Desalination and Water Treatment
www.deswater.com
doi: 10.5004/dwt.2018.22584

125 (2018) 132–136
September

Research on the supervision of water quality inspection bodies in China

Yixian Wang[a], Zhaoying Zuo[a,b,*], Shangrui Wu[a]

[a]*Rizhao Inspection and Certification Co. Ltd, Rizhao, 276800, China, email: cliff0633@sina.com (Y.X. Wang), Tel. +86 6338320729, email: 836594289@qq.com (Z.Y. Zuo), 396777683@qq.com (S.R. Wu)*
[b]*Business School, Hohai School University, Nanjing, 211100, China*

Received 12 March 2018; Accepted 3 June 2018

ABSTRACT

Water is the source of life and human activities can not be separated from water. Especially the quality of drinking water is closely related to human health. The paper constructed game models involving water quality inspection bodies and supervision authorities. Then the paper analyzed the influencing factors to the supervision efficiency of regulatory authorities, including the punishment intensity of the regulatory authority, reputation loss of the water quality inspection bodies and penalty from superior authority due to failure to punish the water quality inspection bodies and so on. Finally the paper put forward specific measures to solve the problem.

Keywords: Water quality inspection; Static game; Evolutionary game

1. Introduction

Water is the source of life and human activities cannot be separated from water. Taking drinking water for example, The quality of drinking water is closely related to human health. Drinking water quality are different not only among countries, but also between different regions of the same country. With the development of social economy and the improvement of living standard, people's requirements for the quality of drinking water have been continuously improved, and the drinking water quality standards have been continuously developed and perfected. In July 1, 2007, the national standard for drinking water hygiene GB 5749-2006 issued by the National Standards Committee and the Ministry of public health and the 13 national standard of drinking water hygiene inspection officially implemented. This is the first revision of the national standard for drinking water released in 1985 for the first time in 21 years. The standard has the following three characteristics. The first one is to strengthen the requirements for the disinfection of water quality organic matter, microorganism and water quality. The second one is to unify the sanitary standards for drinking water in urban and rural areas. The third is to achieve the standards of drinking water and international standards. The selection of the standard takes full account of the actual situation of our country, and referred to WHO's drinking water quality guidelines. Also the standard referred to the drinking water standards of the European Union, the United States, Russia and Japan. There are lots of articles about drinking water. Arsenic presence of drinking water in China was reviewed [1]. Drinking water quality governance from a comparative case study of Brazil, Ecuador, and Malawi was mentioned [2].

Game theory is the study of mathematical models of conflict and cooperation between intelligent rational decision-makers. The game theory model consists of three components: player, strategy, and pay-off. The player is an agent who participates in the game and each player has his own strategies with different pay-offs. With this basic setting, the main purpose of game theory is to derive an equilibrium in the game depending on the players and their strategies. A supply chain enterprises operating mechanism model from

*Corresponding author.

Presented at the 4th Annual Science and Technology Conference (Tesseract'17) at the School of Petroleum Technology, Pandit Deen Dayal Petroleum University, 10–12 November 2017, Gandhinagar, India

the perspective of game theory, used repeated game, individual game and group of evolutionary game and verified the importance of cooperation in creative products supply chain through theoretical proof and examples was established [3]. A new standardization framework by combining network analysis and the game theory model was proposed in literature [4]. The political incentives of government officials to cooperate with one another to achieve a common goal through game theory was studied in literature [5]. Also, national supervision on inspection body by game theory was also studied [6].

Inspection bodies are specialized third party agencies. They help enterprises implement the supply-side reform and respond to consumers' demands, like a strong catalyst to enterprises' vitality. False inspection happens over and over again in China, damaging the interests of consumers and undermining the social credit mechanism. Inspection and certification industry has many similar characteristics. The lack of effective external supervision was believed the cause of false certification and that only by certifying "certifications" and establishing an external supervision system can we prevent false certification [7]. Motivating certification bodies to establish credibility themselves to reject collusion with enterprises was suggested [8]. Monopolistic certification bodies are more likely to comply with certification standards to ensure honest certification. A repeated game model involving enterprises, certification bodies and consumers was constructed. The causes leading to the long-term lack of credibility in certification bodies from the perspective of low efficiency equilibrium was analyzed and corresponding regulatory measures was put forward [9]. Also, the fuzzy method was applied to measure the service quality in certification and inspection industry [10]. Certification effectiveness on organizational performance in China was discussed in literature [11].

