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RESEARCH ARTICLE

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Internal incentives and operations strategies for the water-saving supply chain with cap-and-trade regulation

Abstract Faced with the rapid development of modern industries of agriculture, manufacturing, and services, water resources are becoming increasingly scarce. Industries with high water consumption are generally regulated by the government's water cap-and-trade (CAT) regulation to solve the contradiction between the limited water supply and the rapid growing water demand. Supply chain equilibrium and coordination models under the benchmark scenario without water saving and CAT regulation, water-saving supply chain equilibrium and coordination models under the scenario without/with CAT regulation are developed, analyzed and compared. The corresponding numerical and sensitivity analyses for all models are conducted and compared, and the managerial insights and policy recommendations are summarized in this article. The results indicate that (1) Conducting water saving could improve effectively the operational performance of the water-saving supply chain under the scenario without/with CAT regulation. (2) The coordination strategy based on the revenue sharing contract could efficiently coordinate the water-saving supply chain, enhance water consumption reduction rate, and improve the operational performance of the water-saving supply chain. (3) The implementation of CAT regulation enhances effectively water-consumption-reduction in the water-saving supply chain and improves the operational performance of water-saving supply chain. (4) Simultaneous implementation of CAT regulation by the government and adopting coordination strategy by the water-saving supply chain would be superior to any other scenarios/strategies. (5) A suitable water cap based on the industrial average water consumption and historical water consumption data are beneficial for constructing reasonable and effective incentive mechanism. (6) A higher marginal trade price could induce more reduction in water consumption and create better operational performance for the manufacturer and water-saving supply chain, both under the equilibrium and coordination strategies.

Keywords water-saving supply chain, equilibrium, coordination, internal incentive, cap and trade regulation

1 Introduction

In the context of global climate change and the rapid increase in population and in the face of the fast development of modern industries, water resources are becoming increasingly scarce. The World Water Resources Development Report pointed out that global water abuse in recent years has been very serious, and the global water shortage is estimated to be as high as 40 percent by 2030 based on current water use ratio (WWAP, 2015). In many

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developing countries, the extensive development mode has brought about serious waste of water resources and high consumption of water resources. For example, the utilization coefficient of agricultural irrigation water in China is about half of the international advanced level, the water consumption per 10,000 CNY industry gross production value in China is 10 times that of international advanced level, and the water consumption per 10,000 CNY GDP in China is four times the world average (Shang et al., 2008; Khatib, 2015). As the rapid development poses increasing demand on the capacity of water resources, various water resources saving/conservation plans and schemes for industrial, agricultural, and municipal users have been launched from the perspective of sustainable development in many countries in the world. In China, the "implementing the most stringent water resources management system" regulation was issued by the China State Council in 2012. Under this regulation, the scale of industries and cities will be developed under a water resources cap, and a water-saving/conservation society will be built.

Currently, manufacturers in industries with high water consumption, such as steel, washing, printing and dyeing, leather, coal chemical, are generally regulated by the government's cap-and-trade (CAT) regulation. These manufacturers, whose product-manufacturing process requires the input of water resources, are generally allocated a certain water resources cap at a normal price by the government. The actual water consumption quantity may be more or less than the cap. If the total water consumption quantity is more than the water resources cap, industrial water users can buy the extra water demand quantity from the water trading market for an extra fee. On the contrary, if the total water consumption quantity is less than the water resources cap, the industrial water users can sell the extra quantity to the water trading market for a salvage value. Obviously, these manufacturers have external pressure and internal incentive to reduce water consumption in the product manufacturing process to reduce the cost of water input and improve the benefits of water saving. Furthermore, products with lower water consumption are often more favored by environment-friendly customers. Thus, retailers of these products would hope the manufacturers will provide lower-water-consumption products. These manufacturers also have supply-chain driving force to reduce water consumption in the product-manufacturing process. Based on the foregoing motivations, the manufacturers in the industries of high-water-consumption would input funds, personnel and water-saving facilities and equipment to reduce the water consumption in the product-manufacturing process. Hence, when will these manufacturers have internal incentives to reduce the water consumption in the scene of supply chain, how much effort should these manufacturers input to reduce the water consumption in the scene of supply chain, what kind of operations strategy should be adopted for the water-saving supply chain, and what is the effect of CAT regulation on the water-saving supply chain, are major issues that need to be resolved in the operations of water-saving supply chain.

Therefore, the issues of water-saving supply chain equilibrium and coordination with CAT regulation will be investigated in this paper. The supply chain models under the benchmark scenario without water saving and CAT regulation, the water-saving supply chain models under the scenario without/with CAT regulation are developed, analyzed and compared respectively, the corresponding numerical and sensitivity analysis for all models are conducted and compared, and the managerial insights and policy recommendations are summarized in this paper.

2 Literature review

Water-saving, especially self-water-saving, in industries and their supply chains, is vital for the reduction of water resources cost and the improvement of comprehensive water resources efficiency, which have important economic, social, and ecological benefits for the sustainable development of whole society. Internal incentives and operations strategies are key issues of water-saving from the perspective of supply chain. However, literature pertaining to the internal incentives and operations strategies for the water-saving supply chain from the game-theoretical perspective remains scarce.

Available literature regarding the water-saving focus mainly on water saving quantification (Zhang and Guo, 2016), institutional incentive of water conservation (Nikouei et al., 2012), economic incentive to use water saving systems (Ørum et al., 2010), water-conservation risk behaviors and evolution processes (Liu et al., 2014), water-saving effect (Peterson and Ding, 2005), water-saving attitude and behavior (Gilg and Barr, 2006) and water-conservation environmental impact and resources efficiency in project (Lu and Shang, 2014).

After a basic understanding of water-saving, some scholars began to use professional algorithms and models to design, optimize, and evaluate water-saving activities, such as the behavior change and incentive model for water saving (Novak et al., 2018), the optimization model for improved IWRM system that considers water conservation (Gao et al., 2014), the freshwater consumption reduction via optimal dyeing production schedule (Zhou et al., 2017), the sustainable water management method for agricultural water-saving(Hu et al., 2010), water saving evaluation methodology (Campisano et al., 2017), and the economic impact of water saving on the wastewater reclamation system via CGE model (Luckmann et al., 2016).

Some studies regarding water-saving have used the game theory. For example, Varouchakis et al. (2018)

proposed a game model between the water enterprise and residents to explore the water tariff policy of motivating residents toward water saving. Xin and Sun (2018) studied the dual-decision of production planning and water saving based on the differential oligopoly game and investigated the effect of competition on the social welfare.

Nevertheless, existing studies rarely touch upon the internal incentives and operational strategies issues of water-saving supply chain with CAT ragulation: (1) the internal incentive of conducting water-saving in the scene of supply chain based on the game theory; (2) the effect of CAT on water saving and the operational performance of water-saving supply chain; and (3) the optimal operations strategies for the water saving supply chain. In the face of these research shortcomings identified in existing literature, a decentralized decision model and a coordination model based on the revenue-sharing contract for the water-saving supply chain are developed and analyzed to investigate the internal incentive and operations strategies in the water-saving supply chain.

3 Notation and overview of a stylized water-saving supply chain

A stylized water-saving supply chain generally consists of a water-saving manufacturer and a retailer. The water-saving manufacturer, whose product-manufacturing process requires the input of water resources, is allocated a certain water resources cap by the government in the arid or semi-arid area. The actual water consumption quantity may be more or less than the cap. If the total water consumption quantity is more than the water resources cap, the manufacturer can buy the extra demand from the water trading market for an extra fee. On the contrary, if the total water consumption quantity is less than the water resources cap, the water user can sell the extra quantity to the water trading market for a salvage value. Obviously, the manufacturer has the internal incentive to reduce water consumption in the product manufacturing process to cut the cost of water input and increase the benefit of water saving.

