.

Generally, water consumption of HWC manufacturers in the process of product manufacturing is regulated with a certain water quota; thus, HWC manufacturers would have external pressure to cut down on their water consumption. Furthermore, the lower-water-consumption products are often more favored by environment-friendly customers (Llanos *et al.* 2020). Thus, retailers of such products would expect HWC manufacturers to provide lower-water-consumption products. Apparently, these HWC manufacturers are also driven by the supply chain to reduce their water consumption in the manufacturing process. With the foregoing reasons, HWC manufacturers would have both external pressure and internal incentive to reduce their water consumption in the manufacturing process.

In this background, the specialized third party WSS providers (e.g. Guotai Water-saving-service Co., Dayu Water-saving-service Co., Daneng Water-saving-service Co. etc. in China) came into being. The HWC manufacturers may introduce WSS to reduce their water consumption and thus the cost of water input in the product manufacturing process, the retailers may expect the HWC manufacturer to introduce WSS to increase the demand for their product. Obviously, a HWC supply chain made up of HWC manufacturer and retailer has the economic motivation to introduce a WSS provider, and as a result the three-tier WSS supply chain composed of WSS provider, HWC manufacturer and retailer is formulated (three-tier WSS supply chain will be abbreviated as WSS supply chain). Hence, three urgent issues need to be tackled in the operations management of the WSS supply chain: under what conditions would a HWC supply chain/the WSS provider have the economic motivation to introduce/provide WSS, how much effort should a WSS provider put in to reduce water consumption for the supply chain, and what kind of operational strategy should be adopted for the WSS supply chain?

Therefore, this paper tries to explore the value of WSS in the three-tier WSS supply chain under different decision scenarios. In the following sections, corresponding literatures are reviewed first in a Literature Review; the notation and assumptions for a generic three-tier WSS supply chain model are defined in Modeling Notation and Assumptions; the decentralized and cooperative decision models under the benchmark scenario without WSS are developed and analyzed in Benchmark Scenario without WSS; the decentralized, hybrid and cooperative decision models under the scenario with WSS are developed and analyzed in Scenario with WSS; comparisons and discussions of analytical results are conducted in Comparisons and Discussions of Analytical Results; the numerical and sensitivity analyses for all models are conducted and compared in Numerical and Sensitivity Analyses; the managerial insights are then discussed in Managerial Insights and Policy Recommendations; and, finally, the findings and contributions of the research are synthesized and concluded in the last section.

LITERATURE REVIEW

Based on the research background discussed in Introduction, internal incentives and operational strategies are the key issues for WSS supply chains to tackle to improve operational performance and social welfare. Thus, two streams of literature are related to our research, the first stream is on the incentives of water saving, and the second one is on the resources-/energy-saving supply chain.

Regarding the first stream, the available literature on water-saving incentives has mainly focused on the analysis of behavioral attitudes towards water saving and different incentive mechanisms, such as the attitude toward water saving and relative behavior (Gilg & Barr 2006), the behavior change and incentive model for water saving (Novak *et al.* 2018), the economic incentive to use water-saving systems (Ørum *et al.* 2010), institutional incentive for water conservation (Nikouei *et al.* 2012), the willingness to save water under three alternative incentive policies of water price increase, monetary reward, and symbolic prize (Garrone *et al.* 2020). Besides, some literature can also be found on water-saving incentives using game theory, such as the applicability of game theory to water resources management and conflict resolution (Madani 2010), principal-agent contract design for demand management in urban water systems (Amit & Ramachandran 2010), zero-sum game model to explore the water tariff policy (Varouchakis *et al.* 2018), the differential oligopoly game models for joint decision in production planning and water-saving problem-solving (Xin & Sun 2018), and the selection of sustainable water reuse applications based on the framework combining multicriteria decision analysis and game theory (Chhipi-Shrestha *et al.* 2019).

Regarding the second stream, the available literature on resources-/energy-saving supply chain mainly focused on the design of cost saving and sharing contracts with/without the government's subsidy/regulation and the tradeoffs between key decisions and operational indicators, such as the inconsistency between the goal of maximizing profits and minimizing consumption in the traditional saving-sharing contracts used in chemical purchasing industries (Corbett & Decroix 2001), shared-savings contracts using the double moral hazard framework with broad class of cost-of-effort functions (Corbett *et al.* 2005), the tradeoff between energy savings and profits in the green supply chain coordination with energy-saving regulation (Xie 2015), fixed amount and price discount contracts for energy-saving products in a monopoly with government's budget constraint (Zhou & Huang 2016), the impacts of energy performance contracting on two competing manufacturers (Zhou *et al.* 2017), the effects of six governmental regulation policies on price and energy-saving competition of green supply chains using mathematical programming and Stackelberg game (Hafezalkotob 2018), the cooperation mechanism based on cost-sharing contract for energy saving and emissions reduction of a supply chain under government's subsidies and carbon taxes (Yi & Li 2018), the cooperative mechanism of water-saving service supply chain under social welfare maximization (Chen & Wang 2019), the internal incentives and operational strategies of an autonomous-water-saving supply chain with cap-and-trade regulation (Chen *et al.* 2019).

Nevertheless, the existing literatures fail to take into consideration the following critical factors in the WSS supply chain: (1) the equilibrium/optimal water-saving effort (WSE) in the WSS supply chain; (2) the optimal operational strategies for the WSS supply chain; (3) the value of WSS in the WSS supply chain. To fill the gap in previous research, decentralized, hybrid and cooperative decision models under the scenario with WSS are developed and solved to explore the value of WSS and the operational strategies for the WSS supply chain.

MODELING NOTATION AND ASSUMPTIONS

A stylized three-tier WSS supply chain is generally composed of a retailer, an HWC manufacturer and a WSS provider (Figure 1). The HWC manufacturer produces an HWC product and sells the product to the retailer at a wholesale price. The retailer sells the product to the consumers at a retail price. The HWC manufacturer, whose product-manufacturing process requires the input of water resources, has a strong economic incentive to reduce water consumption and thus the cost of water resources input, especially in arid or semi-arid areas where water is very precious and is usually charged at a high price. The

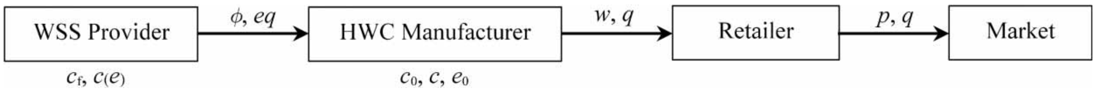

Figure 1 | Three-tier WSS supply chain.

