ISSN: 1813-4890

Analyzing Stakeholder Interactions in Farmland Water Conservancy Projects Using Game Theory

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Abstract

This study, grounded in stakeholder theory, identified five principal stakeholders in farmland water conservancy projects: water administration authorities, project owners, contractors, supervisors, and designers. A case study was conducted using game theory to examine the interactions and strategic behaviors among these stakeholders. The findings revealed that the decision to implement supervision in farmland water conservancy projects was influenced by factors such as the economic incentives for construction enterprises to cut corners, penalties for speculative practices, and rewards for maintaining construction quality and adhering to standards. Additionally, the commitment of participating enterprises to uphold quality standards was closely related to the supervisory costs and the potential repercussions of regulatory negligence. In response to the challenges identified in the construction and management, the study proposed a series of targeted interventions designed to enhance project management practices. The recommendations aimed to promote the sustainable development and operational efficiency of farmland water conservancy projects.

Keywords

Farmland water conservancy projects; Stakeholders; Game analysis.

1. Introduction

Farmland water conservancy represents a fundamental engineering initiative essential for achieving sustainable agricultural development. It is crucial to stabilizing agricultural output, enhancing farmers' incomes, and mitigating the adverse impacts of drought and flood events. Moreover, it serves as a critical component of rural revitalization efforts, supporting economic and social progress in agricultural regions. The farmland water conservancy project system, as a mechanism for rural public service provision, emerged in China in response to the fiscal and administrative imbalances created by the tax-sharing reform. This reform aimed to address disparities between central and local governments, thereby ensuring the equitable delivery of basic public services. Farmland water conservancy projects are characterized as public goods, distinguished by extended return periods, limited profitability, and substantial uncertainties. Therefore, these projects are predominantly financed, constructed, and managed by governmental entities. Nonetheless, the involvement of private sector entities is occasionally integrated to optimize efficiency through the complementary strengths of public-private collaboration. However, the implementation of these projects is challenged by the participation of diverse stakeholders, resulting in complex relational dynamics, inefficient information exchange, and overlapping responsibilities among government agencies. These challenges often manifest as fragmented funding allocations, redundant construction activities, and diminished project coordination. Nonetheless, the involvement of private sector entities is occasionally integrated to optimize efficiency through the complementary strengths of public-

ISSN: 1813-4890

private collaboration. However, the implementation of these projects is challenged by the participation of diverse stakeholders, resulting in complex relational dynamics, inefficient information exchange, and overlapping responsibilities among government agencies.

The stakeholder ecosystem of farmland water conservancy projects encompasses government agencies, water user associations, village committees, contractors, and farming households, each pursuing distinct and occasionally conflicting objectives. Interactions among these stakeholders are characterized by iterative negotiations, aimed at balancing competing interests and fostering cooperative relationships. Through structured communication and consultation, these relationships progress from initial asymmetry to a state of dynamic equilibrium, facilitating effective project governance. Employing a game-theoretic framework to analyze the inherent challenges in the construction and management of farmland water conservancy projects provides a rigorous basis for identifying inefficiencies and devising strategic interventions.

2. Theoretical Basis

2.1. Farmland Water Conservancy Projects

Rodney and Turner describe a project as a temporary organization in which resources, including human, material, and financial assets, are allocated to achieve beneficial changes. Similarly, the Project Management Institute in the United States [7] defines a project as a temporary effort undertaken to create a unique product or service. These perspectives emphasize the uniqueness and temporary nature of projects but do not adequately address the needs of project stakeholders. An important concept in modern project management involves ensuring the satisfaction of stakeholders,[9]. Ding et al. proposed that a project functions as a social networking platform designed to accomplish temporary, unique tasks while addressing the needs of various stakeholders. This study defines farmland water conservancy projects as initiatives involving the allocation of human, material, and financial resources to construct farmland water conservancy infrastructure, with the primary objectives of ensuring agricultural productivity and meeting stakeholder needs.