On this basis, the following parameters and assumptions are provided for further model formulation: raw material and manufacturing cost of product is c_0; water consumption quantity per unit product is e_0 (can be seen as the water saving reference point); cost of unit water is c; wholesale price of the product is w; retail price of the product is p; and water consumption reduction rate (water-saving effort) is r, and $r \in (0,1)$. 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 and Li, 2018), quadratic cost function of water saving (Xin and Sun, 2018). Following Xin and Sun (2018), the cost of water saving for the manufacturer is assumed to be a quadratic form: $c(r)=\frac{1}{2}\kappa r^2$, and the fixed cost of water-saving is c_f. The demand function of the product is assumed to be in linear form, $q(p,r)=a-bp+dr$, where a is the choke quantity of product; b is the price impact coefficient of the ordering quantity (demand), and d is the water-consumption-reduction rate (water-saving effort) impact coefficient of the ordering quantity (demand). Under CAT regulation (Ji et al., 2017; Xu et al., 2017a, 2017b), the manufacturer is allocated a water cap $\overline{e}$. If the total water consumption is more than the cap, i.e., $[e_0(1-r)]q>\overline{e}$, the water user can buy the extra demand from the water trading market for an extra fee $l\{[e_0(1-r)]q-\overline{e}\}$ and if the total water consumption is less than the cap, i.e., $[e_0(1-r)]q<\overline{e}$, the water user can sell the extra quantity to the water trading market for a salvage value $l\{\overline{e}-[e_0(1-r)]q\}$. In this scenario, l is the marginal trading price of extra water demand or extra water quantity. The condition $2b\kappa>[d+b(c+l)e_0]^2$ should also hold.

Based on the foregoing settings, the profit functions of the retailer, water-saving manufacturer and water-saving supply chain under CAT regulation can be formulated as follows:

$$\Pi_r^t(p)=(p-w)q(p,r), \tag{1}$$

$$\Pi_m^t(w,r)=[w-c_0-ce_0(1-r)]q(p,r)-\frac{1}{2}\kappa r^2-c_f-l[e_0(1-r)q(p,r)-\overline{e}], \tag{2}$$

$$\Pi_{sc}^t(p,r)=[p-c_0-ce_0(1-r)]q(p,r)-\frac{1}{2}\kappa r^2-c_f-l[e_0(1-r)q(p,r)-\overline{e}]. \tag{3}$$

4 Water-saving supply chain equilibrium and coordination models with CAT regulation

4.1 Benchmark scenario without water saving and CAT regulation

To investigate the internal incentive of conducting self-water-saving, analysis of the benchmark scenario of a supply chain without water-saving and CAT regulation is conducted, i.e., $d=0$, $\kappa=0$, $r=0$, $c_f=0$, $l=0$. The equilibrium decision and coordination decision models of the supply chain are developed and analyzed in this section (superscript b: benchmark scenario, superscript or subscript d: equilibrium decision, superscript or subscript c: coordination decision).

4.1.1 Supply chain equilibrium without water-saving and CAT regulation

In the supply chain without water-saving and CAT regulation, the optimal problem for the retailer is as follows:

$$\max_{p}\ \Pi_r(p)=(p-w)q(p). \tag{4}$$

Solving this optimal problem, we can obtain the reaction functions $p_d^b(w)$ and $q_d^b(w)$ as follows:

$$p_d^b(w)=\frac{1}{2b}(a+bw), \tag{5}$$

$$q_d^b(w)=\frac{1}{2}(a-bw). \tag{6}$$

Plugging $q_d^b(w)$ into the manufacturer's profit function, we can obtain the optimal problem for the manufacturer as follows:

$$\max_{w}\ \Pi_m(w)=(w-c_0-ce_0)q_d(w). \tag{7}$$

Solving the optimal problem, we can obtain the equilibrium wholesale price w_d^b as follows:

$$w_d^b=\frac{1}{2b}[a-b(c_0+ce_0)]+(c_0+ce_0). \tag{8}$$

Plugging w_d^b into $p_d^b(w)$ and $q_d^b(w)$, we can obtain the equilibrium retail price p_d^b and ordering quantity q_d^b as follows:

$$p_d^b=\frac{3}{4b}[a-b(c_0+ce_0)]+(c_0+ce_0), \tag{9}$$

$$q_d^b=\frac{1}{4}[a-b(c_0+ce_0)]. \tag{10}$$

Then, we can obtain the equilibrium profits of retailer Π_r^{bd}, manufacturer Π_m^{bd} and supply chain Π_{sc}^{bd} as follows:

$$\Pi_r^{bd}=\frac{1}{b}(q_d^b)^2, \tag{11}$$

$$\Pi_m^{bd}=\frac{2}{b}(q_d^b)^2, \tag{12}$$

$$\Pi_{sc}^{bd}=\frac{3}{b}(q_d^b)^2. \tag{13}$$

4.1.2 Supply chain coordination without water-saving and CAT regulation

The optimal problem of the centralized supply chain without water-saving and CAT regulation is as follows:

$$\max_{p}\ \Pi_{sc}(p)=(p-c_0-ce_0)q(p). \tag{14}$$

Solving this optimal problem, we can obtain the optimal retail price p_c^b as follows:

$$p_c^b=\frac{1}{2b}[a-b(c_0+ce_0)]+(c_0+ce_0). \tag{15}$$

Plugging p_c^b into $q(p)$, we can obtain the optimal ordering quantity q_c^b as follows:

$$q_c^b=\frac{1}{2}[a-b(c_0+ce_0)]. \tag{16}$$

Then, we can obtain the optimal profit of the supply chain Π_{sc}^{bc} as follows:

$$\Pi_{sc}^{bc}=\frac{1}{b}(q_c^b)^2. \tag{17}$$

In the supply chain coordination model, the retailer will share a proportion $(1-\phi)$ of her revenue to the manufacturer and $\phi\in(0,1)$. On the premise of the optimal retail price p_c^b, the manufacturer will determine the wholesale price of the product w_c^b to achieve supply chain coordination. Hence, the retailer's transfer payment to the manufacturer is as follows:

$$T=(1-\phi)pq(p). \tag{18}$$

The retailer's and manufacturer's profit functions are as follows:

$$\Pi_m^{bc}(w)=(w-c_0-ce_0)q(p)+T, \tag{19}$$

$$\Pi_r^{bc}(p)=(p-w)q(p)-T. \tag{20}$$

Solving the retailer's optimal problem, we can obtain the reaction function $p_d^b(w)$ as follows:

$$p_d^b(w)=\frac{1}{2b}a+\frac{1}{2\phi}w. \tag{21}$$

The coordination condition $p_d^b(w)=p_c^b$ must hold to coordinate the supply chain. Then, we can obtain the coordination wholesale price for the manufacturer as follows:

$$w_c^b=\phi(c_0+ce_0). \tag{22}$$

We can obtain the optimal profit of supply chain, coordinated profits of the retailer, and manufacturer as follows:

$$\Pi_r^{bc}=\phi\Pi_{sc}^{bc}, \tag{23}$$

$$\Pi_m^{bc}=(1-\phi)\Pi_{sc}^{bc}. \tag{24}$$

Remark 1: Only when the following two conditions hold $\Pi_r^{bc}\geqslant\Pi_r^{bd}$, $\Pi_m^{bc}\geqslant\Pi_m^{bd}$, would the water-saving supply chain members have the economic motivation to coordinate; that is, the reasonable interval of the revenue keeping rate is $\phi_b \in \left[\frac{1}{4},\frac{1}{2}\right]$.

4.2 Scenario without CAT regulation

To investigate the effect of CAT regulation on the optimal/equilibrium decisions and profits in the water-saving supply chain, analysis of water-saving supply chain without CAT regulation is conducted, i.e., $l=0$. The equilibrium decision and coordination decision models of water-saving supply chain are developed and analyzed (superscript or subscript d: equilibrium decision, superscript or subscript c: coordination decision).