WSS provider is typically a professional water-saving service (WSS) agency, who can provide WSS to the HWC manufacturer.

The cost of raw material and manufacturing of a product is c_0, the cost of unit water is c, the wholesale price of the product is w, the retail price of the product is p. The water consumption quantity per unit product is e_0 (can be seen as the water-saving reference point), and WSS provider's water-saving effort (WSE) is e. Generally, the resources/energy saving cost function is assumed to be a quadratic form, such as quadratic cost function of energy saving (Xie 2015; Yi & Li 2018), quadratic cost function of water saving (Xin & Sun 2018). Following Xin & Sun (2018), the cost of WSE for a WSS provider is assumed to be a quadratic form: $c(e) = \frac{1}{2}\kappa e^2$. The fixed cost of water saving is c_f. Without loss of generality, the product demand function is assumed to be the linear form: $q(p, e) = a - bp + de$, where a is the choke quantity of product, b is the sensitivity coefficient of demand-price and d is the sensitivity coefficient of demand-WSE, and satisfies $a > 0$ and $b > d > 0$. Under the water-saving management contract, the benefit of water saving is shared between the HWC manufacturer and the WSS provider, and the HWC manufacturer will share the benefit of water saving with the WSS provider at a benefit sharing rate ϕ. Without loss of generality, the positive externalities of the water-saving effort are assumed to be a quadratic form: $PE(e) = \frac{1}{2}ge^2$, hereinto, g is the positive externalities coefficient of water-saving effort. λ is the bargaining power of the retailer, and τ is the bargaining power of the HWC supply chain, hereinto, $\lambda, \tau \in (0, 1)$. Based on the parameters setting, the profit functions of the retailer, the HWC manufacturer, the HWC supply chain, the WSS provider and the WSS supply chain can be expressed as follows:

$$\Pi_r(p, e) = (p - w)q(p, e) \tag{1}$$

$$\Pi_m(w) = [w - c_0 - c(e_0 - e) - \phi ce]q(p, e) \tag{2}$$

$$\Pi_{sc}(p, e) = [p - c_0 - c(e_0 - e) - \phi ce]q(p, e) \tag{3}$$

$$\Pi_{wss}(e) = \phi ceq(p, e) - \frac{1}{2}\kappa e^2 - c_f \tag{4}$$

$$\Pi_{wsc}(p, e) = [p - c_0 - c(e_0 - e)]q(p, e) - \frac{1}{2}\kappa e^2 - c_f \tag{5}$$

According to the classical economics theory (Marshall 1890), the consumer surplus and social welfare in the WSS supply chain can be expressed as:

$$CS(q) = \frac{1}{2b}q^2 \tag{6}$$

$$SW(q) = \frac{1}{b}[a - b(c_0 + ce_0) + (d + bc)e]q - \frac{1}{2b}q^2 - \frac{1}{2}(\kappa - g)e^2 - c_f \tag{7}$$

GAME-THEORETICAL DECISION MODELS

To understand the economic incentive of introducing WSS, the decentralized and cooperative decision models for the HWC supply chain under the benchmark scenario without WSS are developed and analyzed firstly, and then, the decentralized, hybrid and cooperative decision models for the three-tier WSS supply chain under the scenario with WSS are developed and analyzed, and finally, corresponding comparison is made based on the forgoing analyses.

Benchmark scenario without WSS

To investigate the internal incentive of seeking WSS, the benchmark scenario without WSS is modelled and analyzed, i.e. $d = 0$, $\kappa = 0$, $e = 0$, $c_f = 0$. The decentralized and cooperative decision models for the HWC supply chain are developed and analyzed in this section (superscript b: benchmark scenario, superscript or subscript d: decentralized decision, superscript or subscript c: cooperative decision).

Decentralized decision without WSS

For the decentralized decision without WSS, a Stackelberg game model between the HWC manufacturer and the retailer is developed and analyzed. In this model, the HWC manufacturer first decides the wholesale price of the product, and then the retailer decides the retail price of the product. The Stackelberg game model can be formulated as follows:

$$\begin{cases} \max\limits_{w} \ \Pi_m\left(w, q_d^b\left(p_d^b(w)\right)\right) \\ s.t.\ p_d^b(w) = \arg\max\limits_{p} \ \Pi_r(p) \end{cases} \tag{8}$$

Solving this Stackelberg game, we get the equilibrium wholesale price w_d^b, retail price p_d^b and ordering quantity q_d^b, and on this basis, we can get the equilibrium profits of the retailer, HWC manufacturer and HWC supply chain, the corresponding social welfare and consumer surplus (see Table 1 for the mathematical functions and see Appendix for their derivations).

Cooperative decision without WSS

For the cooperative decision without WSS, a Stackelberg-bargaining game model between the HWC manufacturer and the retailer is developed and analyzed. In this model, the HWC manufacturer and the retailer first bargain over the wholesale price via Nash bargaining mechanism to achieve cooperation within the HWC supply chain, and then the HWC supply chain decides the retail price of the product. The Stackelberg-bargaining game model can be formulated as follows:

$$\max_{w} \Psi(w) = [\Pi_r^{bc}(w) - \Pi_r^{bd}]^{\lambda}[\Pi_m^{bc}(w) - \Pi_m^{bd}]^{1-\lambda}$$

$$s.t. \begin{cases} \Pi_r^{bc}(w) \geq \Pi_r^{bd} \\ \Pi_m^{bc}(w) \geq \Pi_m^{bd} \\ \Pi_r^{bc}(w) + \Pi_m^{bc}(w) = \Pi_{sc}^{bc} \\ s.t. \begin{cases} p_c^b \text{ and } \Pi_{sc}^{bc} \text{ are derived from} \\ \text{solving the following problem} \\ \max\limits_{p} \ \Pi_{sc}(p) \end{cases} \end{cases} \tag{9}$$

Solving this Stackelberg-bargaining game, we get the equilibrium wholesale price w_c^b, retail price p_c^b and ordering quantity q_c^b, and on this basis, we can get the equilibrium profits of the retailer, HWC manufacturer and HWC supply chain, the corresponding social welfare and consumer surplus (see Table 1 for the mathematical functions and see Appendix for their derivations).

