



Article Research on the Value Improvement Model of Private Parties as "Investor-Builder" Dual-Role Entity in Major River Green Public-Private Partnership Projects

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Abstract: In Public–Private Partnership (PPP) projects, the structure of the Special Purpose Vehicle (SPV) significantly impacts the value enhancement of projects. This study conducted a quantitative analysis of value enhancement in green PPP projects under single- and Dual-Role entity models and examined existing SPV private party compositions. A quantitative model was developed to enhance the value in green PPP projects through a Dual-Role "investor–builder" entity approach, comparing it with the single-role entity model. The findings indicate that in the Dual-Role entity mode, the construction party demonstrates a greater willingness to effort, resulting in shorter construction timelines and improved economic benefits for the project company. The preferred equity range for private parties escalates with the total project investment and the extent of "political support". Nevertheless, a disproportionately high government regulation and control should be avoided. This quantitative model serves as a decision-making criterion for selecting the SPV mode and provides an alternative approach for evaluating PPP project performance.

Keywords: Dual-Role entity; major river green PPP projects; value improvement; water environment; principal–agent theory

1. Introduction

Given the substantial investment and prolonged governance required for river ecological conservation and governance projects, sustaining these initiatives solely through government funding is challenging. Contrasting the government's previous unilateral approach, the PPP mode, integrating both public and private resources, has emerged as a pivotal solution to tackle this issue. This PPP model has demonstrated its effectiveness in addressing government funding shortfalls in infrastructure and public service sectors [1], all while enhancing the quality and efficiency of public service delivery [2]. Consequently, it has gained widespread adoption worldwide. According to the 2022 report by the Global Infrastructure Hub [3], in 2021, 80% of global private investment in infrastructure projects occurred in high-income countries, with the remaining 20% in middle-income countries. Private investments in green infrastructure projects reached a historic high, constituting 60% of the total private investment in infrastructure projects. The proportion of green investments in infrastructure projects in high-income countries increased from 62% in 2020 to 65% in 2021, while middle- and low-income countries experienced a resurgence in green investments, rising from 28% in 2020 to 43% in 2021.

As defined by China's Ministry of Finance's Public–Private Partnership Center, green PPP projects encompass various domains, including public transportation, water supply



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Copyright: © 2023 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (https:// creativecommons.org/licenses/by/ 4.0/). and drainage, ecological construction, environmental protection, water conservancy, renewable energy, education, technology, culture, elderly care, healthcare, forestry, and tourism. These projects play a pivotal role in pollution prevention and control while promoting the transition to a greener, low-carbon economic structure [4]. The large river green PPP projects discussed in this paper specifically refer to projects in the field of ecological development and environmental preservation. Similar to most infrastructure projects, these green PPP projects possess the characteristics of public goods and externalities [5]. This implies their potential to generate widespread social benefits while facing constraints due to the limited availability of construction funds [6]. Furthermore, these projects possess distinctive characteristics. Compared to other project types, they hold significant ecological value [7], bear substantial social responsibilities, and adhere to market economic principles. The distinctive attributes of these green PPP projects make it so that successful project implementation must neither neglect the necessity of attaining reasonable economic returns from social capital due to ecological goals nor solely rely on increased or decreased project profitability as the exclusive criterion for implementation [8]. Simultaneously, high investment thresholds, homogenizing competitive trends, and considerable market risks associated with these green PPP projects lead to diminished corporate engagement and potential opportunistic behavior during project operation [9], thereby impacting the value improvement of PPP projects.

The implementation of PPP projects is carried out through an SPV. The SPV serves as the management and operational entity for the project and is the entity that enters into the project contract with the government. In PPP projects, the government delegates various project phases and activities to a single SPV entity [10]. The SPV oversees the entire project, managing the entire process from project initiation to operation and maintenance. Its composition in terms of social capital, i.e., the shareholder makeup, determines the profit sharing among private partners [11], playing a crucial role in driving the project forward. The shareholder structure of the SPV is quite intricate, generally classified into two categories: one category involves specialized companies such as construction firms, equipment suppliers, and service providers, while the other category consists of pure investors such as financial institutions [4]. The Channel Tunnel, one of the world's largest PPP projects, suffered from an impractical SPV structure. The lack of diverse professional expertise among the SPV shareholders and inadequate operational capabilities ultimately led to the project's failure to be completed on time and within budget [12]. In contrast, the Beijing Subway Line 4 project in China, a large-scale engineering project with substantial investment, involved the introduction of financially robust construction contractors and experienced operation contractors as private shareholders. These contractors were responsible for both the construction and operation of the project, leading to its timely completion and successful operation during the collaboration period [13].

