An incentive mechanism for improving urban water supply system

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Abstract: An essential challenge for many developing countries is improvement of water supply system to ensure urban water supply safety and reliability. Penalty, subsidy and water price increase are often considered as the main incentive measures for improving urban water supply system. However, the implementation of these policies is confronting some uncertainties because of the conflicts of involved actors. In order to find the most effective incentive mechanism for improving urban water supply system, this study conducts a game theoretical analysis to analyze the conflicts of interests between municipal government and a water company. The effects of penalty, subsidy and water price increase on behaviors of key stakeholders were obtained. The main findings are that water price and penalty are the effective tools to promote urban water supply system improvement, while subsidy policy is not useful. The conclusion has important policy implication for improving urban water supply system safety.

Key-Words: Water supply system, incentive mechanism, equipment upgrade, China

1 Introduction

China has suffered frequent drinking water supply accidents in the last decade [1]. According to Ministry of Environmental Protection Administration, there were 6928 drinking water pollution accidents from 2000 to 2010 [2]. For example, in July 2009 more than 500 residents became ill and two died after being exposed to cadmium, a heavy metal pollutant discharged into the Liuyang River and surrounding land by the Xianghe Chemical Plant in Liuyang city in Central China’s Hunan Province [3]. To ensure drinking water safety, the new Standards for Drinking Water Quality (GB5749-2006) which make more strict requirements to drinking water were effective in China on 1st July, 2012. All 106 items included were adopted from the WHO guidelines for drinking-water quality. This is the first time a developing country has implemented strict regulations on drinking-water quality. And the first time the same standards have been applied in rural and urban areas in China [4]. However, many of Chinese water companies are having difficulties in complying with the new standards due to the outdated water-processing facilities and techniques [5]. An essential challenge for China in the 21st century will be upgrading and improvement of urban water supply system to ensure water supply safety and reliability.

Since water supply system is one of public utility sectors, governments tend to take a lead role in water industry [6]. The view of water as a public and social good made it necessary to subsidies public water supply sectors heavily [5]. Due to the massive demand for water infrastructure and lack of capital, Chinese government opened up the water sector to domestic and foreign companies since 2002 [7]. Recent studies indicated that improving water supply system would have to confront with some uncertainties because of the conflicts of interests between governments and water companies [8]. Municipal governments are responsible for ensuring and verifying that the water companies are capable of delivering safe water routinely. Governments would like to provide better water service. Meanwhile, they are required to keep water price socially acceptable [9]. In addition, municipal governments in developing countries concentrate more on economic development [10]. Water companies are primarily responsible for producing and delivering safe drinking water. And water companies who fail to meet the standard requirement must be charged according to the severity of the violations [11]. However, water companies may hesitate to improve water supply facilities owing to the heavy investment demands [12]. Many Chinese water companies suffered from poor operating efficiency and slow technological upgrades due to current low level of water prices which can be adjusted only by China's municipal governments [13]. After all, the lack of water regulation and incentive mechanism are the major constraints that require serious attention. It is important to have an efficient monitoring mechanism and incentive policies to ensure water companies to fulfill their obligations and to upgrade their facilities.

It is useful and necessary to get better understand of key stakeholders' conflicts and strategies before designing appropriate policies. Game theoretical approach can be used to predict how people behave following their own interests to deal with conflicts and to provide input for policy and planning purposes. Thus, the objective of this study is to find the effective incentive mechanism for improving urban water supply system using a game theory framework in order to provide implications for government policy-makers.

2 Literature Review

Since V-Neumann and Morgenstern (1994) public their book "The Theory of Game and Economic Behavior", game theory has been widely used as a mathematical and logical approach applied in various research fields, such as economics, marketing and environmental management, etc [14]. Game theory is essentially mathematical analysis of any situation involving a conflict of interest, with the intent of indicating optimal choices that, under given conditions, will lead to a desired outcome [10]. The solutions provides by game theory are usually arrived by considering the interaction between the 'players' who are involved [9].