Scenario with WSS

Under the scenario with WSS, the WSS provider and the corresponding water-saving management contract are introduced to provide comprehensive water-saving solutions for the HWC supply chain, thus formulating a three-tier WSS

Table 1 | Analytical results under the scenario without WSS

Scenario	Decentralized decision	Cooperative decision
w^*	$w_d^b = \frac{1}{2b}[a - b(c_0 + ce_0)] + (c_0 + ce_0)$	$w_c^b = \frac{3-\lambda}{8b}[a - b(c_0 + ce_0)] + (c_0 + ce_0)$
p^*	$p_d^b = \frac{3}{4b}[a - b(c_0 + ce_0)] + (c_0 + ce_0)$	$p_c^b = \frac{1}{2b}[a - b(c_0 + ce_0)] + (c_0 + ce_0)$
q^*	$q_d^b = \frac{1}{4}[a - b(c_0 + ce_0)]$	$q_c^b = \frac{1}{2}[a - b(c_0 + ce_0)]$
Π_r^*	$\Pi_r^{bd} = \frac{1}{b}(q_d^b)^2$	$\Pi_r^{bc} = \frac{1+\lambda}{4}\Pi_{sc}^{bc}$
Π_m^*	$\Pi_m^{bd} = \frac{2}{b}(q_d^b)^2$	$\Pi_m^{bc} = \frac{3-\lambda}{4}\Pi_{sc}^{bc}$
Π_{sc}^*	$\Pi_{sc}^{bd} = \frac{3}{b}(q_d^b)^2$	$\Pi_{sc}^{bc} = \frac{1}{b}(q_c^b)^2$
SW^*	$SW_d^b = \frac{7}{2b}(q_d^b)^2$	$SW_c^b = \frac{3}{2b}(q_c^b)^2$
CS^*	$CS_d^b = \frac{1}{2b}(q_d^b)^2$	$CS_c^b = \frac{1}{2b}(q_c^b)^2$

supply chain. Under the water-saving management contract, the benefit of water saving is shared between the HWC manufacturer and the WSS provider. On this basis, the decentralized, hybrid and cooperative decision models for WSS supply chain under the scenario with WSS are developed and analyzed in this section (superscript or subscript d: decentralized decision, superscript or subscript c: cooperative decision, superscript or subscript h: hybrid decision).

Decentralized decision with WSS

For the decentralized decision with WSS, a two-stage Stackelberg game model is developed and analyzed. In this model, taking the profits under the decentralized decision without WSS as the lower bound, the interval of benefit sharing rate can be calculated under decentralized decision with WSS, and the benefit sharing rate is given within this interval. The detailed decision sequence is as follows: the WSS provider first decides WSE and then the HWC manufacturer decides the wholesale price of the product, and finally the retailer decides the retail price of the product. The two-stage Stackelberg game model can be formulated as follows:

$$\max_{e}\ \Pi_{wss}(e, q_d(e))$$
$$s.t.\begin{cases}\max\limits_{w}\ \Pi_m(w, q_d(p_d(w, e)))\\ s.t.\ p_d(w) = \arg\max\limits_{p}\ \Pi_r(p, e)\end{cases} \tag{10}$$

Solving this two-stage Stackelberg game, we get the equilibrium WSE e_d,wholesale price w_d, retail price p_d and ordering quantity q_d, and on this basis, we can get the equilibrium profits of the retailer, HWC manufacturer, HWC supply chain, WSS provider and WSS supply chain, the corresponding social welfare and consumer surplus (see Table 2 for the mathematical functions and see Appendix for their derivations).

Hybrid decision with WSS

For the hybrid decision (partial cooperative decision) with WSS, a two-stage Stackelberg-bargaining game model is developed and analyzed. In this model, taking the profits under the cooperative decision without WSS as the lower bound, the interval of benefit sharing rate can be calculated under the hybrid decision with WSS, and the benefit sharing rate is given within this interval. The detailed decision sequence is as follows: the WSS provider first decides WSE, and then the HWC manufacturer and the retailer bargain over the wholesale price via Nash bargaining mechanism to achieve cooperation within the HWC supply chain, and finally, the HWC supply chain decides the retail price. The two-stage Stackelberg-bargaining game model can be formulated as follows:

$$\max_{e}\ \Pi_{wss}(e, q_h(e))$$
$$s.t.\begin{cases}\max\limits_{w}\Psi(w) = [\Pi_r^h(w, e) - \Pi_r^{bc}]^{\lambda}[\Pi_m^h(w, e) - \Pi_m^{bc}]^{1-\lambda}\\ s.t.\begin{cases}\Pi_r^h(w, e) \geq \Pi_r^{bc}\\ \Pi_m^h(w, e) \geq \Pi_m^{bc}\\ \Pi_r^h(w, e) + \Pi_m^h(w, e) = \Pi_{sc}^h(e)\\ s.t.\begin{cases}p_h(e)\ \textit{and}\ \Pi_{sc}^h(e)\ \textit{are derived from}\\ \textit{solving the following problem}\\ \max\limits_{p}\ \Pi_{sc}(p, e)\end{cases}\end{cases}\end{cases} \tag{11}$$

Solving this two-stage Stackelberg-bargaining game, we can obtain the equilibrium WSE e_h,wholesale price w_h, retail price p_h and ordering quantity q_h, and on this basis we can get the equilibrium profits of the retailer, HWC manufacturer, HWC supply chain, WSS provider and WSS supply chain, the corresponding social welfare and consumer surplus (see Table 2 for the mathematical functions and see Appendix for their derivations).