The current research on enhancing the value of PPP projects primarily focuses on two aspects. Firstly, from a qualitative perspective, the studies explore the incentive effects of shareholder composite identities and the agency perspective. Utilizing an analytical framework based on Nash bargaining game theory and the principal-agent model, it is believed that an appropriate equity structure can effectively motivate the private sector [14,15]. Private companies with a significant asset share in PPP projects are compelled to increase their level of effort [16]. An appropriate equity structure was found to increase profits for both parties, with professional companies exerting greater effort [17]. However, opposing views exist, which suggest that certain construction and equipment suppliers participate not for future project profitability, but to secure construction or equipment supply contracts, leading to a preference for project companies composed entirely of pure investors [18]. Secondly, quantitative analyses have been conducted on the value improvement models for the performance of PPP projects. Methods like social exchange theory and computer simulation analyses are used to analyze the impact of factors such as social capital's perception of fairness, cooperative behavior, and regional infrastructure output efficiency on PPP project performance improvement models [19,20].

In the field of research on green PPP projects in major river basins, the focus has predominantly been on project value enhancement from the perspective of government incentives. This includes studies on government compensation mechanisms for green PPP projects [21], research on optimal concession period extensions, and risk-sharing investigations. For instance, Xue and Wang [22] used performance evaluation methods to solve for the evolutionary path of behavioral choices among various stakeholders in water pollution control PPP projects. Jin et al. [23] solved for the optimal concession period and the minimum revenue guarantee level pledged by the government. Shi et al. [24] provided incentives for SPVs to adopt innovative investments to improve project performance through risk sharing. Unlike traditional PPP projects, most studies argue that social benefits should be reflected in the value of green PPP projects [25]. For example, Liu et al. [26] suggest that VFM based on social benefits can reveal the true value creation capacity of green PPP projects.

The existing literature presents clear strategies and directions for incentives, but relying solely on traditional PPP contractual frameworks is insufficient to address the complex issues in the practice of major river and green PPP projects. For instance, traditional PPP projects focus mainly on the distribution of economic outputs and risk sharing, whereas the core outputs of green PPP projects are environmental benefits, but corporations do not participate in the distribution of these environmental outputs, complicating contract designs. This suggests that external contractual constraints are costly and ineffective, necessitating the stimulation of the private sector's intrinsic motivation to enhance their willingness to exert effort. As key implementers and crucial members of the SPV in PPP projects, the private sector's ability to fully possess actual control over construction and operation is vital. How to incentivize the private sector to drive the construction of a project that is of higher quality, cost-effective, and ensures operational efficiency is critical to the success and value enhancement of PPP projects.

While there is a substantial amount of literature on PPP project performance, the exploration of SPV shareholders' identities, and research on incentives for green PPP projects, there are still several shortcomings: (a) Single-entity focus—most studies predominantly revolve around a single entity, with the aim of maximizing the profits of a single enterprise and failing to account for the characteristics of major river green PPP projects involving multiple entities, multidimensional structures, and divergent objectives. (b) The neglect of intra-private-sector relationships-the composition mode within the SPV is crucial for value enhancement in major river basin green PPP projects. However, the majority of PPP research places a considerable emphasis on the upstream-downstream relationships between public clients and contractors (whether in construction or operations) or explores the relationships between the public sector and the private sector. The SPV is considered a single entity, neglecting the internal dynamics. Research into how the composition structure of social capital members within the SPV influences the value enhancement of PPP projects remains limited. (c) A lack of research on composite identity entities—there is a noticeable dearth of research concerning composite identity entities, and many of the conclusions are qualitative in nature and lack quantitative models.