There are an increasing number of literatures on inspecting and enforcement in public policies. The Inspection Game was originally proposed by Dresher (1962), and was generalized by Maschler (1966), in the context of checking inspection problems for the treaty of arm reduction. Tomas and Nisgav (1976) extended Maschler's model in which customs keep watch on illegal actions of a smuggler, and then Baston and Bostock (1991), Garnaev (1994) detailed their work. With the purpose of crime deterrence, early studies of Tsebelis (1989, 1990) launched a serious attack on the literatures concerning the optimal deterrence of crime, he used a 2×2 game played by the public and inspectors with a single, mixed-strategy Nash equilibrium. Further, contributions by game theorists to environmental management have been researched during the past few years [15-17].

Game theory is often seen as an essential tool when dealing with water management problems with multiple agents, especially when there are conflicting objectives [18]. The application of game theory to water resources management have been discussed by a number of works, such as water or cost/benefit allocation [19, 20] and water quality management [21, 22]. Yet game theory applications to water supply management are still under development [23]. Tapiero (2004) created a game theory framework to investigate governmental subsidies and penalties which can influence the possible actions of enterprises [15]. Later, the model was modified by formulating a Stackelberg game where the polluting firm is assumed to be a follower, while the environmental agency is a leader [24]. Dong (2010) analyzed the effects of subsidies, penalties and other policy variables on the implementation of clear production policies by conducting a game model between a local government and a potential polluting firm [24]. Zhao (2012) used game theory to analyze the strategies selected by manufacturers to reduce environmental risk and suggested that the strategic choice of the manufactures would be influenced by government penalties or incentives [18]. While previous studies analyzed the influence of penalty and subsidy on the strategies of governments and polluting firms, they fail to consider the adjustable price policy in regulatory game model. In the field of water supply management, there are many researches indicating that changes in water prices affect decision-making of water companies [25].

According to these studies, the game theoretical model developed in this paper has adjustable price considered as well as penalty and subsidy. Inside the game model, municipal governments are taken as a regulator who had the authority to inspect water companies, and water companies are regarded as an agent. The model analysis is revealed how penalty, subsidy and water price increase affect the strategies of water supply system improvement. Further, under what conditions the strategies satisfied both their interests of municipal government and water companies were discussed.

3 Development of Game-theoretical Model

3.1 Assumption

Three policy variables including penalty, subsidy and water price increase, and six input parameters are assumed. Explanations for each variable and parameter are illustrated in Table 1. For a particular water company, all input parameters are fixed. Policy makers can adjust policy variables to influence the strategies of the water company and municipal government.

Table 1 All policy variables and input parameters in the model

Symbols	Notes
Policy variables :	
F	Penalty cost of the "not comply" water company (unit: RMB)
β	Shared Proportion of upgrading cost for municipal government (%)
P	Water price increase (unit: RMB/ m^3)
Input parameters :	
C_0	Water company's unit production cost before upgrading (unit: RMB/ m^3)
C_U	Increased unit cost of Water company after upgrading (unit: RMB/ m^3)
Q	Quantity produced and consumed (unit: m^3)
C_R	Governments' Monitoring cost (unit: RMB)
P_0	The original water price (unit: RMB/ m^3)
α	Tax rate
r	Violation Risk that companies do not meet the standard requirement if not upgrade

The proposed models are based on the following assumptions:

(1) Taking municipal government as a regulator who has the authority to inspect the water companies, give subsidy, penalty or increase water price. Any corrupt activities by municipal government are ignored during enforcement process. Due to the limited budgets and staff, it is difficult for municipal government to inspect all water companies spontaneously. Therefore, the model assumes that municipal government may monitor the company with a specified probability and subsequently stick to it.

(2) If a water company upgrades its facilities, it is considered to comply with the national drinking water standards. Then there is no penalty for it. Since municipal government could not monitor all companies, the company not upgrade facilities can avoid being penalized in a fixed probability.

(3) There is rigid demand for drinking water to consumers, and water is a necessary good for people to live so that water is perfectly inelastic. Thus, the model assumes that demand will not be brought down by increasing water price.