It is obvious that few paper discussed supervisions on water quality inspection bodies. The paper can provide certain reference for promoting the development of modern service industry and national strategic emerging industries. The water quality inspection industry is an important tool and technical support for the national governance system, and also a modern service industry and high-tech service industry encouraged by China. According to the "13th Five-Year" Development Planning for National Strategic Emergency Industries issued in 2016, the inspection industry was included as a national strategic emergency industry. In addition, this research is also of great significance to enhancing regulatory authorities' regulatory supervision on water inspection bodies and key activities, and at the same time provides reference for improving services of inspection bodies.

2. Model establishment and analysis

There are mainly two players in the government regulatory game - the regulatory authority and the water quality inspection bodies. From the perspective of the water quality inspection bodies, there are two strategies: strict inspection and relaxed inspection. The probabilities of the two are denoted as p and (1-p) respectively. From the perspective of the regulatory authority, the strategies are imposing regulatory supervision or not imposing it on the water quality inspection bodies, and the mixed strategy is (p, 1-p). The probability that the regulatory authority does and does not conduct supervision are denoted by q and (1-q) and the mixed strategy is (q, 1-q). Let's suppose if there is any violation or non-standard act in the inspection process by the water quality inspection bodies, the regulatory authority will definitely detect it and impose a penalty. The penalty accounts for a certain percentage of the business income, which is set to be k; the regulatory supervision cost is sum of the costs including on-site inspection fees, which is assumed to be T. If the government regulatory authority conducts the regulatory supervision function, and the water quality inspection bodies performs relaxed inspection, the regulatory authority will be subject to the penalty by a higher authority, which is denoted as F_1. If the government regulatory authority conducts effective supervision and investigates and punishes the unfair conduct or violation by the water quality inspection bodies, the regulatory authority will be recognized by and enjoy better prestige in the public. Such benefit is denoted as R_0. The water quality inspection bodies will be subject to penalty and its violation will be circulated by the regulatory authority, which will damage the reputation of the water quality inspection bodies and further affect its operations. Such loss is denoted as L. If the certification quality conduct quality management system inspection strictly accordance with relevant requirements, it will need to invest high cost, which is denoted as C_1. The cost of relaxed inspection is C_2, and the former is greater than the latter. V represents the certification income earned by the water quality inspection bodies.

The payoff matrix is shown in Table 1.

Expected income of water quality inspection bodies

$$E_1 = pq(V - C_1) + p(1-q)(V - C_1) + (1-p)q(V - C_2 - Vk - L) + (1-p)(1-q)(V - C_2) \quad (1)$$

Expected income of regulatory authority

$$E_2 = pq(-T) + (1-p)q\ (R_0 - T) + (1-p)(1-q)(-F1) \quad (2)$$

Take the derivative of E_1 with respect to p, to obtain the optimal first-order condition for the strict inspection by the water quality inspection bodies:

$$\frac{\partial E_1}{\partial p} = C_2 - C_1 + qVk + qL = 0 \quad (3)$$

Table 1
Payoff matrix for government supervision on water quality inspection bodies

		Water quality inspection bodies	
		Non-rent seeking	Rent seeking
Regulatory authority	Supervision	$-T$, $V-C_1$	$-R_0-T$, $V-C_2-Vk-L$
	General supervision	0, $V-C_1$	$-F_1$, $V-C_2$

Take the derivative of E_2 with respect to q to obtain the optimal first-order condition for the regulatory authority:

$$\frac{\partial E_2}{\delta q} = pT + (1-p) + (1-p)(R_0 - T) + (1-p)F_1 = 0 \quad (4)$$