To address these gaps, the paper presents a research question: how does the composition structure of SPV members impact the value enhancement of major river basin green PPP projects? To address this question, this study surveyed common patterns of private partner structures within the SPV and delved into how the overlapping roles of investors and builders within the SPV influence the value enhancement of PPP projects. This research considered the distinct characteristics of social and economic benefits generated by green PPP projects and suggested altering internal SPV relationships to incentivize all project stakeholders. This aims to reduce internal conflicts and superfluous costs, elevate project quality, shorten construction periods, and facilitate more efficient collaboration in project completion, thereby elevating the value-improvement potential of PPP projects. These findings establish a firmer theoretical groundwork for the government to utilize regulatory incentives to achieve a mutually beneficial outcome by enriching social welfare, environmental quality, and corporate economic returns.

2. Private Party Structure Analysis of SPVs Based on Single- and Dual-Role Entities *2.1. Methodology*

In the realm of organizational management concerning incentive mechanisms, the principal–agent theory is frequently applied. Originating from institutional economics and contract theory, the principal–agent theory effectively deals with how principals can create optimal contracts to motivate agents in scenarios characterized by conflicting interests and information asymmetry [11].

In PPP projects, the objectives of the government and the SPV may differ significantly. The former adopts PPP initiatives to develop infrastructure and improve public services, while the latter seeks commercial opportunities for investment returns. Moreover, the interests of various private participants within the SPV are not aligned. According to agency theory, these issues in PPP projects are known as agency problems, where there exist two layers of principal–agent relationships between the government and the private sector. The government, acting as the principal, grants the right to develop public services to the private sector, the agent, forming the first layer of the principal–agent relationship. The SPV, comprising private sector entities, subcontracts construction and operation work to professional companies, with the SPV acting as the principal and the professional companies as agents; forming the second layer. There are conflicts of interest between principals and agents; the more effort an agent puts in, the more profit the principal receives, so principals want agents to work hard. However, higher effort levels from agents mean more effort costs for them, making them reluctant to exert high levels of effort [19]. Consequently, the private sector exhibits opportunistic tendencies.

In engineering project management, any form of opportunistic behavior can adversely affect project performance [27]. Traditional project governance relies on contract governance to reduce transaction costs and agency costs and mitigate opportunistic behavior. However, due to the higher degree of incompleteness and enforcement costs in PPP project contracts compared to general project contracts, contract governance becomes less advantageous in enhancing project performance. Moreover, mandatory contract governance often impedes cooperation between public and private sectors and may even induce opportunistic behaviors [28]. Relationship governance, based on well-defined transaction structures and relational norms, can effectively improve organizational efficiency [29], enhance project performance [30], and effectively compensate for the shortcomings of contract governance [31], reducing opportunistic behavior and enhancing PPP project performance [32,33]. Therefore, effective relational governance is required to incentivize the agents; otherwise, agents may be unwilling to work as hard as the principals expect.

Furthermore, transaction cost theory serves as a vital bridge linking the principalagent theory with value enhancement in PPP projects as transaction costs are a major factor affecting value enhancement during the construction of PPP projects [34]. In major river basin green PPP projects, transaction costs emerge due to asymmetric information and knowledge among the economic entities and resource depletion during conflict resolution and harmonization processes [35]. By shifting from single to dual roles for professional companies, creating tightly linked temporary, vertical intermediary organizational structures, different interests are harmonized, and joint actions are taken [36]. In other words, when professional companies act only in the role of agents, service providers are segmented, and this model does not incentivize suppliers to optimize their services and contribute to subsequent stages. Conversely, when professional companies act both as agents and principals, there is a close integration among all shareholders. Each step of delivery considers future activities, thereby saving costs and enhancing the revenues for both the SPV and the professional companies.

In essence, alterations in the principal–agent relationship are the result of relational governance, engendering enhanced organizational efficacy through collaboration, trust,

commitment, and effective communication [37]. This practice not only enhances project performance but also effectively supplements the limitations of contractual governance. It establishes incentives for the private sector, driving them to elevate their efforts, reduce opportunistic behaviors, lower transaction costs, and thereby accomplish the objective of enhancing the value of PPP projects [38]. Hence, this study adopted the principal–agent model to analyze the value enhancement of major river basin green PPP projects.