Cooperative decision with WSS

For the cooperative decision with WSS, a two-stage bargaining game model is developed and analyzed. In this model, taking the profits under the cooperative decision without WSS as the breakdown point of negotiation, the benefit sharing rate will be decided via negotiation between the WSS provider and the HWC supply chain. The detailed decision sequence is as follows: the HWC manufacturer and the retailer first bargain over the wholesale price via Nash bargaining mechanism to achieve cooperation within the HWC supply chain, and then the WSS provider and the HWC supply chain bargain over the benefit sharing rate via Nash bargaining mechanism to achieve cooperation within the three-tier WSS supply chain, and finally the WSS

Table 2 | Analytical results under the scenario with SWM

Scenario	Decentralized decision	Hybrid decision	Cooperative decision
$e*$	$e_d = \frac{\phi_d c[a - b(c_0 + ce_0)]}{4\kappa - 2\phi_d c[d + (1 - \phi_d)bc]}$	$e_h = \frac{\phi_h c[a - b(c_0 + ce_0)]}{2\{\kappa - \phi_h c[d + (1 - \phi_h)bc]\}}$	$e_c = \frac{(d + bc)}{2b\kappa - (d + bc)^2}[a - b(c_0 + ce_0)]$
$w*$	$w_d = \frac{4\kappa - \phi_d c[d + 3(1 - \phi_d)bc]}{4b\{2\kappa - \phi_d c[d + (1 - \phi_d)bc]\}}[a - b(c_0 + ce_0)] + (c_0 + ce_0)$	$w_h = \frac{1 - \lambda}{b} q_h - \frac{1 - 3\lambda}{4b} \frac{(q_c^b)^2}{q_h} + (c_0 + ce_0) - (1 - \phi_h)ce_h$	$w_c = \frac{[\kappa - (d + bc)c]q_c}{b\kappa} - \frac{\lambda\tau(\Pi_{wsc}^c - \Pi_{sc}^{bc}) + \Pi_r^{bc}}{q_c} + (c_0 + ce_0)$
$p*$	$p_d = \frac{12\kappa - \phi_d c\{3d + 7(1 - \phi_d)bc\}}{8b\{2\kappa - \phi_d c[d + (1 - \phi_d)bc]\}}[a - b(c_0 + ce_0)] + (c_0 + ce_0)$	$p_h = \frac{2\kappa - \phi_h c[d + 3(1 - \phi_h)bc]}{4b\{\kappa - \phi_h c[d + (1 - \phi_h)bc]\}}[a - b(c_0 + ce_0)] + (c_0 + ce_0)$	$p_c = \frac{\kappa - (d + bc)c}{2b\kappa - (d + bc)^2}[a - b(c_0 + ce_0)] + (c_0 + ce_0)$
$q*$	$q_d = \frac{4\kappa - \phi_d c[d + (1 - \phi_d)bc]}{8\{2\kappa - \phi_d c[d + (1 - \phi_d)bc]\}}[a - b(c_0 + ce_0)]$	$q_h = \frac{2\kappa - \phi_h c[d + (1 - \phi_h)bc]}{4\{\kappa - \phi_h c[d + (1 - \phi_h)bc]\}}[a - b(c_0 + ce_0)]$	$q_c = \frac{b\kappa}{2b\kappa - (d + bc)^2}[a - b(c_0 + ce_0)]$
Π_r^*	$\Pi_r^d = \frac{1}{b} q_d^2$	$\Pi_r^h = \lambda\Pi_{sc}^h + \frac{1 - 3\lambda}{4}\Pi_{sc}^{bc}$	$\Pi_r^c = \lambda\tau(\Pi_{wsc}^c - \Pi_{sc}^{bc}) + \Pi_r^{bc}$
Π_m^*	$\Pi_m^d = \frac{2}{b} q_d^2$	$\Pi_m^h = (1 - \lambda)\Pi_{sc}^h - \frac{1 - 3\lambda}{4}\Pi_{sc}^{bc}$	$\Pi_m^c = (1 - \lambda)\tau(\Pi_{wsc}^c - \Pi_{sc}^{bc}) + \Pi_m^{bc}$
Π_{sc}^*	$\Pi_{sc}^d = \frac{3}{b} q_d^2$	$\Pi_{sc}^h = \frac{1}{b} q_h^2$	$\Pi_{sc}^c = \tau\Pi_{wsc}^c + (1 - \tau)\Pi_{sc}^{bc}$
Π_{wss}^*	$\Pi_{wss}^d = \frac{4(\phi_d c)^2\{2\kappa - \phi_d c[d + (1 - \phi_d)bc]\}}{\{4\kappa - \phi_d c[d + (1 - \phi_d)bc]\}^2} q_d^2 - c_f$	$\Pi_{wss}^h = \frac{2(\phi_h c)^2\{\kappa - \phi_h c[d + (1 - \phi_h)bc]\}}{\{2\kappa - \phi_h c[d + (1 - \phi_h)bc]\}^2} q_h^2 - c_f$	$\Pi_{wss}^c = (1 - \tau)(\Pi_{wsc}^c - \Pi_{sc}^{bc})$
Π_{wsc}^*	$\Pi_{wsc}^d = \left\{\frac{3}{b} + \frac{4(\phi_d c)^2\{2\kappa - \phi_d c[d + (1 - \phi_d)bc]\}}{\{4\kappa - \phi_d c[d + (1 - \phi_d)bc]\}^2}\right\} q_d^2 - c_f$	$\Pi_{wsc}^h = \left\{\frac{1}{b} + \frac{2(\phi_h c)^2\{\kappa - \phi_h c[d + (1 - \phi_h)bc]\}}{\{2\kappa - \phi_h c[d + (1 - \phi_h)bc]\}^2}\right\} q_h^2 - c_f$	$\Pi_{wsc}^c = \frac{2b\kappa - (d + bc)^2}{2b^2\kappa} q_c^2 - c_f$
$SW*$	$SW_d = \left\{\frac{7}{2b} + \frac{4(\phi_d c)^2\{2\kappa - \phi_d c[d + (1 - \phi_d)bc]\}}{\{4\kappa - \phi_d c[d + (1 - \phi_d)bc]\}^2}\right\} q_d^2 + \frac{1}{2} g e_d^2 - c_f$	$SW_h = \left\{\frac{3}{2b} + \frac{2(\phi_h c)^2\{\kappa - \phi_h c[d + (1 - \phi_h)bc]\}}{\{2\kappa - \phi_h c[d + (1 - \phi_h)bc]\}^2}\right\} q_h^2 + \frac{1}{2} g e_h^2 - c_f$	$SW_c = \frac{3b\kappa - (d + bc)^2}{2b^2\kappa} q_c^2 + \frac{1}{2} g e_c^2 - c_f$
$CS*$	$CS_d = \frac{1}{2b} q_d^2$	$CS_h = \frac{1}{2b} q_h^2$	$CS_c = \frac{1}{2b} q_c^2$
ϕ_*	$(\phi_d c)^2[a - b(c_0 + ce_0)]^2 > 16\{2\kappa - \phi_d c[d + (1 - \phi_d)bc]\}c_f \ and \ \phi_d \in (0, 1)$	$(\phi_h c)^2[a - b(c_0 + ce_0)]^2 > 8\{\kappa - \phi_h c[d + (1 - \phi_h)bc]\}c_f \ and \ \phi_h \in (0, 1)$	$\phi_c = \frac{\kappa\{q_c^2 - b[\tau\Pi_{wsc}^c + (1 - \tau)\Pi_{sc}^{bc}]\}}{(d + bc)c q_c^2}$