(4) The extra social cost for municipal government is ignored. In general, most of Chinese water facilities and techniques could comply with the national drinking water standards presently. Therefore, the social cost is relatively small. Furthermore, there is no objective assessment system of urban water supply safety for municipal governments in China. In additional, the calculation of social cost is complex and inaccurate, it is still difficult to quantify these costs. Thus, it does not consider the social cost for municipal governments.

(5) This research focuses on urban water supply systems and management. Because of natural monopoly and scale effect, urban water services are usually supplied by a few large-scale water companies. The annual quantity of water supply is fairly large. Therefore, the model assumes that $Q \gg rF$ and $Q \gg C_R$ to simplify the analysis.

3.2 Payoff Matrix

In this study, the game is played by the municipal government (MG) and a water company (WC). The interest lies on a 2×2 simultaneous-move game in Table 2. The municipal government is assumed to minimize the sum of expected subsidies and inspection costs, and the company is to maximize the profit. The municipal government has two strategies, called "Implement" or "Not implement". The water company has two strategies, called "Upgrade" or "Not upgrade".

Table 2 The payoff matrix between municipal government and a water company

		WC	
		Upgrade	**Not upgrade**
MG	**Implement**	(U_{11}, π_{11})	(U_{10}, π_{10})
	Not implement	(U_{01}, π_{01})	(U_{00}, π_{00})

For identification, the formulas in the left side and right side of the semicolons are used for strategies of the municipal government and strategies for the water company, respectively (Table 2). According to the assumptions, the net benefit of the water company before upgrading facilities is $(P_0 - C_0)Q$. The inspection cost of municipal government is C_R. The company pays tax to the municipal government at the rate of α. If the municipal government plays "Not implement", the company pays no penalty for its violation. The payoffs for the municipal government and the water company are $U_{00} = \alpha(P_0 - C_0)Q$ and $\pi_{00} = (1-\alpha)(P_0 - C_0)Q$, respectively. If the municipal government plays "Implement", the company has to pay penalty F for its violation with risk r. For this case the company is found not to be in compliance. Therefore, the payoffs for the municipal government and the company are $U_{10} = \alpha(P_0 - C_0)Q + rF - C_R$ and $\pi_{10} = (1-\alpha)(P_0 - C_0)Q - rF$, respectively.

If the company chooses to upgrade its facilities, the unit cost for upgrading facilities is C_U. In this case, if the municipal government plays "Not implement", the payoffs for the municipal government and the company are $U_{01} = \alpha(P_0 - C_0 - C_U)Q$ and $\pi_{01} = (1-\alpha)(P_0 - C_0 - C_U)Q$, respectively. If the municipal government plays "Implement", an equipment subsidy rate of β is provided to the water company and the water price is raised to P_0+P. Then the payoffs for the municipal government and the company are $U_{11} = \alpha[(P_0+P) - C_0 - (1-\beta)C_U]Q - \beta C_U Q - C_R$ and $\pi_{11} = (1-\alpha)[(P_0+P) - C_0 - (1-\beta)C_U]Q$, respectively.

4 Model analysis

4.1 The Nash Equilibrium

Obviously, the water company prefers not to upgrade if municipal government does not to implement because $(1-\alpha)(P_0 - C_0)Q > (1-\alpha)(P_0 - C_0 - C_U)Q$, which means that the payoffs for the company to choose "not upgrade" is higher than that to choose "upgrade". In practice, the inspection cost are usually lower than the penalty ($rF>C_R$). Then, the municipal government prefers to implement if the water company does not upgrade facilities. In order for the water company to upgrade facilities, the payoffs for the water company must be satisfied:

$$\pi_{11} \geq \pi_{10} \tag{1}$$

Due to $Q \gg rF$, equation (1) can be rewritten as:

$$P \geq (1-\beta)C_U - \frac{rF}{(1-\alpha)Q} \approx (1-\beta)C_U \tag{2}$$

Notice that the Nash equilibriums are various under different policy conditions. If the municipal government tends to implement in the scenario that the water company upgrades facilities, (Implement, Upgrade) is the unique Nash equilibrium. It means that:

$$U_{11} \geq U_{01} \tag{3}$$

Due to $Q \gg C_R$, P and β should satisfy the following equation:

$$P \geq \frac{\beta C_U Q(1-\alpha) + C_R}{\alpha Q} \approx \frac{\beta C_U (1-\alpha)}{\alpha} \tag{4}$$