2.2. Theoretical Model of the Impact of SPV Private Party Composition Modes on PPP Value Enhancement

PPP project value is considered to be the economic value improvement and the time and cost savings brought about by various capital inputs into PPP projects [33]. In current research, PPP project value is believed to encompass public sector performance and value in the interests of the public [39], and its influencing factors primarily involve construction benefits, private party benefits, and public sector benefits, among others [40]. The concept of value improvement originates from the value chain theory. The existing research on the mechanism of value improvement in PPP projects suggests that PPP project value is related to factors such as incentives, risks, and reward allocation in partner relationship configurations [27]. Allowing professional companies to invest and form project companies is advantageous for engineering projects to meet commercial completion standards on time and within budget, and it enhances operational efficiency [28]. This is important in cases with the participation of multiple private parties in green PPP projects to promote high-quality development [4].

Based on the characteristics of the green PPP projects in major river basins, this paper posits that the value of green PPP projects in major river basins, as a specific value, differs fundamentally from the definition and essence of commodity value. It refers to the difference between the comprehensive benefits inherent in infrastructure projects and the total cost to obtain such benefits. This encompasses economic benefits to businesses, environmental benefits, and social benefits, while aiming to meet the value requirements of the public sector and enhance infrastructure satisfaction. It reflects the degree and rationality to which the activities and outcomes of green PPP projects in major river basins satisfy the needs of all stakeholders. The value improvement of green PPP projects in major river basins refers to the surplus value when the comprehensive value provided by an SPV company for the environmental governance project of major rivers surpasses the cost of providing infrastructure engineering functions and services. It primarily involves project cost, quality, and progress from the perspective of project construction benefits; potential corporate profits, social prominence, and satisfaction from the standpoint of social capital benefits; and environmental governance effects from the viewpoint of public sector benefits.

In actual PPP projects, the dual-role entity formed by investors and builders can incentivize builders to put forth greater effort. This encourages all project stakeholders to reduce internal conflicts, avoid unnecessary cost expenditures, shorten the construction period, and enhance the quality of the infrastructure and public services. These actions influence the overall value and expenditure of green PPP projects in major river basins, thereby impacting the value improvement of PPP projects. Combining the aforementioned analysis, this study constructed a theoretical model for the value improvement of green PPP projects in major river basins, as depicted in Figure 1.

2.3. The Private Party Composition Mode of SPVs

The existing SPV shareholders can be categorized into two types: the first type is a private party (which can be a single enterprise or a consortium of multiple enterprises) that contributes capital following market-oriented principles and is responsible for financing, construction, operation, and other project-related matters; the second type is a composite of the government and a private party, or a private party that establishes the SPV and is subsequently designated by the government agency to participate in the project company according to the law. Therefore, the composition of SPV shareholders can be either a single

type with only a private party or a composite type with both government and private party participation. This study introduces the concept of Dual-Role entities (investor–builder) and analyses the private party membership composition mode within an SPV and its meanings and characteristics, which are detailed in Table 1.



Figure 1. Theoretical model of the relationship between different SPV modes and the value improvement of PPP projects.

Туре	Mode	Private Party	Investment Elements	Key Elements	Examples
Single- Role Entity Scenario	Ι	Pure financial institutions	Funds	 During the financing phase, the SPV company acts as both the principal and the agent. During the construction and operation phases, the SPV company acts as the principal, while the construction contractor and operator act as the agents. 	Guizhou's Guanshan Lake Environmental Improvement PPP project, with a total investment of CNY 1.135 billion and a 32-year cooperation period. The winning private party was the Guizhou Public and Social Capital Cooperation Industrial Investment Fund.
Dual- Role Entity Scenario	Π	Construction contractors	Funds + Knowledge	 During the construction phase, the SPV company acts as both the principal and the agent. During the financing and operation phases, the SPV company acts as the principal, while financial institutions and operators act as the agents. Construction companies are responsible for project construction, ensuring quality, progress, and safety to mitigate construction risks. 	Yunnan's Underground Comprehensive Pipe Gallery Project PPP project, with a total investment of CNY 6.759 billion and a 20-year project period. The winning private party was Yunnan Construction Group Co., Ltd.

Table 1. Single- and Dual-Role entity modes and characteristics.