supply chain decides the retail price and WSE. The two-stage bargaining game model can be formulated as follows:

$$\max_{w} \Psi(w) = [\Pi_r^c(w) - \Pi_r^{bc}]^{\lambda}[\Pi_m^c(w) - \Pi_m^{bc}]^{1-\lambda}$$

$$s.t. \begin{cases} \Pi_r^c(w) \geq \Pi_r^{bc} \\ \Pi_m^c(w) \geq \Pi_m^{bc} \\ \Pi_r^c(w) + \Pi_m^c(w) = \Pi_{sc}^c \\ s.t. \begin{cases} \max\limits_{\phi}\ \Omega(\phi) = [\Pi_{sc}^c(\phi) - \Pi_{sc}^{bc}]^{\tau}[\Pi_{wss}^c(\phi)]^{1-\tau} \\ s.t. \begin{cases} \Pi_{sc}^c(\phi) \geq \Pi_{sc}^{bc} \\ \Pi_{wss}^c(\phi) > 0 \\ \Pi_{sc}^c(\phi) + \Pi_{wss}^c(\phi) = \Pi_{wsc}^c \\ s.t. \begin{cases} p_c,\ e_c \text{ and } \Pi_{wsc}^c \text{ are derived from} \\ \text{solving the following problem} \\ \max\limits_{p,e}\ \Pi_{wsc}(p, e) \end{cases} \end{cases} \end{cases} \end{cases} \quad (12)$$

Solving this two-stage bargaining game, we obtain the equilibrium WSE e_c,wholesale price w_c, retail price p_c and ordering quantity q_c, and on this basis, we can get the equilibrium profits of the retailer, HWC manufacturer, HWC supply chain, WSS provider and WSS supply chain, the corresponding social welfare and consumer surplus (see Table 2 for the mathematical functions and see Appendix for their derivations).

Comparisons and discussion of analytical results

Based on the findings from previous analytical result comparisons in the Benchmark Scenario without WSS and the Scenario with WSS, the scenario with WSS outperforms that without WSS regarding profits, social welfare and consumer surplus. The corresponding remarks can be summarized as follows.

Remark 1. Only when the following three conditions hold: $\Pi_r^d(\phi) \geq \Pi_r^{bd}$, $\Pi_m^d(\phi) \geq \Pi_m^{bd}$, and $\Pi_{wss}^d(\phi) > 0$, would the HWC supply chain members have the economic motivation to introduce WSS and the WSS provider have the economic incentive to provide WSS, i.e. the reasonable interval of the revenue keeping rate ϕ_d *satisfies:*

$$(\phi_d c)^2[a - b(c_0 + ce_0)]^2 > 16\{2\kappa - \phi_d c[d + (1 - \phi_d)bc]\}c_f \text{ and } \phi_d \in (0, 1)$$

Remark 2. Only when the following three conditions hold: $\Pi_r^h(\phi) \geq \Pi_r^{bc}$, $\Pi_m^h(\phi) \geq \Pi_m^{bc}$, and $\Pi_{wss}^h(\phi) > 0$, would the HWC supply chain members have the economic motivation to introduce WSS and the WSS provider have the economic incentive to provide WSS, i.e. the reasonable interval of the revenue keeping rate ϕ_h satisfies:

$$(\phi_h c)^2[a - b(c_0 + ce_0)]^2 > 8\{\kappa - \phi_h c[d + (1 - \phi_h)bc]\}c_f \text{ and } \phi_h \in (0, 1)$$

Remark 3. Only when the following three conditions hold: $\Pi_r^c \geq \Pi_r^{bc}$, $\Pi_m^c \geq \Pi_m^{bc}$, and $\Pi_{wss}^c > 0$, would the HWC supply chain members have the economic motivation to introduce WSS and the WSS provider have the economic incentive to provide WSS, i.e., the following condition must hold:

$$(d + bc)^2[a - b(c_0 + ce_0)]^2 > 4b[2b\kappa - (d + bc)^2]c_f$$

In order to make the results comparable, the water-saving benefit sharing rate under the decentralized decision and hybrid decision can be set to equal that under the cooperative decision; that is, $\phi_d = \phi_c = \phi_h$, on the premise that the conditions mentioned in Remarks 1, 2 and 3 are satisfied. In the next section, the corresponding numerical and sensitivity analyses will be conducted on this basis.

NUMERICAL AND SENSITIVITY ANALYSES

Based on the actual characteristics of water-saving practices in high-water-consumption (HWC) industries, the relationships between the WSS provider, HWC manufacturer and retailer in the three-tier WSS supply chain are set to mimic the real-world case, and the values of parameters relating to the three-tier WSS supply chain are set for numerical analysis as follows: the raw material and manufacturing cost of the product c_0 is 50 Yuan/unit, the water consumption quantity per unit product e_0 is 8 m^3/unit, and the cost of unit water c is 3.0 Yuan/m^3, the cost coefficient of WSE κ is 5,000, and the fixed cost of water saving c_f is 2,000 Yuan. The positive externalities coefficient of water-saving effort g is 10,000. The choke quantity of product a is 50,000, the sensitivity coefficient of demand-price b is 500, the sensitivity coefficient of demand-WSE d is 10. The bargaining power of the retailer λ is 0.5, and the bargaining power of the HWC supply chain τ is 0.7. In order to make the results comparable, the water-saving benefit sharing rate ϕ under the decentralized decision and hybrid decision are set to equal that under the cooperative decision. It should be noted that the conditions mentioned in Remarks 1, 2 and 3 are satisfied for these parameter settings. Based on the above parameter settings, the numerical and sensitivity analyses will be conducted in Numerical analysis and Sensitivity analysis.