If the municipal government prefers not to implement in the scenario that the water company plays "Upgrade", the Nash equilibrium of this finite game is unique and in mixed strategies. It holds that:

$$U_{11} < U_{01} \tag{5}$$

In this case, P and β will satisfy the following expression:

$$P < \frac{\beta C_U Q(1-\alpha) + C_R}{\alpha Q} \approx \frac{\beta C_U (1-\alpha)}{\alpha} \tag{6}$$

Under the condition of equations (2) and (4), (Implement, Upgrade) is the dominant strategy for municipal government and a water company, respectively. When P and β satisfy equations (2) and (6), the Nash equilibrium is unique and in mixed strategies. Otherwise, the municipal government will not implement and the water company prefers not to upgrade facilities. Furthermore, equation (2) suggest that if F=0 (there's no penalty) the price increase has to be at least what the company spend in the new technology, $(1-\alpha)C_U$. The game equilibrium under various policy conditions were shown in Figure 1. As a result, the policy goal of (Implement, Upgrade) will be achieved under the optimal conditions of $P \geq \text{Max}\ [(1-\beta)C_U, \beta(1-\alpha)C_U/\alpha]$. It means that water price increase is equal or more than the maximum between the unit upgrading cost of the water company and the upgrading cost shared by municipal government. It is assumed to minimize the water price increase to satisfy basic needs of people. In addition, the subsidies provided by municipal government are limited because of the government's tight budget. The lowest subsidy rate and the lowest water price increase can be easily shown as $\beta^*=\alpha$ and $P^*=(1-\alpha)C_U$, respectively. For social welfare and equality, the maximum of water increase should not be higher than increased unit upgrading cost, C_U. Therefore, the scope of the optimal water increase is [(1－α)C_U, C_U]. And the scope of the optimal subsidy is [α, 1].

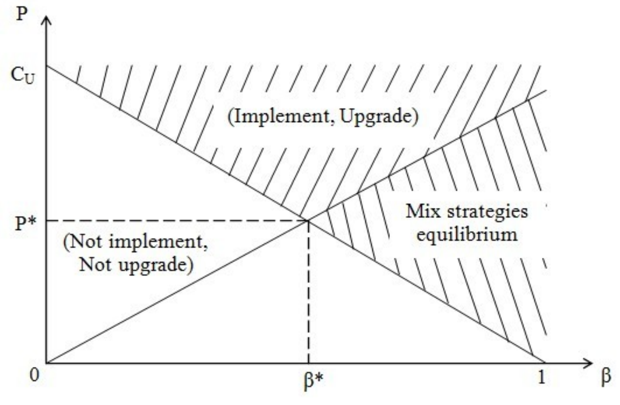

Figure 1 The game equilibrium under various policy conditions

4.2 Impact of Policy Variables

According to the research by Dong (2010), comparative static analysis is used to investigate how the mixed-equilibrium respond to changes in variables F, P and β, under the conditions of P∈[(1 - β)C_U, β(1 - α)C_U/α]. Let η be the probability with which municipal government plays "Implement" and μ be the probability with which a water company plays "Upgrade". The equilibrium choice of μ^* is to make the municipal government indifferent between "Implement" and "Not implement" so that they receive the same payoff U, with

$$U = \mu U_{11} + (1-\mu) U_{10} = \mu U_{01} + (1-\mu) U_{00} \quad (7)$$

Similarly, the probability η^* can be derived from

$$\pi = \eta\pi_{11} + (1-\eta)\pi_{01} = \eta\pi_{10} + (1-\eta)\pi_{00} \quad (8)$$

where π is the payoff of the water company when the game reaches an equilibrium.