Combine the above two equations to obtain the optimal probability of strict inspection by the water quality inspection bodies at the equilibrium state:

$$p^* = 1 - \frac{T}{F_1 + R_0} \quad (5)$$

Optimal probability of regulatory authority supervision:

$$q^* = \frac{C_1 - C_2}{Vk + L} \quad (6)$$

Let's discuss influencing factors to the optimal probability p^* of strict inspection by the water quality inspection bodies. Take the partial derivative of p^* with respect to R_0 to obtain: $\frac{\partial p^*}{\partial R_0} = \frac{T}{(R_0 + F_1)^2} > 0$, indicating that p^* is the monotonic increasing function of the income R_0 and that the greater R_0 is, the greater p^* will be. When the regulatory authority conducts effective supervision, the more positive effects investigating the water quality inspection bodies bring, the more it will tend to conduct supervision. Take the partial derivative of p^* with respect to T to obtain $\frac{\partial p^*}{\partial T} = -\frac{1}{R_0 + F_1} < 0$, So when the supervision cost is high, the regulatory authority will relax supervision and in this case, the probability of strict inspection by the water quality inspection bodies will decrease and the likelihood of quality issues will increase. Take the partial derivative of p^* with respect to F to obtain $\frac{\partial p^*}{\partial F} = \frac{T}{(R_0 + F_1)^2} > 0$, So when the regulatory authority fails to conduct effective supervision, the more negative feedback it receives, the more it will tend to conduct supervision, the more likely the water quality inspection bodies will be investigated and fined and the higher the probability of strict inspection will be.

The more of C_1–C_2 is and the higher the probability of supervision by the regulatory authority will be. Take the partial derivative of q^* with respect to C_1–C_2 to obtain $q_{C1-C2}{}^* = \frac{1}{Vk + L} > 0$, that is, $q_{C1-C2}{}^*$ is the monotonic increasing function of C_1–C_2. The greater the difference between the costs of strict inspection and non-compliant inspection is, the more effective supervision the regulatory authority will provide. The greater the punishment intensity k by the regulatory authority is, the smaller the probability of optimal supervision by the regulatory authority will be. Take the partial derivative of q^* with respect to k to obtain $q_k{}^* = \frac{C_1 - C_2}{Vk^2} < 0$, that is, q^* is the monotonic decreasing function of k. If the non-compliant inspection behavior of the water quality inspection bodies is discovered, the greater the amount and intensity of the penalty is, the more deterrent effects there will be on the water quality inspection bodies; and the more reputation loss the water quality inspection bodies suffers, the smaller the probability of optimal supervision by the regulatory authority will be. Take the partial derivative of q^* with respect to L to obtain $q_L{}^* = \frac{C_1 - C_2}{Vk^2} < 0$ .The greater reputation loss the water quality inspection bodies suffers if its violation is discovered, the less motive the water quality inspection bodies will have to conduct non-compliant inspection, and the less supervision the regulatory authority will impose.

Let's suppose: there are also two strategies for the regulator: strict supervision and general supervision, whose costs are k_1 and k_2, respectively; when the water quality inspection bodies chooses strict inspection and the regulatory authority will choose general supervision, the water quality inspection bodies receives the normal income R_1 without any extra income or loss, and the regulatory authority only needs to pay a low supervision cost k_2; when the regulatory authority chooses general supervision, it cannot penalize the water quality inspection bodies for relaxed inspection, so the water quality inspection bodies can obtain extra income from relaxed inspection R_2, and the regulatory authority, besides paying the general supervision cost, also needs to suffer from a reputation damage H due to inadequate supervision; when the water quality inspection bodies is under the strict supervision by the regulatory authority due to relaxed inspection, it will be subject to a penalty, for which it will pay L_2, and besides, it will also suffer from a reputation damage S due to the penalty, that is, the loss the water quality inspection bodies needs to bear due to relaxed inspection is $L_2 + S$. At this time, due to stricter supervision, the regulatory authority will have to pay more cost than that of general supervision $k_1 (k_1 > k_2)$.

The payoff matrix is shown in Table 2.