Numerical analysis

Results from the numerical analysis of the game-theoretical decision models for the WSS supply chain under the scenario with/without WSS (Table 3) show the following.

(1) Comparing the numerical results between the decentralized decision and the cooperative decision under the benchmark scenario without WSS, (i) the wholesale price under the cooperative decision is lower than that under the decentralized decision; (ii) the retail price under the cooperative decision is lower than that under the decentralized decision; (iii) the ordering quantity under the cooperative decision is higher than that under the decentralized decision; (iv) the profits of the supply chain and its members under the cooperative decision are higher than those under the decentralized decision; (v) the social welfare under the cooperative decision is higher than that under the decentralized decision; (vi) the consumer surplus under the cooperative decision is higher than that under the decentralized decision.

(2) Comparing the numerical results among the decentralized decision, the hybrid decision and the cooperative decision under the scenario with WSS, (i) the WSE under the cooperative decision is higher than that under the hybrid decision, and the WSE under the hybrid decision is higher than that under the decentralized decision; (ii) the wholesale price under the cooperative decision is lower than that under the hybrid decision, and the wholesale price under the hybrid decision is lower than that under the decentralized decision; (iii) the retail price under the cooperative decision is lower than that under the hybrid decision, and the retail price under the hybrid decision is lower than that under the decentralized decision; (iv) the ordering quantity under the cooperative decision is higher than that under the hybrid decision, and the ordering quantity under the hybrid decision is higher than that under the decentralized decision; (v) the profits of the WSS supply chain and its members under the cooperative decision are higher than those under the hybrid decision, and the profits of the WSS supply chain and its members

Table 3 | Numerical results of game-theoretical decision models

	Scenario without WSS		Scenario with WSS		
Scenario	Decentralized decision	Cooperative decision	Decentralized decision	Hybrid decision	Cooperative decision
e^*	NA	NA	1.30	2.96	7.22
w^*	87.00	82.13	86.22	79.21	71.58
p^*	93.50	87.00	93.12	85.21	76.25
q^*	3,250.00	6,500.00	3,451.98	7,422.61	11,948.97
Π_r^*	21,125	31,688	23,832	44,533	55,780
Π_m^*	42,250	52,813	47,665	65,658	76,905
Π_{sc}^*	63,375	84,500	71,497	110,190	132,686
Π_{wss}^*	NA	NA	1,732	15,045	20,651
Π_{wsc}^*	NA	NA	73,229	125,235	153,337
SW^*	73,938	126,750	93,536	224,098	556,553
CS^*	10,563	42,250	11,916	55,095	142,778
ϕ^*	NA	NA	0.59	0.59	0.59

under the hybrid decision are higher than those under the decentralized decision; (vi) the social welfare under the cooperative decision is higher than that under the hybrid decision, and the social welfare under the hybrid decision is higher than that under the decentralized decision; (vii) the consumer surplus under the cooperative decision is higher than that under the hybrid decision, and the consumer surplus under the hybrid decision is higher than that under the decentralized decision.

(3) Be it under the decentralized decision or cooperative decision, comparing the numerical results under the scenario with WSS with those under the benchmark scenario without WSS, (i) the wholesale price under the scenario with WSS is lower than that under the benchmark scenario without WSS; (ii) the retail price under the scenario with WSS is lower than that under the benchmark scenario without WSS; (iii) the ordering quantity under the scenario with WSS is higher than that under the benchmark scenario without WSS; (iv) the profits of the WSS supply chain and its members under the scenario with WSS are higher than those under the benchmark scenario without WSS; (v) the social welfare under the scenario with WSS is higher than that under the benchmark scenario without WSS; (vi) the consumer surplus under the scenario with WSS is higher than that under the benchmark scenario without WSS.

Sensitivity analysis

Since the scenario with WSS outperforms the scenario without WSS in terms of the profits and social welfare, and the key parameters regarding water-saving management have important effects on the operational decisions and outcomes of the three-tier WSS supply chain, the sensitivity analysis will focus on the impacts of the following two key parameters on profits and social welfare under the scenario with WSS: (1) the cost coefficient of water-saving effort (κ); (2) the fixed cost of water saving (c_f). The incremental scale and range of each parameter are listed in Table 4.

The sensitivity analysis results under the scenario with WSS (see Figure A1 and Figure A2 in the Appendix) show the following.

Table 4 | Ranges of key parameters for sensitivity analysis

Parameters	Original value	± Increment	Range
κ Cost coefficient of water-saving effort	5,000	50	[5,000, 10,000]
c_f Fixed cost of water saving	2,000	500	[1,000, 30,000]

The impact of the cost coefficient of water-saving effort (κ)

(1) As the cost coefficient of water-saving effort increases, the profits of the WSS supply chain and its members decrease, the social welfare decreases, and the benefit sharing rate increases.

(2) As the cost coefficient of the water-saving effort increases, the profits of the WSS supply chain and its members under cooperative decision are higher than those under hybrid decision, and the profits of the WSS supply chain and its members under hybrid decision are higher than those under decentralized decision.

(3) As the cost coefficient of water-saving effort increases, the social welfare under cooperative decision is higher than that under hybrid decision, and the social welfare under hybrid decision is higher than that under decentralized decision.

The impact of the fixed cost of water saving (c_f)

(1) As the fixed cost of water saving increases, the profits of the WSS supply chain and its members decrease, the social welfare decreases, and the benefit sharing rate increases.

(2) As the fixed cost of water saving increases, the profits of the WSS supply chain and its members under cooperative decision are higher than those under hybrid decision, and the profits of the WSS supply chain and its members under hybrid decision are higher than those under decentralized decision.

(3) As the fixed cost of water saving increases, social welfare under cooperative decision is higher than that under hybrid decision, and social welfare under hybrid decision is higher than that under decentralized decision.

MANAGERIAL INSIGHTS AND POLICY RECOMMENDATIONS

Managerial insights

Based on the results from analytical and numerical analysis of all game-theoretical decision models under the scenario without/with WSS, the following managerial insights can be summarized.