4.2.1 Water-saving supply chain equilibrium without CAT regulation

In the water-saving supply chain without CAT regulation, the optimal problem for the retailer is as follows:

$$\max_{p}\ \Pi_r(p) = (p-w)q(p,r). \tag{25}$$

Solving the optimal problem, we can obtain the reaction functions as follows:

$$p_d(w,r) = \frac{1}{2b}(a+bw+dr), \tag{26}$$

$$q_d(w,r) = \frac{1}{2}(a-bw+dr). \tag{27}$$

Plugging $q_d(w,r)$ into the profit function of water-saving manufacturer, we can obtain the optimal problem for the water-saving manufacturer as follows:

$$\max_{w,r}\ \Pi_m(w,r) = [w-c_0-ce_0(1-r)]q_d(w,r)-\frac{1}{2}\kappa r^2-c_f. \tag{28}$$

Solving this optimal problem, when condition $4b\kappa > (d+bce_0)^2$ holds, we can obtain the equilibrium water-consumption-reduction rate r_d and the equilibrium wholesale price w_d as follows:

$$r_d = \frac{(bce_0+d)[a-b(c_0+ce_0)]}{4b\kappa-(d+bce_0)^2}, \tag{29}$$

$$w_d = \frac{2\kappa-(d+bce_0)ce_0}{4b\kappa-(d+bce_0)^2}[a-b(c_0+ce_0)]+(c_0+ce_0). \tag{30}$$

Plugging r_d and w_d into $p_d(w,r)$ and $q_d(w,r)$, we can obtain the equilibrium retail price p_d and the equilibrium ordering quantity q_d as follows:

$$p_d = \frac{3\kappa-(d+bce_0)ce_0}{4b\kappa-(d+bce_0)^2}[a-b(c_0+ce_0)]+(c_0+ce_0), \tag{31}$$

$$q_d = \frac{b\kappa[a-b(c_0+ce_0)]}{4b\kappa-(d+bce_0)^2}. \tag{32}$$

We can then obtain the equilibrium profits of the retailer, the water-saving manufacturer, and the water saving supply chain as follows:

$$\Pi_r^d = \frac{1}{b}q_d^2, \tag{33}$$

$$\Pi_m^d = \frac{4b\kappa-(d+bce_0)^2}{2b^2\kappa}q_d^2-c_f, \tag{34}$$

$$\Pi_{sc}^d = \frac{6b\kappa-(d+bce_0)^2}{2b^2\kappa}q_d^2-c_f. \tag{35}$$

4.2.2 Water-saving supply chain coordination without CAT regulation

The optimal problem of the centralized water-saving supply chain is as follows:

$$\max_{p,r}\ \Pi_{sc}(p,r) = [p-c_0-ce_0(1-r)]q(p,r)-\frac{1}{2}\kappa r^2-c_f. \tag{36}$$

Solving this optimal problem, when the condition $2b\kappa > (d+bce_0)^2$ holds, we can obtain the optimal retail price p_c and the optimal water-consumption-reduction rate r_c as follows:

$$p_c = \frac{\kappa-(d+bce_0)ce_0}{2b\kappa-(d+bce_0)^2}[a-b(c_0+ce_0)]+(c_0+ce_0), \tag{37}$$

$$r_c = \frac{(d+bce_0)[a-b(c_0+ce_0)]}{2b\kappa-(d+bce_0)^2}. \tag{38}$$

Plugging r_c and p_c into $q(p,r)$, we can obtain the optimal ordering quantity q_c as follows:

$$q_c = \frac{b\kappa[a-b(c_0+ce_0)]}{2b\kappa-(d+bce_0)^2}. \tag{39}$$

We can then obtain the optimal profit of the water saving supply chain Π_{sc}^c as follows:

$$\Pi_{sc}^{c}=\frac{2b\kappa-(d+bce_0)^2}{2b^2\kappa}q_c^2-c_f. \tag{40}$$

Likewise, under the revenue sharing contract, the retailer's transfer payment to the water-saving manufacturer is as follows:

$$T=(1-\phi)pq(p,r)+\frac{1}{2}\phi\kappa r^2+\phi c_f. \tag{41}$$

The retailer's and water-saving manufacturer's profit functions are as follows:

$$\Pi_m^c(w,r)=[w-c_0-ce_0(1-r)]q(p,r)-\frac{1}{2}\kappa r^2+T, \tag{42}$$

$$\Pi_r^c(p)=(p-w)q(p,r)-T. \tag{43}$$

Solving the optimal problem, we can obtain the reaction functions as follows:

$$p_d(w,r)=\frac{1}{2b}(a+dr)+\frac{1}{2\phi}w. \tag{44}$$

Plugging the optimal water-consumption-reduction rate r_c into the $p_d(w,r)$, we can obtain the reaction function of the retail price p_d w.r.t. the wholesale price of the product w as follows:

$$p_d(w)=\frac{1}{2b}\left\{a+\frac{d(d+bce_0)[a-b(c_0+ce_0)]}{2b\kappa-(d+bce_0)^2}\right\}+\frac{1}{2\phi}w. \tag{45}$$

To coordinate the water-saving supply chain, the coordinated condition $p_d(w)=p_c$ must hold. We can obtain the coordinated wholesale price for the water-saving manufacturer as follows:

$$w_c=\phi\left\{c_0+ce_0\left[1-\frac{(d+bce_0)[a-b(c_0+ce_0)]}{2b\kappa-(d+bce_0)^2}\right]\right\}. \tag{46}$$

We can get the coordinated profits of the retailer and water-saving manufacturer as follows:

$$\Pi_r^c=\phi\Pi_{sc}^c, \tag{47}$$

$$\Pi_m^c=(1-\phi)\Pi_{sc}^c. \tag{48}$$

Remark 2: Only when the following conditions hold: $\Pi_r^c\geqslant\Pi_r^d$, $\Pi_m^c\geqslant\Pi_m^d$ would the water-saving supply chain members have the economic motivation to coordinate; that is, the reasonable interval of the revenue keeping rate is: $\phi_c\in\left[\underline{\phi}_c,\overline{\phi}_c\right]$.

Hereinto,

$$\underline{\phi}_c=\frac{2b\kappa q_d^2}{[2b\kappa-(d+bce_0)^2]q_c^2-2b^2\kappa c_f},$$

$$\overline{\phi}_c=\frac{[2b\kappa-(d+bce_0)^2]q_c^2-[4b\kappa-(d+bce_0)^2]q_d^2}{[2b\kappa-(d+bce_0)^2]q_c^2-2b^2\kappa c_f}.$$

4.3 Scenario with CAT regulation

Based on the foregoing analysis of the benchmark scenario, the water CAT regulation is introduced into the water-saving supply chain, and the equilibrium decision and coordination decision models of water-saving supply chain with CAT regulation are developed and analyzed (superscript t: with CAT regulation, superscript or subscript d: equilibrium decision, superscript or subscript c: coordination decision).

4.3.1 Water-saving supply chain equilibrium with CAT regulation

In the water-saving supply chain with CAT regulation, the optimal problem for the retailer is as follows:

$$\max_{p}\ \Pi_r^t(p)=(p-w)q(p,r). \tag{49}$$

Solving the optimal problem, we can obtain the reaction functions as follows:

$$p_d^t(w,r)=\frac{1}{2b}(a+bw+dr), \tag{50}$$

$$q_d^t(w,r)=\frac{1}{2}(a-bw+dr). \tag{51}$$

Plugging $q_d^t(w,r)$ into the profit function of the water-saving manufacturer, we can obtain the water-saving manufacturer's optimal problem as follows:

$$\max_{w,r}\ \Pi_m^t(w,r)=[w-c_0-ce_0(1-r)]q_d(w,r)-\frac{1}{2}\kappa r^2-c_f-l[e_0(1-r)q_d(w,r)-\overline{e}]. \tag{52}$$

Solving this optimal problem, when the condition $4b\kappa>[d+(c+l)be_0]^2$ holds, we can determine the equilibrium water consumption reduction rate r_d^t and the equilibrium wholesale price w_d^t as follows:

$$r_d^t=\frac{[d+b(c+l)e_0]\{a-b[c_0+(c+l)e_0]\}}{4b\kappa-[d+(c+l)be_0]^2}, \tag{53}$$

$$w_d^t=\frac{2\kappa-[d+b(c+l)e_0](c+l)e_0}{4b\kappa-[d+b(c+l)e_0]^2}\{a-b[c_0+(c+l)e_0]\}+[c_0+(c+l)e_0]. \tag{54}$$