Next we describe pure strategy Nash equilibrium analysis. When $L_2 - k_1 < -H - k_2$, the equilibrium solution is ($-H-k_2$, $R_1 + R_2$). When the regulatory authority penalizes the violation of the water quality inspection bodies under the strict supervision strategy at a higher cost than that of general supervision, the regulatory authority will tend to choose the general regulatory strategy, and the water quality inspection bodies will also choose relaxed inspection for the extra benefits from the violation. Such game equilibrium is not conducive to the development of water quality inspection bodies. When $L_2 + H > k_1 - k_2$, it is necessary to perform mixed strategy analysis based on the probabilities of specific behaviors by the regulatory authority and the water quality inspection bodies.

Also we use evolutionary game analysis on the water quality inspection bodies. Suppose the probability that the

Table 2
Payoff matrix of regulatory authority supervision on water quality inspection bodies

		Water quality inspection bodies	
		Strict inspection	Relaxed inspection
Regulatory authority	Supervision	$-k_1$, R_2	L_2-k_1, $-L_2-S$
	General supervision	$-k_2$, R_1	$-H-k_2$, R_1+R_2

water quality inspection bodies chooses compliant operation is p, that the probability that it chooses non-compliant operation is (1-p), that the probability that the regulatory authority chooses strict supervision is q and that the probability that it chooses general supervision is (1-q), the expected income from strict supervision by the regulatory authority is:

$$U_1 = -k_1 p + (L_2 - k_1)(1-p) = L_2 - L_2 p - k_1 \quad (7)$$

The expected income from general supervision by the regulatory authority is:

$$U_2 = -k_2 p - (H + k_2)(1-p) = Hp - k_2 - H \quad (8)$$

The expected income from general supervision by the regulatory authority

$$\begin{aligned} U_3 &= q[-k_1 p + (L_2 - k_1)(1-p)] + (1-q)[-k_2 p - (H+k_2)(1-p)] \\ &= L_2 - k_1 + k_2 + H + pq(L+H) + Hp \end{aligned} \quad (9)$$

The replicator dynamics equation for the regulatory authority implementing strict supervision over the time t is:

$$F(q) = dq/dt = q(U_1 - U_3) = q(1-q)(L_2 - L_2 p - k_1 - Hp + k_2 + H) \quad (10)$$

According to the dynamic equation result, this model has three steady states (Fig. 1). When the replicator dynamics equation reaches the equilibrium state, the ratio of the game players adopting different strategies remains constant (denoted as p_0), that is, $F(q) = 0$ is the evolution equilibrium state of the game. When $p = (L - k_1 + k_2 + H)/(L_2 + H)$, $F(q) = 0$ i.e. when the probability that the water quality inspection bodies chooses compliant operation is $(L_2 - k_1 + k_2 + H)/(L_2 + H)$, whether the regulatory authority chooses to impose supervision or not, this game will be at a stable state; When $p \neq (L_2 - k_1 + k_2 + H)/(L_2 + H)$, let $F(q) = 0$, and then $q = 0$ or $q = 1$. Take the derivative of $F(q)$ with respect to q to obtain: $F(q) = (1-2q)(L - Lp - C_1 - Hp + C_2 + H)$.

When $p < (L_2 - k_1 + k_2 + H)/(L_2 + H)$, $F(0)' > 0$ and $F(1)' < 0$, so $q = 1$ is the stable strategy;

When $p > (L_2 - k_1 + k_2 + H)/(L_2 + H)$, $F(1)' < 0$ and $F(1)' > 0$, so $q = 0$ is the stable strategy;

As shown in Fig. 1:

Let the expected income from the compliant operation by the water quality inspection bodies be U_4, that from the non-compliant operation be U_5 and the average income be U_6, then:

$$U_4 = R_1 q + R_1(1-q) = R_1 \quad (11)$$

$$U_5 = (-L_2 - S)q + (R_1 + R_2)(1-q) = R_1 + R_2 - (L_2 + S + R_1 + R_2)q \quad (12)$$

$$\begin{aligned} U_6 &= pU_4 + (1-p)U_5 = R_1 q + R_1(1-q) + (-L_2 - S)q \\ &+ (R_1 + R_2)(1-q) = (1-p)[R_1 + R_2 - (L_2 + S + R_1 + R_2)q] \end{aligned} \quad (13)$$