First, if WSS is not introduced into the HWC supply chain, compared with the decentralized decision, the cooperative decision via Nash bargaining mechanism could effectively improve the operational performance of the HWC supply chain and its members and boost the social welfare and consumer surplus. Hence, all the stakeholders in the HWC supply chain would have the economic incentive to adopt the cooperative strategy.

Second, if WSS is introduced into the HWC supply chain and a three-tier WSS supply chain is thus formed, compared with the decentralized decision and hybrid decision (partial cooperative decision), the cooperative decision could effectively enhance WSE, improve the operational performance of the WSS supply chain and its members, and boost the social welfare and consumer surplus. Hence, perfect cooperation among the retailer, the HWC manufacturer and the WSS provider is the best strategy for the WSS supply chain, and all the stakeholders in the WSS supply chain would have the economic incentive to adopt the cooperative strategy.

Third, if WSS is introduced into the HWC supply chain and a three-tier WSS supply chain is thus formed, compared with the decentralized decision, the hybrid decision (partial cooperative decision), could effectively enhance the WSE, improve the operational performance of the WSS supply chain and its members, and boost the social welfare and consumer surplus. Hence, if perfect cooperation within the WSS supply chain cannot be achieved, the hybrid strategy (partial cooperative strategy) between the retailer and HWC manufacturer within the HWC supply chain is the second-best strategy for the WSS supply chain, and all the stakeholders in the WSS supply chain would have the economic incentive to adopt a partial cooperative strategy.

Fourth, be it under the decentralized decision, hybrid decision (partial cooperative decision) or cooperative decision, compared with the scenario without WSS, seeking WSS from WSS provider and adopting water-saving solutions in the manufacturing process could effectively enhance the WSE, improve the operational performance of the WSS supply chain and its members, and boost the social welfare and consumer surplus under the scenario with WSS. As a result, all the stakeholders in the WSS supply chain would have the economic incentive to seek WSS and conduct water-saving solutions. WSS brings great benefit to the HWC supply chain.

Finally, be it under the decentralized decision, hybrid decision (partial cooperative decision) or cooperative decision, reducing the cost of WSE and the fixed cost of water saving could effectively enhance the water consumption reduction, improve the operational performance of the WSS supply chain and its members, boost the social welfare and consumer surplus under the scenario with WSS.

In sum, water saving service (WSS) with appropriate effect and cost is highly recommended for enhancing water consumption reduction in the HWC supply chain. The cooperative strategy is the best strategy and the hybrid strategy (partial cooperative strategy) is the second-best strategy regarding operational performance, social welfare and consumer surplus for the three-tier WSS supply chain.

Policy recommendations

From the perspective of governance, the following policy initiatives are recommended for relative governments.

First, stricter regulations for water consumption and water conservation for HWC industries should be formulated. Effective scientific policy and institution and technical standards for contracted water-saving management should be established and improved. Advanced and applicable water-saving technologies, processes, equipment and products should be comprehensively applied on a large scale.

Second, WSS enterprises with professional technology and strong financing ability should be cultivated, supported and expanded, corresponding fiscal and tax policy support should be strengthened, and even appropriate subsidy policies can be established and implemented according to the practical situation.

Third, HWC industries (such as steel, textile printing and dyeing, paper making, chemical industry, leather, etc.), HWC services (such as golf courses, car washes, artificial snow ski resorts, catering, hotels, etc.), HWC agriculture, and even public institutions and buildings should be encouraged to introduce WSS and sign WSS contracts with WSS providers/enterprises to promote contracted water-saving management.

Finally, the competition order in the WSS market should be regulated and the development environment of WSS industry should be further optimized, to gradually improve water efficiency and efficiency, and promote the rapid and healthy development of the WSS industry.

Overall, the regulations for contracted water-saving management should be established and tightened, the WSS providers/enterprises should be cultivated and supported, HWC industries should be encouraged to promote the contracted water-saving management mechanism, and the corresponding competition order and development environment should be regulated and improved.

CONCLUSIONS

As water resources become increasingly scarce, high-water-consumption (HWC) supply chains are under great pressure to reduce water consumption in their product manufacturing process. To solve this issue, water-saving service (WSS) and corresponding water-saving management contract come into being. In this background, the decentralized and cooperative decision models for the HWC supply chain under the benchmark scenario without WSS, and the decentralized, hybrid and cooperative decision models for the three-tier WSS supply chain under the scenario with WSS are developed and analyzed, corresponding numerical and sensitivity analyses for all models are conducted and compared, and finally, the managerial insights are summarized in this article. Results from the research indicate that: (1) introducing WSS could effectively improve the operational performance, social welfare and consumer surplus for the HWC supply chain. (2) cooperative strategy could effectively improve the operational performance, social welfare and consumer surplus, and is the best strategy for the three-tier WSS supply chain. (3) if perfect cooperation within the three-tier WSS supply chain cannot be achieved, the hybrid strategy (partial cooperative strategy) could effectively improve the operational performance, social welfare and consumer surplus, and is the second-best strategy for the three-tier WSS supply chain. (4) reducing the costs of water saving could effectively enhance the water consumption reduction, improve the operational performance, social welfare and consumer surplus for the three-tier WSS supply chain.

In terms of theoretical contribution, the available literature rarely touches upon the value of water-saving service (WSS) for the sustainability of high-water-consumption (HWC) supply chain. This study designed a novel and useful game-theoretical approach to investigate the adoption decisions of WSS in an HWC supply chain, discuss the effect of WSS adoption on the water consumption reduction and corresponding social welfare improvement in an HWC supply chain, and compare the operational strategies for the three-tier WSS supply chain. This study has not only addressed the research gap in the area of WSS supply chain operations management but also enriched the theory of resources-/energy-saving supply chain management.

With regard to practical contribution, the modeling and numerical results provide guidelines and insights for the three-tier WSS supply chain stakeholders to make better supply chain strategy choices and related optimal/equilibrium decisions concerning water-saving effort (WSE), pricing and production, which will, in turn, improve operational performance, social welfare and consumer surplus, bringing benefit to the economy, the society and the ecological environment.