2.2. Stakeholder Identification and Classification

Stakeholders play a critical role in determining the success of a project [11]. Effective stakeholder management requires scientific identification and reasonable classification. Recognizing the limitations of single-dimensional stakeholder identification, many scholars have adopted multi-dimensional evaluation and classification approaches. Based on the "multi-dimensional segmentation" concept, Mitchell and Wood [11] categorized stakeholders into definitive, expectant, and latent stakeholders using three attributes: legitimacy, power, and urgency. This approach, widely known as the "Mitchell Scoring Method," is illustrated in Figure 1. Poplawska et al. [13] proposed a multi-dimensional stakeholder identification method employing fuzzy logic and visual analysis to rank stakeholders by their level of importance. Chen and Jia developed an early stakeholder identification and classification method tailored to the Chinese context. Building on Mitchell's research, they incorporated dimensions such as proactiveness, significance, and urgency to identify and categorize stakeholders. This represents an early contribution by Chinese scholars.

ISSN: 1813-4890

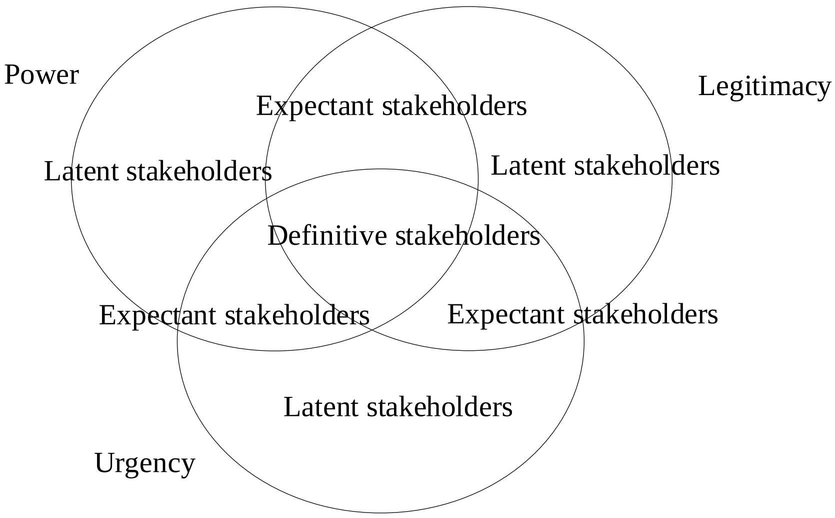

Figure 1. Mitchell's stakeholder identification and classification method.

2.3. Stakeholders in Farmland Water Conservancy Projects

The implementation of engineering projects involves a diverse array of stakeholders, making stakeholder management a complex task. To address these challenges, researchers have developed methods for identifying and classifying stakeholders during project implementation. Wang and Xu performed an empirical analysis based on urgency, influence, proactiveness, and comprehensive dimensional attributes, ranking stakeholders of large-scale engineering projects by comprehensive dimension scores. Jiang et al. [17] classified stakeholders into internal and external groups, analyzing the needs, expectations, and impacts of internal stakeholders. Sun et al. identified key stakeholders in engineering projects by examining their positions within relational network structures. Ding proposed a three-dimensional framework for stakeholder identification in generalized engineering projects, consisting of (1) lifecycle-based identification: stakeholders are determined based on their involvement at various stages of the project lifecycle. (2) task-based identification: stakeholders are identified according to their roles in specific project tasks, such as planning, operations, and maintenance activities. (3) role-based differentiation: stakeholders are categorized based on their defined roles and responsibilities within the project framework. This three-dimensional approach accounts for the dynamic characteristics of projects and the evolving roles of stakeholders, making it particularly suitable for stakeholder definition in engineering project contexts.