Let's construct the replicator dynamics equation for the water quality inspection bodies choosing strict inspection:

$$F(p) = dp/dt = p(U_6 - U_4) = -p(1-q)[R_2 - (R_1 + R_2 + L + S)q]q \quad (14)$$

When $q = R_2/(R_1 + R_2 + L_2 + S)$, that is, when the regulatory authority conducts strict supervision at a probability of $q = R_2/(R_1 + R_2 + L_2 + S)$, the ratio between strict and relaxed inspection by the water quality inspection bodies remains unchanged, as shown in Fig. 2a. When $q \neq R_2/(R_1 + R_2 + L_2 + S)$, let $F(P) = 0$, and then $p = 0$ or $p = 1$. Take the derivative of $F(p)$ with respect to p to obtain: $F(p) = (2p-1)[R_2 - (R_1 + R_2 + L_2 + S)q]$.

When $q > R_2/(R_1 + R_2 + L_2 + S)$, $F(0)\Delta > 0$, $F(1)\ \Delta < 0$, so $p = 1$ is the stable strategy, as shown in Fig. 2. (b);

When $q < R_2/(R_1 + R_2 + L + S)$, $F(0)\Delta < 0$, $F(1)\Delta > 0$, so $p = 0$ is the stable strategy, as shown in Fig. 2 (c).

The greater the penalty intensity L_2 is, the greater the probability that the water quality inspection bodies choose compliant operation, the smaller the probability that the regulatory authority imposes strict supervision will be. So increasing the intensity of penalty on the violations of certification bodies can improve the self-discipline of the industry and then reduce the probability of strict supervision. Reputation loss is also a key factor affecting the self-discipline of the certification industry. Strengthening media supervision and public reporting can effectively improve the self-discipline of the certification industry and reduce the probability of non-compliant operations. The extra income from non-compliant operations is the main cause that attracts a water quality inspection bodies to conduct such non-compliant operations, and the investment income from the huge amount of customer precipitation fund is the main incentive that makes the water quality inspection bodies chooses the violation strategy. How to regulate the use of the pre-

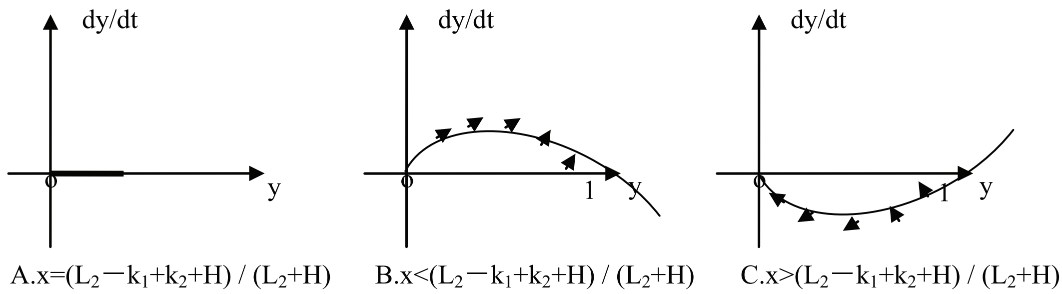

Fig. 1. Dynamic phase diagram of regulatory authority.

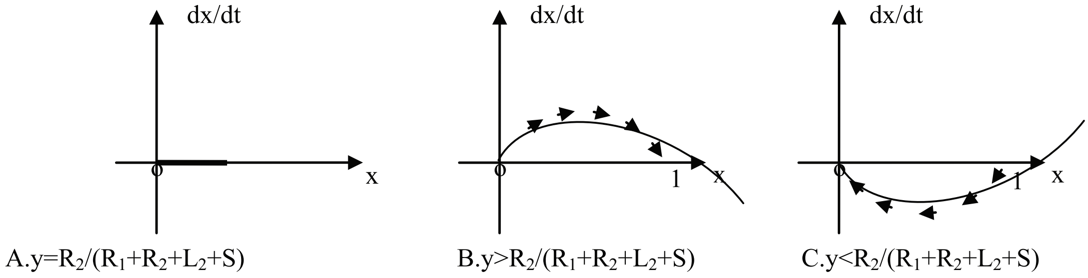

Fig. 2. Dynamic phase diagram of water quality inspection bodies.

cipitation fund will have a direct impact on the strategy selection of certification bodies.