Plugging r_d^t and w_d^t into $p_d^t(w,r)$ and $q_d^t(w,r)$, we can obtain the equilibrium retail price p_d^t and the equilibrium ordering quantity q_d^t as follows:

$$p_d^t = \frac{3\kappa - [d + b(c + l)e_0](c + l)e_0}{4b\kappa - [d + b(c + l)e_0]^2}\{a - b[c_0 + (c + l)e_0]\} + [c_0 + (c + l)e_0], \tag{55}$$

$$q_d^t = \frac{b\kappa\{a - b[c_0 + (c + l)e_0]\}}{4b\kappa - [d + b(c + l)e_0]^2}. \tag{56}$$

We can obtain the equilibrium profits of the retailer Π_r^{td}, the water-saving manufacturer Π_m^{td} and the water saving supply chain Π_{sc}^{td} as follows:

$$\Pi_r^{td} = \frac{1}{b}(q_d^t)^2, \tag{57}$$

$$\Pi_m^{td} = \frac{4b\kappa - [d + b(c + l)e_0]^2}{2b^2\kappa}(q_d^t)^2 - c_f + l\bar{e}, \tag{58}$$

$$\Pi_{sc}^{td} = \frac{6b\kappa - [b(c + l)e_0 + d]^2}{2b^2\kappa}(q_d^t)^2 - c_f + l\bar{e}. \tag{59}$$

4.3.2 Water-saving supply chain coordination with CAT regulation

The optimal problem for a centralized water-saving supply chain with CAT regulation is as follows:

$$\max_{p,r}\ \Pi_{sc}^t(p,r) = [p - c_0 - ce_0(1 - r)]q(p,r) - \frac{1}{2}\kappa r^2 - c_f - l[e_0(1 - r)q(p,r) - \bar{e}]. \tag{60}$$

Solving the optimal problem, when the condition $2b\kappa > [d + b(c + l)e_0]^2$ holds, we can obtain the optimal retail price p_c^t and the optimal water consumption reduction rate r_c^t as follows:

$$r_c^t = \frac{[d + b(c + l)e_0]\{a - b[c_0 + (c + l)e_0]\}}{2b\kappa - [d + b(c + l)e_0]^2}, \tag{61}$$

$$p_c^t = \frac{\kappa - [d + b(c + l)e_0](c + l)e_0}{2b\kappa - [d + b(c + l)e_0]^2}\{a - b[c_0 + (c + l)e_0]\} + [c_0 + (c + l)e_0]. \tag{62}$$

Plugging r_c^t and p_c^t into $q(p,r)$, we can obtain the optimal ordering quantity q_c^t as follows:

$$q_c^t = \frac{b\kappa\{a - b[c_0 + (c + l)e_0]\}}{2b\kappa - [d + b(c + l)e_0]^2}. \tag{63}$$

We can obtain the optimal profit of the water saving supply chain Π_{sc}^{tc} as follows:

$$\Pi_{sc}^{tc} = \frac{2b\kappa - [d + b(c + l)e_0]^2}{2b^2\kappa}(q_c^t)^2 - c_f + l\bar{e}. \tag{64}$$

Under the revenue sharing contract, the retailer's transfer payment to the water-saving manufacturer is as follows:

$$T = (1 - \phi)pq(p,r) + \frac{1}{2}\phi\kappa r^2 + \phi c_f + \phi l[e_0(1 - r)q(p,r) - \bar{e}]. \tag{65}$$

Thus, the retailer's and the water-saving manufacturer's profit functions are as follows:

$$\Pi_r^{tc}(p) = (p - w)q(p,r) - T, \tag{66}$$

$$\Pi_m^{tc}(w,r) = [w - c_0 - ce_0(1 - r)]q(p,r) - \frac{1}{2}\kappa r^2 - c_f - l[e_0(1 - r)q(p,r) - \bar{e}] + T. \tag{67}$$

Solving the optimal problem, we can obtain the reaction functions as follows:

$$p_d^t(w,r) = \frac{1}{2b}[a + (d - ble_0)r + ble_0] + \frac{1}{2\phi}w. \tag{68}$$

Plugging the optimal water-consumption-reduction rate r_c^t into the $p_d^t(w,r)$, we can obtain the reaction function of the retail price p_d^t w.r.t. the wholesale price of the product w as follows:

$$p_d^t(w) = \frac{1}{2b}\left\{a + ble_0 + \frac{(d - ble_0)[d + b(c + l)e_0]\{a - b[c_0 + (c + l)e_0]\}}{2b\kappa - [d + b(c + l)e_0]^2}\right\} + \frac{1}{2\phi}w. \tag{69}$$

To coordinate the water-saving supply chain, the coordinated condition $p_d^t(w) = p_c^t$ must hold. Thus, we can obtain the coordinated wholesale price for the water-saving manufacturer as follows:

$$w_c^t = \phi\left\{c_0 + ce_0\left\{1 - \frac{[d + b(c + l)e_0]\{a - b[c_0 + (c + l)e_0]\}}{2b\kappa - [d + b(c + l)e_0]^2}\right\}\right\}. \tag{70}$$

We can obtain the coordinated profits of the retailer and water-saving manufacturer as follows:

$$\Pi_r^{tc} = \phi \Pi_{sc}^{tc}, \tag{71}$$

$$\Pi_m^{tc} = (1-\phi)\Pi_{sc}^{tc}. \tag{72}$$

Remark 3: Only when the following conditions hold: $\Pi_r^{tc} \geqslant \Pi_r^{td}$, $\Pi_m^{tc} \geqslant \Pi_m^{td}$ would the water-saving supply chain members have the economic motivation to coordinate; that is, the reasonable interval of the revenue keeping rate is $\phi_t \in \left[\underline{\phi}_t, \overline{\phi}_t\right]$.

That is,

$$\underline{\phi}_t = \frac{2b\kappa (q_d^t)^2}{\{2b\kappa - [d + b(c+l)e_0]^2\}(q_c^t)^2 - 2b^2\kappa\left(c_f - l\overline{e}\right)},$$

$$\overline{\phi}_t = \frac{\{2b\kappa - [d + b(c+l)e_0]^2\}(q_c^t)^2 - \{4b\kappa - [d + b(c+l)e_0]^2\}(q_d^t)^2}{\{2b\kappa - [d + b(c+l)e_0]^2\}(q_c^t)^2 - 2b^2\kappa\left(c_f - l\overline{e}\right)}.$$

4.4 Comparison of analytical results

The analytical results of the supply chain models under the benchmark scenario and the water-saving supply chain models under the scenario with/without CAT regulation, including optimal/equilibrium solutions and the corresponding profits are compared to derive the internal incentives and operations strategies for the water-saving supply chain as follows.

Remark 4: The equilibrium profits in the water-saving supply chain are compared with those in the benchmark scenario without water-saving, only when the following conditions hold: $\Pi_r^d \geqslant \Pi_r^{bd}$, $\Pi_m^d \geqslant \Pi_m^{bd}$, i.e. $(d + bce_0)^2[a - b(c_0 + ce_0)]^2 > 8b[4b\kappa - (d + bce_0)^2]c_f$, supply chain members would have internal incentive to conduct water-saving.

Remark 5: The coordination profits in the water-saving supply chain are compared with those in the benchmark scenario without water-saving, only when the following condition holds: $\Pi_{sc}^c \geqslant \Pi_{sc}^{bc}$, i.e., $(d + bce_0)^2[a - b(c_0 + ce_0)]^2 > 4b[2b\kappa - (d + bce_0)^2]c_f$, the supply chain members would have internal incentive to conduct water-saving.

Remark 6: The equilibrium profits in the water-saving supply chain with CAT regulation are compared with those in the benchmark scenario without water-saving, only when the following conditions hold: $\Pi_r^{td} \geqslant \Pi_r^{bd}$, $\Pi_m^{td} \geqslant \Pi_m^{bd}$, i.e., $q_d^t > q_d^b$, and $\{4b\kappa - [d + b(c+l)e_0]^2\}(q_d^t)^2 - 4b\kappa(q_d^b)^2 > 2b^2\kappa\left(c_f - l\overline{e}\right)$, the supply chain members would have internal incentive to conduct water-saving.