From Equations (7) and (8), the mixed strategy equilibrium of the water company and the municipal government can be obtained

$$\mu^* = \frac{rF - C_R}{rF + Q[(1-\alpha)\beta C_U - \alpha P]} \quad (9)$$

$$\eta^* = \frac{(1-\alpha)C_U Q}{(1-\alpha)(P+\beta C_U)Q + rF} \quad (10)$$

The equations (9) and (10) suggest that the probability of the water company to upgrade facilities is (rF － C_R)/{rF+Q[(1 － α)βC_U － αP]} while the probability of the municipal government to implement water policies is (1－α)C_UQ/[(1－α)(P+βC_U)Q+rF].

From Equation (9), the derivatives of μ^* with respect to F, P and β can be derived as equations (11), (12) and (13), respectively.

$$\frac{\partial\mu^*}{\partial F} = \frac{r\{C_R + Q[(1-\alpha)\beta C_U - \alpha P]\}}{\{rF + Q[(1-\alpha)\beta C_U - \alpha P]\}^2} > 0 \quad (11)$$

$$\frac{\partial\mu^*}{\partial P} = \frac{(rF - C_R)\alpha Q}{\{rF + Q[(1-\alpha)\beta C_U - \alpha P]\}^2} > 0 \quad (12)$$

$$\frac{\partial\mu^*}{\partial\beta} = \frac{-(rF - C_R)(1-\alpha)QC_U}{\{rF + Q[(1-\alpha)\beta C_U - \alpha P]\}^2} < 0 \quad (13)$$

Given that P∈[(1 - β)C_U, β(1 - α)C_U/α] and rF>C_R, the derivatives of μ^* with respect to F, P and β are positive, positive, and negative, respectively. This means that increasing penalty (i.e. raising F) and water price (i.e. raising P) increase the probability that the water company plays "Upgrade", and increasing subsidy to the water company (i.e. raising β) reduces the probability that the water company plays "Upgrade".

The derivatives of η^* with respect to F, P and β, respectively, derived from equation (10)

$$\frac{\partial\eta^*}{\partial F} = \frac{-r(1-\alpha)QC_U}{[(1-\alpha)(P+\beta C_U)Q + rF]^2} < 0 \quad (14)$$

$$\frac{\partial\eta^*}{\partial P} = \frac{-(1-\alpha)^2 Q^2 C_U}{[(1-\alpha)(P+\beta C_U)Q + rF]^2} < 0 \quad (15)$$

$$\frac{\partial\eta^*}{\partial\beta} = \frac{-(1-\alpha)^2 Q^2 C_U^2}{[(1-\alpha)(P+\beta C_U)Q + rF]^2} < 0 \quad (16)$$

It is obviously that the derivatives of η^* with respect to F, P and β are all negative shown in equations (14), (15) and (16). It indicate that either increasing penalty (i.e. raising F) or equipment subsidy (i.e. raising β) to the water company reduces the probability that municipal government plays "Implement", and increasing water price (i.e. raising P) also reduces the probability that municipal government plays "Implement"

According to game theory, each player's (mixed) equilibrium strategy depends upon the other player's payoffs associated with the strategy the player chosen. Along with the increase of penalty, more water companies will play "Upgrade" because of the fear of fines. With the increase of water price, more companies will play "Upgrade" for the purpose of more profits. Aware of the water companies' strategies, the municipal government tends to reduce the probability of inspection to save expenses. However, providing subsidies will increase government budget, which leads to negative attitudes of municipal government towards implementation. The water company realizes that the government will not implement the subsidy policy well. These may eventually lead to the lower policy efficiency. This implies that government policy makers would increase penalty and water price to encourage water companies to upgrade their facilities while subsidy is not an efficient policy.

6 Model Extensions

In order to optimize the incentive mechanisms for improving urban water supply system, the proposed model is extended by introducing policy variables such as reputation damage of water companies, social cost of municipal government and external rewards to municipal government.

6.1 Reputation Damage of Water Companies

Recently, modern companies pay more and more attention to their ethical responsibilities and social reputation (Alsop, 2004). Thus, the proposed model could be extended by introducing reputation damage to water companies. It is assumed that the water company which chooses to "Not Upgrade", will suffer a reputation damage (D). The new payoff matrix is shown in Table 3.