The probability of compliant operation by the water quality inspection bodies is closely related to the supervision cost of the regulatory authority. Reducing the difference between the costs of strict and general regulation can effectively increase the probability of strict inspection by the water quality inspection bodies. The cost of general supervision is assumed to be minimal, so the cost of strict supervision should be reduced as much as possible. Excessively high supervision cost will make it more difficult for the regulatory authority to conduct supervision and at the same time, increase the probability of non-compliant operation by the water quality inspection bodies.

3. Conclusions

The paper constructs a static game model for regulatory authorities and water quality inspection bodies from a new perspective. Then the paper analyzes the influencing factors to the probability of optimal supervision and those to the optimal probability of strict inspection by the water quality inspection bodies. Then the paper constructs a dynamic evolutionary game model under the bounded rationality of the regulatory authority and the water quality inspection bodies. The players always choose and adjust their own strategy according to the counterpart's strategy, and the two sides are mutually dependent. The punishment intensity of the regulatory authority, reputation loss of the water quality inspection bodies, regulatory supervision cost, proceeds from punishment of the water quality inspection bodies, and penalty from superior authority due to failure to punish the water quality inspection bodies all affect the supervision efficiency of the regulatory authority. Finally, this paper puts forward specific solution. However, the paper neither give deep analysis on the dynamic game between the two parties in full rational conditions, nor the game between supervision departments, which are all the future research directions.

References

[1] J. He, L.A. Charlet, A review of arsenic presence in China drinking water, J. Hydrology, 492 (2013) 79–88.
[2] G.L. Kayser, U. Amjad, F. Dalcanale, J. Bartram, M.E. Bentley, Drinking water quality governance: a comparative case study of Brazil, Ecuador, and Malawi, Environ. Sci. Policy, 48 (2015) 186–195.
[3] T. Chen, Y. Jiang, Research on operating mechanism for creative products supply chain based on game theory, Discrete Cont. Dynam. Syst. – Ser. S (DCDS-S), 8 (2017) 1103–1112.
[4] K. Kim, S. Jung, J. Hwang, A. Hong, A dynamic framework for analyzing technology standardisation using network analysis and game theory, Technol. Anal. Strat. Manage., 394 (2017) 1–16.
[5] Y. Chen, A.G.O. Yeh, Y. Zhang, Political tournament and regional cooperation in china: a game theory approach, Annals Region. Sci., 58 (2017) 1–26.
[6] Y.S. Zhang, Y.X. Wang, Z.Y. Zuo, M.J. Hu, Z.C. Xiang, H.Y. Li, F. Wang, Research on the evolution game of national Supervision on Inspection Body, Revista de la Facultad de Ingeniería, 32 (2017) 182–188.
[7] D.M. Cain, G. Loewenstein, D.A. Moore, The dirt on coming clean: perverse effects of disclosing conflicts of interest, J. Legal Studies, 34 (2005) 1–25.
[8] R. Strausz, Honest certification and the threat of capture, Int. J. Ind. Org., 23 (2005) 45–62.
[9] C.H. Miao, Competition in quality standards, J. Ind. Econ., 57 (2009) 214–214.
[10] R. Liu, L. Cui, G. Zeng, H.Y. Wu, C.J. Wang, S. Yan, B.Y. Yan, Applying the fuzzy servqual method to measure the service quality in certification and inspection industry, Appl. Soft Comp. J., 26 (2014) 508–512.
[11] Z. Zuo, D. Tang, Research on the impact of ISO9001 certification effectiveness on organizational performance in China, Boletin tecnico/Technical Bulletin, 55 (2017) 644–655.