2.4. Elements and Classification of Game Theory

Game theory, a contemporary mathematical discipline and a vital component of operations research, examines how individuals or groups formulate strategies in response to others under defined constraints. It provides robust analytical frameworks for resolving conflicts and facilitating cooperation among different parties. Games are broadly categorized into cooperative and non-cooperative types, distinguished by the feasibility of binding agreements among participants. Further classifications arise based on the timing of decisions and the availability of information, resulting in four primary game types: static games with complete information, dynamic games with complete information, static games with incomplete information, and dynamic games with incomplete information. The fundamental components of game theory include participants, information, payoffs, behavioral decisions, and equilibrium outcomes. Among them, equilibrium is the optimal strategy combination for all participants.

ISSN: 1813-4890

2.5. Application of Game Theory in Farmland Water Conservancy Projects

The enhancement of farmland water conservancy systems is essential for advancing these projects. Cai developed an evolutionary model grounded in endogenous game theory to guide system improvements in farmland water conservancy projects. Du employed game theory to propose recommendations for optimizing government-related farmland water conservancy systems. These included reforms to the tax-sharing fiscal system, strengthening legal frameworks for central government oversight of local governments, and establishing mechanisms for supervision and incentives to regulate central government investments in local farmland water facilities. Liu and Wang identified, through game theory analysis, that excessive dependence on government provision for farmland water conservancy resulted in inadequate supply for small-scale projects and overuse of government-operated facilities. To encourage enterprises to engage in high-quality construction, Feng and Yang recommended strategies such as increasing financial incentives, enhancing external benefits, and imposing stricter penalties for non-compliance. Farmers, as primary beneficiaries and key decision-makers in agricultural production, play a pivotal role in the construction and maintenance of farmland water facilities. However, as rational economic agents, their participation is shaped by various influencing factors. Researchers have recommended measures such as reducing transaction costs in water cooperation [23], implementing effective penalty mechanisms, and reestablishing shared norms to enhance cooperation.

Game theory serves as a powerful analytical framework for addressing the coordination of stakeholder interests and participation in farmland water conservancy projects. Rural regions, characterized by low population mobility and close interpersonal relationships, form the social context in which these projects are undertaken. Consequently, stakeholder definitions in these projects must incorporate the broader socio-environmental construction context. In this study, stakeholders in farmland water conservancy projects were defined as individuals or groups with vested interests in the project outcomes and the surrounding construction environment. Five stakeholder groups were identified as having the greatest influence: water administrative authorities, project owners, contractors, supervisory bodies, and design entities. For analytical clarity, contractors and design entities, due to their alignment in strategic decision-making, were collectively categorized as participating enterprises. Similarly, water administrative authorities, project owners, and supervisory bodies, which perform overlapping functions such as financial oversight, progress management, and design and quality supervision during construction, were grouped under the category of regulators. This categorization facilitates a focused exploration of stakeholder interactions and strategic behaviors in the context of farmland water conservancy projects.

3. Assumptions of the Game Model

(1) Basic Assumptions: The game is characterized by limited yet complete information. It is dynamic in nature, with all participants assumed to act rationally to maximize their respective benefits. The behavioral strategies of all stakeholders involve elements of uncertainty.

(2) Strategy Set: The regulator has two strategic options: to monitor or not monitor the participating enterprises. The probability of monitoring is denoted as θ, while the probability of not monitoring is $1-\theta$. Participating enterprises aim to maximize their profits by choosing between maintaining construction quality, with a probability of γ, or cutting corners, with a probability of $1-\gamma$.

(3) Costs and Benefits of Regulators: When the regulator chooses to monitor, a cost c ($c > 0$) is incurred. If a participating enterprise engages in corner-cutting and substandard construction while the regulator opts not to monitor, the regulator suffers a dereliction loss d. This loss

includes penalties such as administrative sanctions, reputational damage, and diminished credibility.

(4) Participating enterprises may cut corners during project construction to reduce costs and maximize profits. The associated costs and benefits are as follows: Upon successful project completion, the participating enterprise earns a base benefit of S. If the enterprise adheres to contractual obligations and maintains quality, an additional incentive reward m is awarded, and if the enterprise cuts corners but evades detection, it still receives the incentive reward m. Cost savings resulting from corner-cutting are denoted as K. If the enterprise's corner-cutting is detected by the regulator, a penalty F is imposed.