Remark 7: The coordination profits in the water-saving supply chain with CAT regulation are compared with those in the benchmark scenario without water-saving, only when the following condition holds under the coordination scenario: $\Pi_{sc}^{tc} \geqslant \Pi_{sc}^{bc}$, i.e., $\{2b\kappa - [d + b(c+l)e_0]^2\}(q_c^t)^2 - 2b\kappa(q_c^b)^2 > 2b^2\kappa\left(c_f - l\overline{e}\right)$, the supply chain members would have internal incentive to conduct water-saving.

Remark 8: The equilibrium profits in the water-saving supply chain with CAT regulation are compared with those in the water-saving supply chain without CAT regulation, only when the following conditions hold: $\Pi_r^{td} \geqslant \Pi_r^d$, $\Pi_m^{td} \geqslant \Pi_m^d$, i.e., $q_d^t \geqslant q_d$, and $\{4b\kappa - [d + b(c+l)e_0]^2\}(q_d^t)^2 + 2b^2\kappa l\overline{e} \geqslant [4b\kappa - (d + bce_0)^2]q_d^2$, the supply chain members could obtain more profits under the scenario with CAT regulation than under the scenario without CAT regulation, and would wish the government to implement CAT regulations.

Remark 9: The coordination profits in the water-saving supply chain with CAT regulation are compared with those in the water-saving supply chain without CAT, only when the following condition holds under the coordination scenario: $\Pi_{sc}^{tc} \geqslant \Pi_{sc}^c$, i.e., $\{2b\kappa - [d + b(c+l)e_0]^2\}(q_c^t)^2 + 2b^2\kappa l\overline{e} \geqslant [2b\kappa - (d + bce_0)^2]q_c^2$, the supply chain members could obtain more profits under the scenario with CAT regulation than under the scenario without CAT regulation, and would wish the government to implement CAT regulations.

5 Numerical and sensitivity analysis

5.1 Numerical analysis

Based on the realistic characteristics of water-saving in high water consumption industries such as steel, washing, printing and dyeing, leather making, coal chemical, and golf courses, the values of parameters related to the water-saving supply chain are set for the numerical analysis as follows: raw material and manufacturing cost of product c_0 is 50 CNY/unit; water consumption quantity per unit product (the water saving reference point) e_0 is 8 m^3/unit; cost of unit water c is 2.5 CNY/ m^3; cost coefficient of water-saving κ is 60,000, and fixed cost of water-saving c_f is 10,000 CNY. Choke quantity of product a is 5000; price impact coefficient of ordering quantity (demand) b is 2; water consumption reduction rate (water-saving effort) impact coefficient of ordering quantity (demand) d is 0.5. Water cap for the manufacturer $\overline{e}$ is 10,000 m^3 and the marginal trading price of extra water demand or extra water quantity l is 0.5 CNY/ m^3. Obviously, the condition $2b\kappa > [d + b(c+l)e_0]^2$ holds. The revenue keeping rate (cost sharing rate) ϕ is 0.5. Table 1 shows the results of the numerical analysis for the water-saving supply chain models with/without CAT regulation.

Table 1 Numerical results of water-saving supply chain without/with CAT regulation

Scenario	Benchmark scenario		Scenario without CAT		Scenario with CAT	
	Equilibrium	Coordination	Equilibrium	Coordination	Equilibrium	Coordination
r^*	-	-	41.15%	82.58%	49.27%	99.02%
w^*	1,285.00	35.00	1,280.94	26.74	1,281.15	25.10
p^*	1,892.50	1,285.00	1,890.52	1,276.85	1,890.64	1,275.24
q^*	1,215.00	2,430.00	1,219.17	2,446.72	1,218.97	2,450.01
Π_r^*	738,112.50	1,476,225.00	743,183.01	1,481,383.50	742,948.33	1,483,432.69
Π_m^*	1,476,225.00	1,476,225.00	1,471,286.83	1,481,383.50	1,473,614.98	1,483,432.69
Π_{sc}^*	2,214,337.50	2,952,450.00	2,214,469.85	2,962,767.00	2,216,563.31	2,966,865.38
ϕ^*	-	[0.2500, 0.5000]	-	[0.2508, 0.5034]	-	[0.2504, 0.5033]

The numerical analysis results of the water-saving supply chain models with/without CAT regulation show the following:

(1) A comparison of the numerical results under the equilibrium strategy with those under the coordination strategy shows that regardless of the scenario (benchmark, or without CAT regulation, or with CAT regulation), (i) the water consumption reduction rate (water-saving effort) under the coordination strategy is higher than that under the equilibrium strategy; (ii) the wholesale price under the coordination strategy is lower than that under the equilibrium strategy; (iii) the retail price under the coordination strategy is lower than that under the equilibrium strategy; (iv) the ordering quantity under the coordination strategy is higher than that under the equilibrium strategy; and (v) the profits of the (water saving) manufacturer and retailer under the coordination strategy are higher than those under the equilibrium strategy.

(2) A comparison of the numerical results under the scenario without CAT regulation with those under the benchmark scenario shows that regardless of the scenario being under the equilibrium or the coordination strategy, (i) the wholesale price under the scenario without CAT regulation is lower than that under the benchmark scenario; (ii) the retail price under the scenario without CAT regulation is lower than that under the benchmark scenario; (iii) the ordering quantity under the scenario without CAT regulation is higher than that under the benchmark scenario; and (iv) the profits of the (water saving) manufacturer and retailer under the scenario without CAT regulation are higher than those under the benchmark scenario.

(3) A comparison of the numerical results under the scenario with CAT regulation with those under the benchmark scenario shows that regardless of the scenario being under the equilibrium or the coordination strategy, (i) the wholesale price under the scenario with CAT regulation is lower than that under the benchmark scenario; (ii) the retail price under the scenario with CAT regulation is lower than that under the benchmark scenario; (iii) the ordering quantity under the scenario with CAT regulation is higher than that under the benchmark scenario; and (iv) the profits of the (water saving) manufacturer and retailer under the scenario with CAT regulation are higher than those under the benchmark scenario.

(4) A comparison of the numerical results under the scenario with CAT regulation with those under the scenario without CAT regulation shows that (i) the water consumption reduction rate (water-saving effort) under the scenario with CAT regulation is higher than that under the scenario without CAT regulation, regardless of the scenario being under the equilibrium or coordination strategy; (ii) under the equilibrium strategy, the wholesale price under the scenario with CAT regulation is higher than that under the scenario without CAT regulation; under the coordination strategy, the wholesale price under the scenario with CAT regulation is lower than that under the scenario without CAT regulation; (iii) under the equilibrium strategy, the retail price under the scenario with CAT regulation is higher than that under the scenario without CAT regulation; under the coordination strategy, the retail price under the scenario with CAT regulation is lower than that under the scenario without CAT regulation; (iv) under the equilibrium strategy, ordering quantity under the scenario with CAT regulation is lower than that under the scenario without CAT regulation; under the coordination strategy, the ordering quantity under the scenario with CAT regulation is higher than that under the scenario without CAT regulation; and (v) under the equilibrium strategy, the profit of the retailer under the scenario with CAT regulation is lower than that under the scenario without CAT regulation, and the profits of the (water saving) manufacturer under the scenario with CAT regulation is higher than that under the scenario without CAT regulation; under the coordination strategy, the profits of the (water saving) manufacturer and retailer under the scenario with CAT regulation are higher than those under the scenario without CAT regulation.