Туре	Mode	Private Party	Investment Elements	Key Elements	Examples
Dual- Role Entity Scenario	III	Operators	Funds + Knowledge	 During the operation phase, the SPV company acts as both the principal and the agent. During the financing phase, the SPV company acts as the principal, while financial institutions act as the agents. Typically used for complex comprehensive operation and management projects, favorable for project operation and risk avoidance. 	Anhui's Chizhou Main Urban Area Sewage Treatment and Municipal Drainage Facility Purchase Service PPP project, with a total investment of CNY 2.054 billion and a 26-year cooperation period. The winning private party was Shenzhen Water (Group) Co., Ltd.
	IV	Construction contractors and operators	Funds + Knowledge	 During both the construction and operation phases, the SPV company acts as both the principal and the agent. During the financing phase, the SPV company acts as the principal, while financial institutions act as the agents. 	Yunnan's Kunming Guandu District River Comprehensive Management Project PPP project, with a total investment of CNY 1.555 billion and a 15-year project period. The winning private party was a consortium formed by Shenzhen TIEHAN Ecological Environment Co., Ltd.; China Railway Shanghai Engineering Bureau Group Co., Ltd.; and China Municipal Engineering South Design & Research Institute Co., Ltd. China Railway Shanghai Engineering Bureau Group Co., Ltd., and China Municipal Engineering South Design & Research Institute Co., Ltd. are responsible for the construction process, while Shenzhen TIEHAN Ecological Environment Co., Ltd. oversees both construction and operation.
	V	Financial institutions and construction contractors	Funds + Knowledge	 During the financing and construction phases, the SPV company acts as both the principal and the agent. During the operation phase, the SPV company acts as the principal, while operators act as the agents. 	Shandong's Rizhao Kuishan Comprehensive Passenger Transport Terminal and Supporting Project, with a total investment of CNY 1.634 billion and a 12-year project period. The winning private party was a consortium formed by China Construction Eighth Engineering Division Corp. Ltd. and GF Xinde Investment Management Co., Ltd.
	VI	Financial institutions, construction contractors, and operators	Funds + Knowledge	Throughout the entire PPP project operation, the SPV company acts as both the principal and the agent.	Hohhot City Urban Rail Transit Line 1 Phase I Project, with a total investment of CNY 15.584 billion and a 30-year project period. The winning private party is a consortium formed by China Railway Corporation and Shenzhen Taiping Investment Co., Ltd. Shenzhen Taiping Investment Co., Ltd. is responsible for financing, while China Railway Corporation handles both construction and operation.

Table 1. Cont.

3. Model Assumption

Based on the assumptions of the principal–agent theory and references from relevant research [17,41], this study established the following fundamental assumptions:

- (1) Independent Entity Assumption: Each participant in the PPP project is an independent entity and belongs to different interest groups, meaning their objectives are different.
- (2) Information Asymmetry Assumption: This assumption, based on agency theory, postulates that there is information asymmetry between the principal and the agent at various stages of PPP project development, leading to "adverse selection" and "moral hazard".
- (3) Rational Economic Actor Assumption: All participating parties are rational economic actors, and they choose compensation and effort levels to maximize their own interests.
- (4) Adherence to the Basic Framework of Agency Theory: It is assumed that the SPV company, as the principal, is risk-neutral, while the financing party, construction party, and operating party, as agents, are risk-averse. The utility function of the agents exhibits characteristics of constant absolute risk aversion. Assuming the agent's cost coefficient is β , where $\beta > 0$, and the agent's effort level is α , where $\alpha > 0$, then the agent's effort cost for constructing the PPP project is represented as $g(\alpha) = \frac{1}{2}\beta\alpha^2$.
- (5) Project Completion Time Assumption: The time of project completion is denoted as t_j , the predicted completion time as t_a , the variable construction time as t_b , and the construction party's effort to reduce the variable construction period is represented by λ , where $\lambda > 0$. Therefore, $t_j = t_a \lambda \alpha t_b$.
- (6)Environmental Benefit Assumption: Environmental benefits are the benefits of the project that can be perceived directly from the perspectives of citizens and the government after the implementation and completion of the project. In the context of a major river green PPP project, environmental benefits are divided into two aspects: water environmental benefits and other resource utilization environmental benefits. Other resource utilization environmental benefits mainly pertain to the content of resource utilization and reuse engineering, which is not relevant to the discussion in this paper and will not be considered here. As for water environmental benefits, they primarily include aspects such as water quality compliance, improvement in water landscapes, and the enhancement of the living environment for residents. These benefits are assessed based on a "baseline standard", which is the minimum acceptance standard set by the government for green PPP projects. This standard includes assessment criteria for indicators such as the compliance rate of water quality within the project scope, the proportion of elimination of polluted and odorous water bodies, the percentage reduction in the COD concentration, and the percentage reduction in the total phosphorus concentration [42,43]. It is assumed that the projects discussed in this paper can meet this "baseline standard" upon acceptance. The set of standards is represented by Δ , where $\Delta = \{\delta_1, \delta_2, \dots, \delta_n\}$, and δ_i represents the basic standard for each water environmental management assessment indicator. *n* represents the total number of assessment indicators. The weights for each indicator are denoted by W, where $W = \{w_1, w_2, \dots, w_N\}$. From the completion of construction to the end of the project's operational period, the total environmental benefit derived from the green PPP project is calculated as