Table 1 Payoff matrix of the game

		Participating enterprises	
		Maintaining quality γ	Cutting corners 1-γ
Regulators	Monitoring θ	(-c, S+m)	(-c, S+K-F)
	Not monitoring 1-θ	(0, S+m)	(-d, S+K+m)

4. Game Model Analysis

(1) When the probability of the participating enterprise maintaining quality is γ, the expected payoff for the regulator under the monitoring strategy (θ=1) is expressed as follows:

$$\pi_g(1,\gamma) = -c\gamma - c(1-\gamma) = -c \tag{1}$$

When the probability of the participating enterprise maintaining quality is γ, the expected payoff for the regulator under the non-monitoring strategy (θ=0) is expressed as follows:

$$\pi_g(0,\gamma) = d\gamma - d \tag{2}$$

Solving for the equilibrium condition, $\pi_g(1,\gamma) = \pi_g(0,\gamma)$, the probability $\gamma^* = 1\text{-}\frac{c}{d}$.

(2) When the regulator's probability of monitoring is θ, the expected payoff for the participating enterprise when maintaining quality (γ = 1) is expressed as follows:

$$\pi_p(1,\theta) = (S+m)\theta + (S+m)(1-\theta) = S+m \tag{3}$$

When the regulator's probability of monitoring is θ, the expected payoff for the participating enterprise when cutting corners (γ = 0) is expressed as follows:

$$\begin{aligned}&\pi_p(0,\theta) = (S+K-F)\theta + (S+m+K)(1-\theta)\\&= -\theta(m+F) + S+m+K\end{aligned} \tag{4}$$

Solving for the equilibrium condition $\pi_p(1,\theta) = \pi_p(0,\theta)$, the probability was obtained as $\theta^* = \frac{K}{m+F}$.

Based on the above analysis, the Nash equilibrium for the mixed-strategy game model is

$$\gamma^* = 1\text{-}\frac{c}{d},\ \theta^* = \frac{K}{m+F} \tag{5}$$

Interpretation of γ^*: If the probability of the participating enterprise maintaining quality γ is less than γ^*, the regulator will adopt the monitoring strategy. If γ exceeds γ^*, the regulator will choose not to monitor. When $\gamma = \gamma^*$, the regulator is indifferent between monitoring and not monitoring.

Interpretations of θ^*: If the probability of the regulator monitoring θ is less than θ^*, the participating enterprise will cut corners. If θ exceeds θ^*, the participating enterprise will maintain quality. When $\theta = \theta^*$, the participating enterprise is equally likely to choose either strategy.

5. Discussion of Game Results

The analysis yields the following conclusions: (1) The probability of participating enterprises maintaining construction quality is negatively correlated with the regulator's monitoring cost (c) and positively correlated with the regulator's dereliction loss (d). This relationship arises for the following reasons: When monitoring costs are high, the regulator is more inclined to adopt the non-monitoring strategy, encouraging enterprises to cut corners. Conversely, low monitoring costs increase the likelihood of monitoring, discouraging corner-cutting due to the heightened risk of detection. When the regulator's dereliction loss is high, the regulator is motivated to monitor to avoid reputational and administrative penalties, prompting enterprises to maintain quality. A low dereliction loss reduces the incentive for monitoring, increasing the likelihood of corner-cutting by enterprises. To reduce the probability of corner-cutting during project implementation, monitoring costs (c) should be minimized, and dereliction losses (d) should be increased. (2) The likelihood of the regulator monitoring is positively correlated with the savings (K) achieved by enterprises through corner-cutting and negatively correlated with the penalties for detection (F) and incentive rewards for maintaining quality (m). Higher savings (K) from corner-cutting attract greater regulatory scrutiny, increasing the probability of monitoring. When penalties (F) for corner-cutting and incentive rewards (m) for maintaining quality are high, enterprises are more inclined to maintain quality, reducing the regulator's need to monitor. Conversely, low penalties and rewards increase the likelihood of corner-cutting, necessitating greater regulatory oversight.