Due to limited research funds and time constraints, the following areas are not adequately addressed in this research, which leaves room for further research in the future. First, the empirical data may be collected from a pure real-world case to investigate the adopting decision of WSS, the effect of WSS adoption and corresponding operational strategies for the three-tier WSS supply chain. Second, the value of WSS for the sustainability and competitivity of dual/multiple competing HWC supply chains can be explored via game-theoretical approach. Third, government's subsidy policy design for water-saving effort in the three-tier WSS supply chain also deserve further discussion. All these can be covered in our future research.

SUPPLEMENTARY MATERIAL

The Supplementary Material for this paper is available online at https://dx.doi.org/10.2166/ws.2020.112.

ACKNOWLEDGEMENTS

This work is supported by the National Natural Science Foundation of China (71603125), China Scholarship Council (201706865020), Project funded by Social Science Foundation of Jiangsu Province (19GLC003), Project funded by China Postdoctoral Science Foundation (2019M651833), the National Key R&D Program of China (2017YFC0404600), the Natural Science Research Project of Colleges and Universities in Jiangsu Province (15KJB110012), the Key project of Social Science Foundation of Jiangsu Province (18EYA002), Young Leading Talent Program of Nanjing Normal University.

REFERENCES

Amit, R. K. & Ramachandran, P. 2010 A fair contract for managing water scarcity. *Water Resources Management* **24** (6), 1195–1209.

Chen, Z. & Wang, H. 2019 Water-saving service supply chain cooperation under social welfare maximization. *Journal of Water and Climate Change*. https://doi.org/10.2166/wcc.2019.188.

Chen, Z., Fang, L. & Wang, H. 2019 Internal incentives and operations strategies for the water-saving supply chain with cap-and-trade regulation. *Frontiers of Engineering Management* **6** (1), 87–101.

Chhipi-Shrestha, G., Rodriguez, M. & Sadiq, R. 2019 Selection of sustainable municipal water reuse applications by multi-stakeholders using game theory. *Science of The Total Environment* **650**, 2512–2526.

China state council 2012 State Council's Opinion on 'Implementing the Most Stringent Water Resources Management System' *(State Council [2012], No. 3) [EB/OL]*. Available from: http://www.gov.cn/zwgk/2012-02/16/content_2067664.htm (accessed 23 February 2020).

Corbett, C. J. & Decroix, G. A. 2001 Shared-savings contracts for indirect materials in supply chains: channel profits and environmental impacts. *Management Science* **47** (7), 881–893.

Corbett, C. J., Decroix, G. A. & Ha, A. Y. 2005 Optimal shared-savings contracts in supply chains: linear contracts and double moral hazard. *European Journal of Operational Research* **163** (3), 653–667.

Garrone, P., Grilli, L. & Marzano, R. 2020 Incentives to water conservation under scarcity: comparing price and reward effects through stated preferences. *Journal of Cleaner Production*. https://doi:10.1016/j.jclepro.2019.118632.

Gilg, A. & Barr, S. 2006 Behavioural attitudes towards water saving? Evidence from a study of environmental actions. *Ecological Economics* **57** (3), 400–414.

Hafezalkotob, A. 2018 Modelling intervention policies of government in price-energy saving competition of green supply chains. *Computers & Industrial Engineering* **119**, 247–261.

Llanos, E. J., Barroso, P. D. & Ramírez, R. R. 2020 Analysis of consumer awareness of sustainable water consumption by the water footprint concept. *Science of the Total Environment*. https://doi.org/10.1016/j.scitotenv.2020.137743.

Madani, K. 2010 Game theory and water resources. *Journal of Hydrology* **381** (3–4), 225–238.

Marshall, A. 1890 *Principles of Economics*. Macmillan, London. 1890 (1st edn.), 1920 (8th edn).

NDRC and Ministry of water resources 2019 *'National Water-Saving Action Plan' (NDRC [2019], No. 695) [EB/OL]*. Available from: https://www.ndrc.gov.cn/xxgk/zcfb/ghxwj/201904/t20190418_960963.html (accessed 23 February 2020).

NDRC (National Development and Reform Commission) 2016 *The Advice on 'Promoting Water-Saving Management Contract and Promoting the Development of Water-Saving Service Industry'(NDRC [2016], No. 1629) [EB/OL]*. Available from: http://www.gov.cn/xinwen/2016-08/04/content_5097640.htm (accessed 23 February 2020).

Nikouei, A., Zibaei, M. & Ward, F. A. 2012 Incentives to adopt irrigation water saving measures for wetlands preservation: an integrated basin scale analysis. *Journal of Hydrology* **464–465**, 216–232.

Novak, J., Melenhorst, M., Micheel, I., Pasini, C., Fraternali, P. & Rizzoli, A. E. 2018 Integrating behavioural change and gamified incentive modelling for stimulating water saving. *Environmental Modelling and Software* **102**, 120–137.

Ørum, J. E., Boesen, M. V., Jovanovic, Z. & Pedersen, S. M. 2010 Farmers' incentives to save water with new irrigation systems and water taxation-a case study of Serbian potato production. *Agricultural Water Management* **98** (3), 465–471.

Varouchakis, E. A., Apostolakis, A., Siaka, M., Vasilopoulos, K. & Tasiopoulos, A. 2018 Alternatives for domestic water tariff policy in the municipality of Chania. *Greece, Toward Water Saving Using Game Theory. Water Policy* **20** (1), 175–188.

WWAP (United Nations World Water Assessment Programme) 2015 *The United Nations World Water Development Report 2015: Water for A Sustainable World*. UNESCO (United Nations Educational, Scientific and Cultural Organization), Paris.

Xie, G. 2015 Modelling decision processes of a green supply chain with regulation on energy saving level. *Computers & Operations Research* **54**, 266–273.

Xin, B. & Sun, M. 2018 A differential oligopoly game for optimal production planning and water savings. *European Journal of Operational Research* **269** (1), 206–217.

Yi, Y. & Li, J. 2018 Cost-Sharing contracts for energy saving and emissions reduction of a supply chain under the conditions of government subsidies and a carbon tax. *Sustainability* **10** (3), 895.

Zhou, W. & Huang, W. 2016 Contract designs for energy-saving product development in a monopoly. *European Journal of Operational Research* **250** (3), 902–913.

Zhou, W., Huang, W. & Zhou, S. 2017 Energy performance contracting in a competitive environment. *Decision Sciences* **48** (4), 723–765.

First received 26 March 2020; accepted in revised form 15 May 2020. Available online 28 May 2020