5.2 Sensitivity analysis

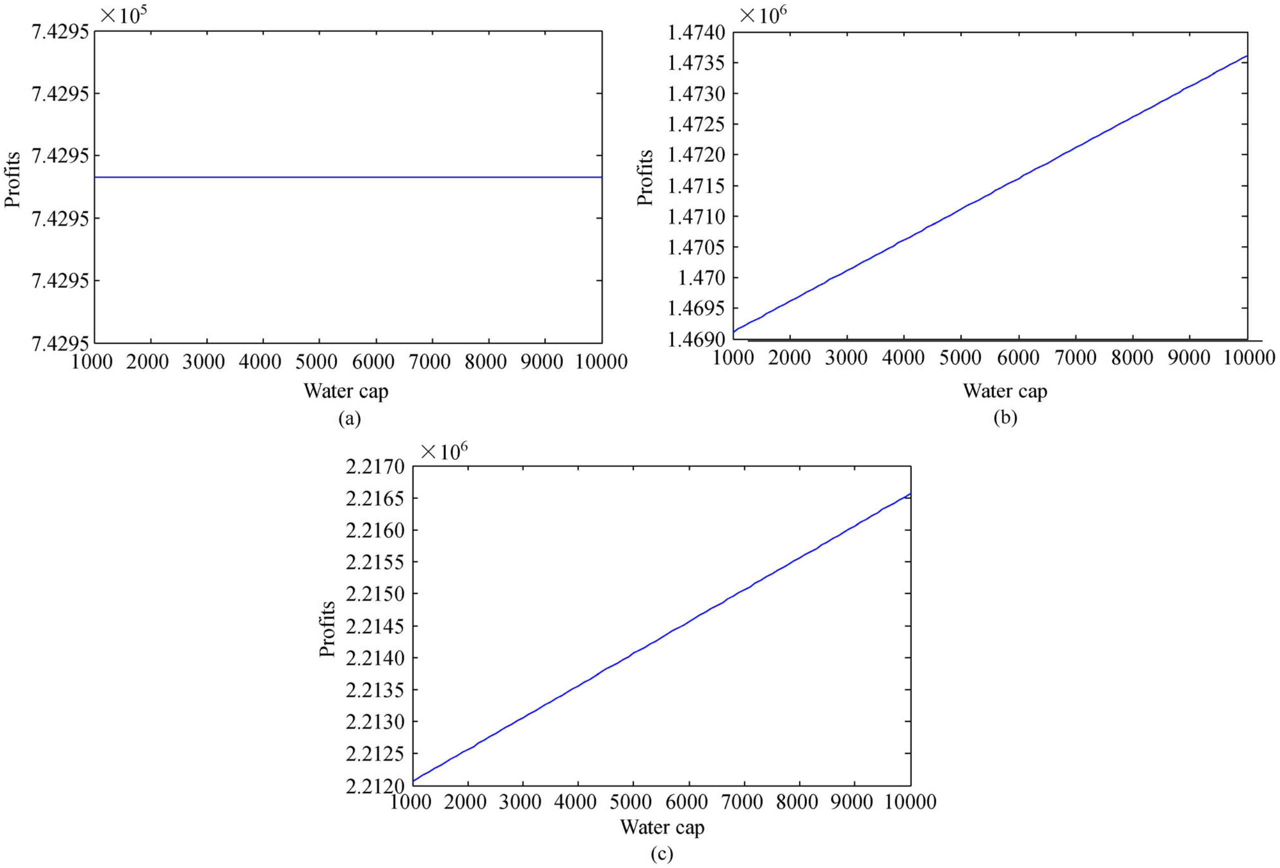
The water cap ($\overline{e}$) and marginal trade price (l) are selected for further sensitivity analysis to investigate the effects of key parameters on the water-saving supply chain. The sensitivity analysis assess only the water-saving supply chain equilibrium and coordination models with CAT regulation because this model provide the highest supply chain profits among all analytical supply chain models and allows an investigation into the effects of the chosen parameters with reasonable effort.

5.2.1 Sensitivity analysis of water cap

The results of the sensitivity analysis of the water cap for the water-saving supply chain equilibrium and coordination models with CAT regulation are shown in Figs. 1 and 2, respectively. The results show that (1) Under the equilibrium strategy, the profits of the water-saving manufacturer decrease as the water cap decreases, the profits of the retailer remain the same as the water cap decreases, and the profits of the water-saving supply chain decrease as the water cap decreases. (2) Under the coordination strategy, the profits of water-saving manufacturer, retailer and water-saving supply chain decrease as the water cap decreases.

5.2.2 Sensitivity analysis of marginal trading price

The results of the sensitivity analysis of marginal trading price for the water-saving supply chain equilibrium and coordination model with CAT regulation are shown in Tables 2 and 3, respectively. Accordingly, Figs. 3 and 4 present the effect of marginal trading price change on the equilibrium and coordinated profits of water-saving supply chain and its members in Tables 2 and 3, respectively. The results show that (1) the water-consumption-reduction rate decrease as the marginal trade price decreases under the equilibrium and the coordination strategies; (2) under the equilibrium strategy, the wholesale price decreases as the marginal trade price decreases, whereas under the coordination strategy, the wholesale price increases as



(a)

(b)

(c)

Fig. 1 Effects of water cap change on the profits of retailer, water-saving manufacturer and water-saving supply chain under the equilibrium strategy

(a) Retailer; (b) water-saving manufacture; (c) water-saving supply chain

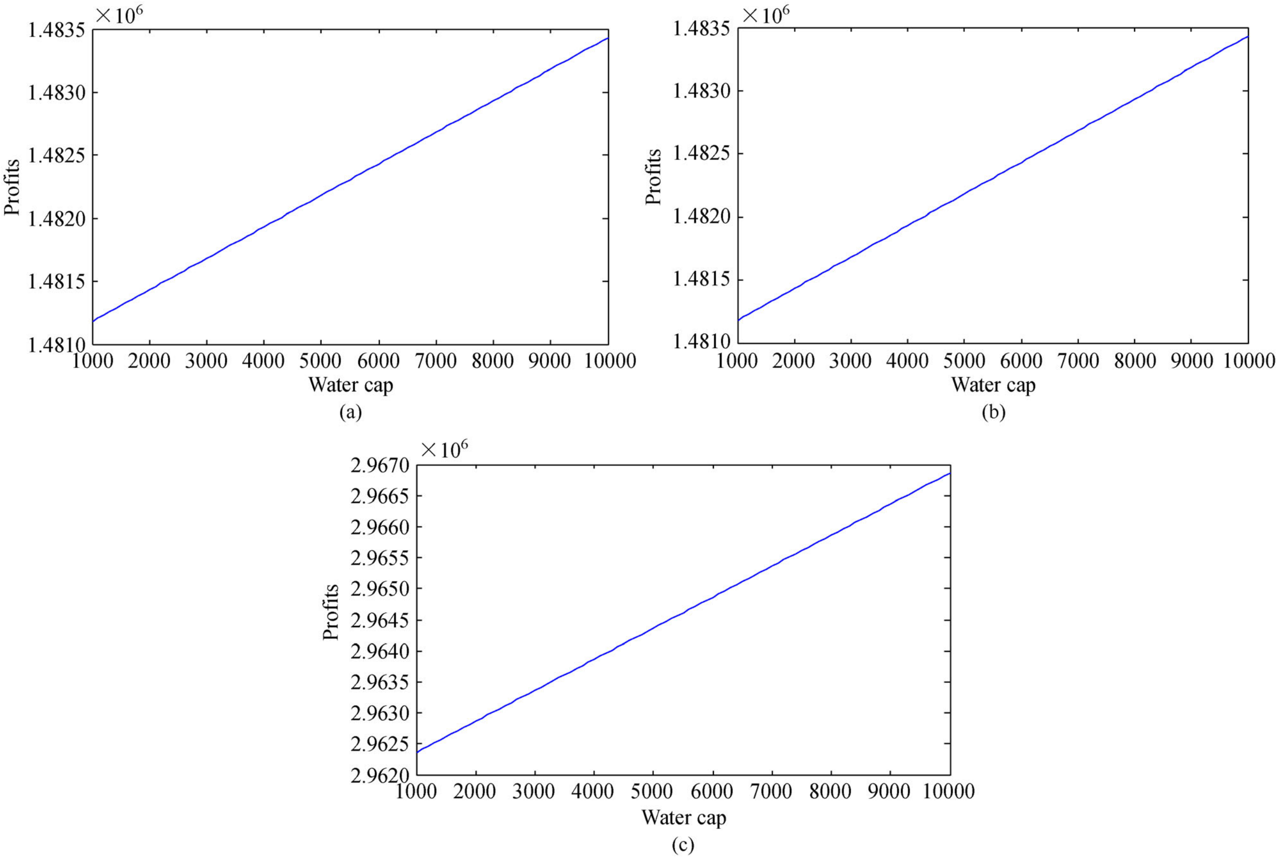


Fig. 2 Effects of water cap change on the profits of retailer, water-saving manufacturer and water-saving supply chain under the coordination strategy