Table 3 The modified payoff matrix by introducing reputation damage (D)

		WC	
		Upgrade	**Not upgrade**
MG	**Implement**	(U_{11}, π_{11})	$(U_{10}, \pi_{10} - D)$
	Not implement	(U_{01}, π_{01})	$(U_{00}, \pi_{00} - D)$

As shown in Table 3, introducing reputation damage of water companies will not change the condition of Nash equilibrium. The new mixed equilibrium strategies of the water company and the municipal government are given by

$$\mu_D^* = \frac{rF - C_R}{rF + Q[(1-\alpha)\beta C_U - \alpha P]} = \mu^* \quad (17)$$

$$\eta_D^* = \frac{(1-\alpha)C_U Q - D}{(1-\alpha)(P + \beta C_U)Q + rF} < \eta^* \quad (18)$$

From equations (17) and (18), it is found that considering reputation damage to water companies will decrease the municipal government' probability of "Implement". However, the water company's probability of "Upgrade" is not affected by reputation damage. These findings imply that if the policy makers want to affect the water company's behaviour, they should change the payoffs of municipal government. Any change in water company's payoffs would leave municipal government's strategy unaltered.

In addition, the derivatives of η_D^* with respect to D is

$$\frac{\partial \eta_D^*}{\partial D} = \frac{-1}{(1-\alpha)(P + \beta C_U)Q + rF} < 0 \quad (19)$$

From equation (19), increasing reputation damage to water company reduces the probability with which municipal government plays to "Implement" while leaves the water company's strategy unaltered.

6.2 Social Cost of Municipal Government

One limitation of the proposed model is that it does not account for the social cost of municipal government. The social cost of this study is defined as the actual or potential public loss due to water supply accidents. It is assumed that when the water company plays to "Upgrade", the municipal government should pay for the social cost of actual or potential public loss. The new payoff matrix is shown in Table 4.

The mixed Nash equilibrium strategy of the water company is given by

$$\mu_S^* = \frac{rF - C_R}{rF + Q[(1-\alpha)\beta C_U - \alpha P]} = \mu^* \quad (20)$$

Table 4 The modified payoff matrix by introducing social loss (S)

		WC	
		Upgrade	**Not upgrade**
MG	**Implement**	(U_{11}, π_{11})	(U_{10}- S, π_{10})
	Not implement	(U_{01}, π_{01})	(U_{00}- S, π_{00})

From equation (20), it implies that there is no change in the probability with which the water company plays to "Upgrade" by introducing the social cost of municipal governments. Because adding the social cost, there is no effect on the expected payoff gap of the municipal government between "Implement" and "Not implement". The water company will not change their choices if they find the equilibrium of the municipal government unchanged. This finding supported the premise assumption of the proposed model.

6.3 External Reward to Municipal Government

In China, there is no objective assessment system of urban water supply safety for municipal governments presently. When water companies comply with the national drinking water standards, the externalities of water supply system are indistinct and difficult to evaluate. Because of equipment subsidy, municipal government may hesitate to promote the improvement of water supply system. Providing external rewards for the municipal government's subsidy, the water company's choice may be optimized by changing the municipal government's payoff. It is assumed that when the water company chooses to "Upgrade", the municipal government will gain an external reward, R. The new payoff matrix is shown in Table 5.

Table 5 The modified payoff matrix by introducing external reward (R)

		WC	
		Upgrade	**Not upgrade**
MG	**Implement**	(U_{11}+R, π_{11})	(U_{10}, π_{10})
	Not implement	(U_{01}, π_{01})	(U_{00}, π_{00})

The new Nash equilibrium of the water company is given by

$$\mu_R^* = \frac{rF - C_R}{rF + Q[(1-\alpha)\beta C_U - \alpha P] - R} > \mu^* \quad (21)$$

Equation (21) indicates that adding external motivations to the municipal government for the implementation will change expected payoff equilibrium of the water company. The water company's probability of "Upgrade" is increased by introducing external rewards to municipal government. Since the external reward is added to U_{11}, it is helpful to achieve the optimal policy condition as shown in Equation (3).