6. Management Insights and Recommendations

The regulator's decision to oversee farmland water conservancy projects is influenced by several factors, including the profits that participating enterprises gain through shortcuts, penalties for speculative behavior, and incentives for high-quality construction. Similarly, the commitment of enterprises to high-quality construction is shaped by the regulator's oversight costs and the penalties for negligence. To minimize speculative behavior by enterprises, it is recommended to increase penalties for cutting corners while enhancing rewards for adhering to high-quality standards.

6.1. Improving Supervision and Management Systems for Project Construction

The strategy adopted by participating enterprises in the construction of farmland water conservancy projects is closely tied to whether the regulator implements supervision. Therefore, measures should be adopted to encourage the regulator to apply supervisory strategies, thereby reducing speculative practices by enterprises and promoting high-quality project construction. First, clearly delineating the roles and responsibilities of the regulator ensures effective oversight and rational task allocation. In farmland water conservancy projects, the supervisory body should primarily manage quality control, progress tracking, investment oversight, and contract management, while the project owner should be responsible for overall

ISSN: 1813-4890

coordination and financial management. Second, leveraging advanced supervisory tools, such as internet and network technologies, can enhance supervision efficiency and reduce oversight costs. Third, implementing a comprehensive, tiered supervision system, supported by a coordinated regulatory mechanism, facilitates effective interaction among supervisory bodies, minimizes redundancy, and boosts the efficiency of oversight activities. Fourth, involving external supervision sources, such as water users, media outlets, and the public, strengthens monitoring efforts. Public engagement can be incentivized through mechanisms that encourage reporting and exposing illegal activities, such as corner-cutting by enterprises, thereby promoting accountability.

6.2. Implementing a Strict Accountability System for Projects

Higher costs for regulatory negligence increase the likelihood of supervision, thereby reducing the tendency for enterprises to cut corners and contributing to better project quality. Consequently, it is crucial to impose stricter penalties for regulatory negligence and hold project supervisory departments accountable for failing to meet construction standards. First, implementing strict institutional measures ensures that regulatory authority and responsibilities are clearly defined. Joint liability for quality issues resulting from negligence should be assigned to regulators. Second, establishing a comprehensive system, including a robust regulatory credit framework, can record the institutions and individuals involved in negligence for future reference. Third, designing legal mechanisms for negligence should include a well-developed litigation system. Those responsible for quality issues arising from dereliction of duty should be held legally accountable.

6.3. Strengthening Penalties for Enterprises Engaging in Substandard Construction Practices

The likelihood of participating enterprises engaging in substandard practices increases as the fines for such behavior decrease. Therefore, it is essential to impose more stringent penalties for speculative behavior. First, fines for enterprises found cutting corners should be significantly increased. In addition to higher financial penalties, these enterprises should be required to make corrective actions within a specified timeframe. Second, a blacklist for the agricultural water conservancy construction sector should be established, listing enterprises with a history of substandard practices that have resulted in quality issues. Enterprises on this list would face industry restrictions, serving as a deterrent to future misconduct.

6.4. Increasing the Proportion of Additional Incentive Rewards in Project Settlement

Additional incentive rewards in project construction influence both the willingness of the regulatory body to supervise and the efforts made by participating enterprises. Lower incentive rewards increase the likelihood of speculative behavior during project implementation. Since enterprises for agricultural water conservancy projects are typically selected through a bidding process, project management authorities may have limited information about the enterprises' qualifications and capabilities. To encourage high-quality construction, the contract should stipulate a reasonable increase in the proportion of additional incentive rewards in the total settlement. The basic project payment should cover the enterprise’s expenditures on raw materials, labor, and management during construction. Additional incentive rewards, however, should be contingent upon the results of project performance assessments, ensuring that rewards are only granted if the construction meets established standards and is of reliable quality.

Acknowledgements

This research was funded by the National Natural Science Foundation of China: 72062022

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