(a) Retailer; (b) water-saving manufacture; (c) water-saving supply chain

Table 2 Sensitivity analysis results of marginal trade price under the equilibrium strategy

l	r_d^t	w_d^t	p_d^t	q_d^t	Π_r^{td}	Π_m^{td}	Π_{sc}^{td}
0.5	49.27%	1,281.15	1,890.64	1,218.97	742,948.33	1,473,614.98	2,216,563.31
0.4	47.64%	1,281.13	1,890.63	1,218.99	742,963.47	1,473,117.65	2,216,081.12
0.3	46.02%	1,281.10	1,890.61	1,219.01	742,994.52	1,472,636.16	2,215,630.68
0.2	44.39%	1,281.06	1,890.59	1,219.05	743,041.47	1,472,170.53	2,215,212.00
0.1	42.77%	1,281.01	1,890.56	1,219.10	743,104.30	1,471,720.75	2,214,825.06

Table 3 Sensitivity analysis results of marginal trade price under the coordination strategy

l	r_c^t	w_c^t	p_c^t	q_c^t	Π_r^{tc}	Π_m^{tc}	Π_{sc}^{tc}
0.5	99.02%	25.10	1,275.24	2,450.01	1,483,432.69	1,483,432.69	2,966,865.38
0.4	95.72%	25.43	1,275.62	2,449.25	1,482,958.43	1,482,958.43	2,965,916.86
0.3	92.43%	25.76	1,275.96	2,448.54	1,482,516.44	1,482,516.44	2,965,032.88
0.2	89.14%	26.09	1,276.28	2,447.88	1,482,106.65	1,482,106.65	2,964,213.31
0.1	85.86%	26.41	1,276.58	2,447.27	1,481,729.02	1,481,729.02	2,963,458.05

the marginal trade price decreases; (3) under the equilibrium strategy, the retail price decreases as the marginal trade price decreases, whereas under the coordination strategy, the retail price increases as the marginal trade price decreases; (4) under the equilibrium strategy, the ordering quantity increases as the marginal trade price decreases, whereas under the coordination strategy, the ordering quantity decreases as the marginal

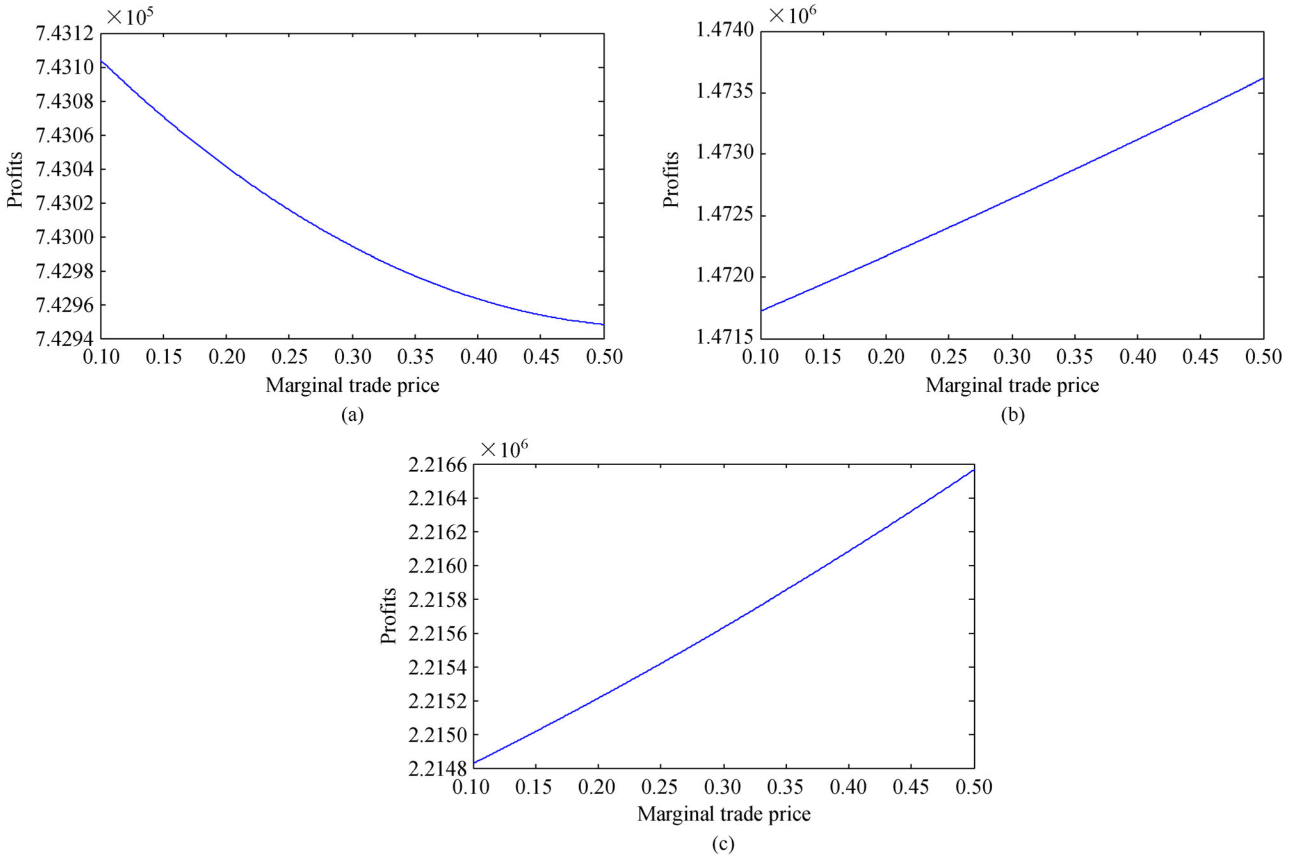


Fig. 3 Effect of marginal trade price change on the profits of retailer, water-saving manufacturer and water-saving supply chain under the equilibrium strategy

(a) Retailer; (b) water-saving manufacture; (c) water-saving supply chain

trade price decreases; and (5) under the equilibrium strategy, the profits of the retailer increase as the marginal trade price decreases, the profits of the water-saving manufacturer decrease as the marginal trade price decreases, and the profits of the water-saving supply chain decrease as the marginal trade price decreases; meanwhile, under the coordination strategy, the profits of the water-saving supply chain and its members decrease as the marginal trade price decreases.

6 Managerial insights and policy recommendations

Based on the foregoing analytical and numerical analyses of the water-saving supply chain models under the scenario with CAT regulation and compared with those under the scenario without water-saving and CAT regulation, the following managerial insights and policy recommendations are given:

(1) Compared with the equilibrium strategy, the revenue sharing contract could coordinate effectively the water-saving supply chain, enhance water-consumption-reduction rate and increase the operational performance of the water-saving supply chain and its members under the coordination strategy, both under the benchmark scenario and the scenario without/with CAT regulation. Therefore, the coordination strategy is recommended for optimal operations management of water-saving supply chain.

(2) Compared with the benchmark scenario, when the conditions presented in Remarks 4 and 5 hold, conducting water saving could increase effectively the operational performance of the water-saving supply chain and its members under the scenario without CAT regulation. The water-saving supply chain adopting coordination strategy could also gain more profits than when adopting equilibrium strategy under the scenario without CAT regulation. Therefore, all members in the water-saving supply chain have internal economic incentive to conduct water saving and adopt the coordination strategy under the scenario without CAT regulation.

(3) Compared with the benchmark scenario, when conditions presented in Remarks 6 and 7 hold, conducting water saving could increase effectively the operational performance of the water-saving supply chain and its members under the scenario with CAT regulation.