The derivatives of μ_R^* with R is

$$\frac{\partial \mu_R^*}{\partial R} = \frac{rF - C_R}{\{rF + Q[(1-\alpha)\beta C_U - \alpha P] - R\}^2} > 0 \quad (22)$$

From equation (22), it can be obtained that increasing reward of the municipal government's investment in incentive policies for improving water supply system, increases the probability that the water company upgrades their water supply facilities. Therefore, it is effective to provide external rewards to municipal government for encouraging water supply system improvement.

7 Conclusion

In this paper, a game model between municipal government and a water company has been developed to analyze their conflicts of interests and to optimize the incentive mechanism for improving urban water supply system. The optimal combination of policies based on penalty, subsidy and water price increase is achieved. A mixed-strategy game-theoretic model is used to analyze how the regulation and incentive policies would affect the strategies for water companies to upgrade water supply facilities. In addition, the model is enriched by adding some policy variables, such as reputation damage of water companies, social cost of municipal government and external rewards to municipal government, to change the payoff of municipal government or the water company, which can improve the current polices.

It is concluded that raising water price or increasing penalty could encourage water companies to upgrade their facilities and technologies, but decrease the probability of "Implement" by municipal government. The increase of subsidy will both decrease the probability of implementation and the probability of upgrading facilities. It is suggested that penalty is an effective measure to promote water supply system improvement. Yet it cannot be assure that all water companies will upgrade their facilities. Water price increase is a necessary policy to ensure water companies to upgrade their facilities efficiently. In order to achieve the policy goals that the municipal government implements fully and water companies upgrade actively, water price increase should be equal or more than the maximum between the unit upgrading cost of the water company and the unit upgrading cost shared by municipal government. However, water price increase should not be higher than the increased unit upgrading cost. Under the optimal policy conditions, the lowest subsidy rate is equal to tax rate while the lowest water price rise is equal to the unit cost of upgrading paid by water companies. In order to minimize the water price increase, municipal governments share the upgrading cost by offering subsidy. Yet subsidy policy is not useful to promote water companies upgrading their facilities. By extending the proposed model, it is suggested that providing external rewards for municipal government's subsidy is useful and effective to encourage water supply system improvement.

In agreement with other authors [15, 18], this study confirm that penalty is a useful incentive measure. Based on cost-benefit analysis, previous studies indicated that subsidy provides economic incentives for agents to apply new technologies or participation in environmental programs [26, 27]. Heumesser (2012) applied a stochastic dynamic programming model to analyze a farmer's optimal investment strategy to adopt water-saving irrigation technologies. They found that investment is unlikely unless subsidies for equipment cost are grated. And water prices do not increase the probability to adopt irrigation system [28]. Finger (2012) analyzed policy effects on water-saving irrigation technologies in Switzerland. They found that subsidies may have crowing out effects and the implementation of water prices would lead to a sustainable increase in the share of water-saving technologies [29]. From previous studies, the incentive effect of subsidy is ambiguous and complicated. In this research, an agent's behavior depends on both its own interests and its interactions with other stakeholders and the environment under the constraints of market prices and economic incentives (penalty/subsidy). The analysis suggested that subsidy itself is not a useful policy to promote water facility upgrading. This result is similar to the research by Dong (2010). To our knowledge, previous studies failed to consider the adjustable price policy in regulatory game model. However, water price is a key factor in affect strategies of water supply stakeholders. Wei (2009) developed an integrated modeling approach to compare policy incentives to reduce nitrate leaching into groundwater. They suggested that if the water price increases were coupled with subsidies for adopting nitrate leaching mitigation practices, environmental gains could come at a lower cost [30]. From the proposed game model, water price adjustment is the most efficient policy to encourage equipment upgrading

This research focuses on urban water supply systems and management. The proposed model is applicable to urban area which has been covered by centralized water supply systems. More empirical evidences of applications is needed in further research.

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