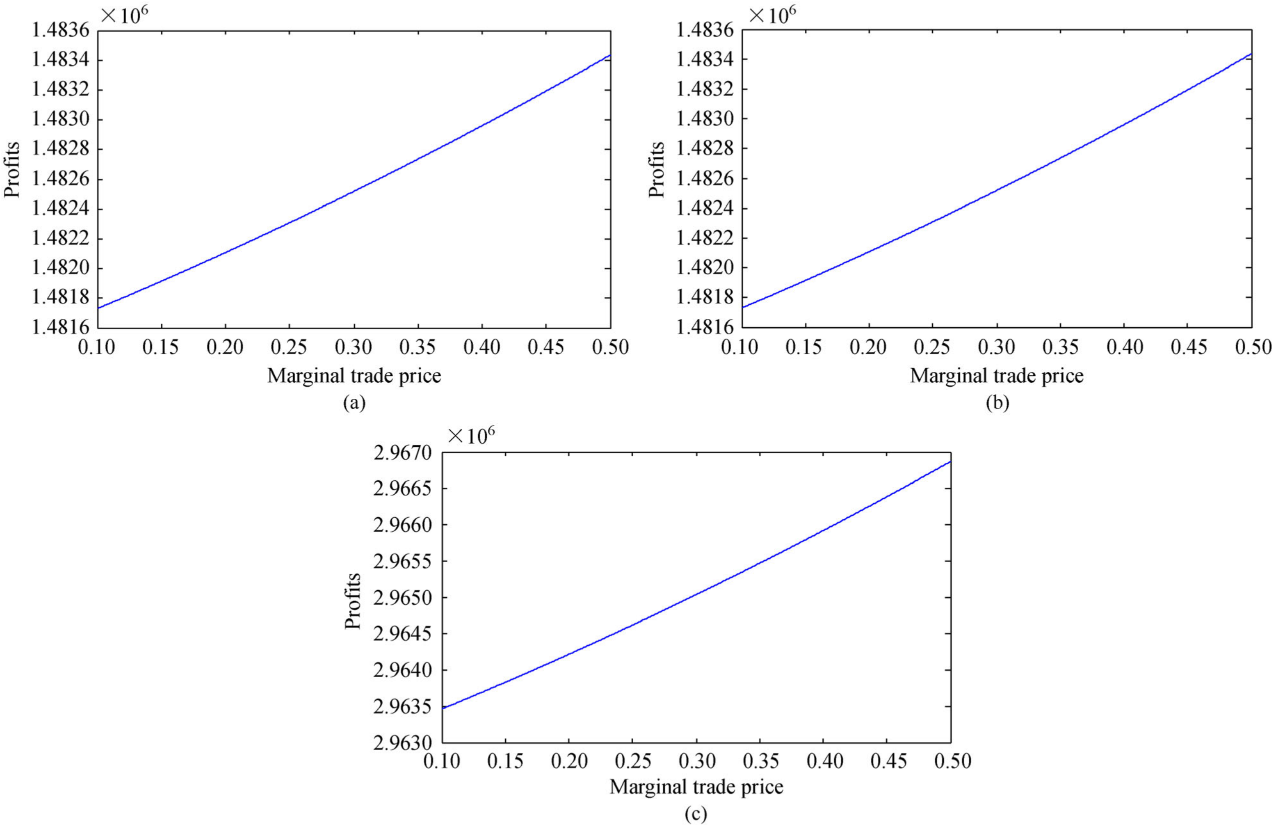


Fig. 4 Effect of marginal trade price change on the profits of retailer, water-saving manufacturer and water-saving supply chain under the coordination strategy

(a) Retailer; (b) water-saving manufacture; (c) water-saving supply chain

Furthermore, the water-saving supply chain could gain more profits by adopting coordination strategy than by adopting equilibrium strategy under the scenario with CAT regulation. Therefore, all members in the water-saving supply chain have internal economic incentive to conduct water saving and adopt coordination strategy under the scenario with CAT regulation.

(4) Compared with the scenario without CAT regulation, when conditions presented in Remarks 8 and 9 hold, implementing the CAT regulation could enhance effectively the water-consumption-reduction rate in the water-saving supply chain and improve the operational performance of water-saving supply chain under the scenario with CAT regulation. Hence, the government would have incentive to implement CAT regulation to improve the social and ecological environmental benefits of water saving. All members in the water-saving supply chain under the scenario with CAT regulation would have more economic incentive to conduct water saving than those under the scenario without CAT regulation, both under the equilibrium and the coordination strategies. Furthermore, the water-saving supply chain could gain more profits by adopting coordination strategy than by adopting the equilibrium strategy under the scenario with CAT regulation. Therefore, simultaneous implementation of CAT regulation by the government and adoption of the coordination strategy by the water-saving supply chain would be superior to any other scenarios/strategies.

(5) Under CAT regulation, if the water consumption is more than the cap, the manufacturer has to buy extra demand quantity from water trading market. Hence, the supply chain and its members have economic incentive to enhance water saving to reduce water cost. If water consumption is less than the cap, the manufacturer could sell the extra quantity to the water trading market with salvage value. Hence, the supply chain and its members have economic incentive to enhance water-consumption-reduction rate to obtain higher salvage value of water saving. Therefore, the supply chain and its members under CAT regulation have more economic incentive to conduct water saving than those under the scenario without CAT regulation.

(6) Under CAT regulation, if the water cap is set too high, the manufacturer's actual water consumption may be much lower than the water cap, which creates arbitrage opportunities for the manufacturer. If the water cap is set too low, the manufacturer's actual water consumption may be much higher than the water cap, which brings more cost

pressure to the manufacturer. Therefore, setting a suitable cap based on industrial average water consumption and historical water consumption data are beneficial for constructing reasonable and effective incentive mechanism.

(7) Under CAT regulation, a higher marginal trade price could induce more water consumption reduction and create better operational performance for the manufacturer and the water-saving supply chain, regardless of using the equilibrium or the coordination strategy.

In sum, the supply chain would be better off performing water saving and adopting a coordination strategy, which is beneficial to the improvement of economic, social and ecological environmental benefits. The government should also encourage the construction of water resources CAT market and set a suitable water cap based on industrial average water consumption and historical water consumption data.

7 Conclusions

Water resources are becoming increasingly scarce due in part to the rapid development of modern industries of agriculture, manufacturing, and services. To address the contradiction between the water supply and the rapidly growing water demand, industries with high water consumption are being regulated by the government's water cap-and-trade (CAT) regulation. Supply chain equilibrium and coordination models under the benchmark scenario without water saving and CAT regulation and water-saving supply chain equilibrium and coordination models under the scenario without/with CAT regulation are developed, analyzed, and compared. The corresponding numerical and sensitivity analyses for all models are also conducted and compared, and the managerial insights and policy recommendations summarized. The research results indicate that (1) Conducting water saving could improve effectively the operational performance of the water-saving supply chain and its members under the scenario with/without CAT regulation. (2) The coordination strategy based on the revenue sharing contract could coordinate effectively water-saving supply chain, enhance water consumption reduction, and improve the operational performance of the water-saving supply chain and its members. (3) Implementing CAT regulation by the government could enhance effectively the water consumption reduction in the water-saving supply chain and improve the operational performance of water-saving supply chain. (4) Simultaneous implementation of the CAT regulation by the government and adoption of the coordination strategy by the water-saving supply chain is superior to any other scenarios/strategies. (5) A suitable water cap based on industrial average water consumption and historical water consumption data are beneficial for constructing reasonable and effective incentive mechanism. (6) A higher marginal trade price can induce more water consumption reduction and create better operational performance for the manufacturer and the water-saving supply chain, both under the equilibrium and coordination strategies.

In terms of theoretical contribution, the available literature rarely touches upon the internal incentive and operations strategies of the self-water-saving supply chain. This study designed a novel and useful approach toward internal incentive and operations strategies for the self-water-saving issues under the CAT regulation from the perspective of supply chain management. These strategies address the research gap in the self-water-saving supply chain and enriched the water saving issues to the scope of supply chain. In the practical contribution, the modeling and numerical results provide better decision support for government to make appropriate water CAT regulation policies for the operations management of water-saving supply chain and provide better decision support for the water-saving supply chain stakeholders to make better decisions of water consumption reduction, pricing, and production to improve their operational performance.

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