$$E(V) = \sum_{i=1}^{n} \rho q(a) \delta_i w_i (T_c - t_j)$$
⁽¹⁾

where $t \in [t_j, T_c]$. Here, ρ represents the government's emphasis coefficient on environmental benefits, and $\rho > 1$; q(a) represents the quality of the major river green PPP project, and $q(a) = \varphi a$. Higher quality corresponds to stronger ecological environmental protection and better overall environmental benefits. φ represents the coefficient of influence of the construction party's effort level on the major river green PPP project. These assumptions are foundational to the modeling approach and help establish the framework for analyzing the value improvement of PPP projects.

4. Establishment and Solution of PPP Project Value Improvement Model

This study is grounded in agency theory and transaction cost theory. It draws upon established models on project duration, effort levels, and company economic benefits as presented by Li [43], Wang [11], and Zuo [17], alongside Bao [21], Li [35], and Wei's [41] model concerning environmental benefits in PPP projects. It combines the specific characteristics of high government involvement, low profitability, and strong public interest in green PPP projects of major rivers, along with the segmented objectives of various stakeholders. Considering the differences in the incentive levels for private party participation in project construction under the Dual-Role "investor–operator" subject model and the single-role subject model, this study established value models for stakeholders in the two scenarios.

Let the actual project completion time be t_i :

$$t_i = t_a - \lambda \alpha t_b \tag{2}$$

where t_a is the predicted completion time and t_b is the variable construction time; both t_a and t_b are greater than 0.

The total construction contract amount received by the construction firm is denoted as F, and the construction cost is C. The construction cost consists of a fixed cost c_0 and a variable cost c_1 and is expressed as

$$C = c_0 + c_1 \tag{3}$$

where the variable cost c_1 is related to the construction firm's effort level, i.e., the length of the construction period, and it can be represented as

$$c_1 = \frac{1}{2}\beta\alpha^2 + \theta t_j \tag{4}$$

where θ is the time cost coefficient, and $\theta > 0$.

Let the net income generated per unit time after the construction project is completed be denoted as R, where $R = P - kc_2$. Here, P represents the revenue generated per unit time after the construction project is completed, k is the shareholding percentage of

the professional company in the project company, $k = \begin{cases} 0, \sin gle - role entity mode \\ (0, 1], dual - role entity mode ' \\ and c_2 represents the management costs incurred by the professional company when participating as a shareholder in the role of the principal, such as the need to allocate more personnel for project management, quality control, safety management, and progress monitoring within the SPV company.$

4.1. Value Model for Single-Role Entity Scenario

The profit of the project company is given by

$$Q = (T_c - t_j)R \tag{5}$$

where T_c is the concession period. The concession period can refer specifically to the concession operation period and may not include the construction period. For convenience, this study followed the existing literature [32] and defined the concession period to include both the construction and operation periods; hence, $T_c > t_a$.

The expected profit for the construction party is

$$E(\pi_s) = E(F - C) = F - c_0 - \frac{1}{2}\beta\alpha^2 - \theta(t_a - \lambda\alpha t_b)$$
(6)

The expected total environmental benefit is

$$E(V_s) = \sum_{i=1}^{n} \rho \varphi \alpha \delta_i w_i (T_c - t_j)$$
(7)

Assuming that the social benefit consists of the benefits u brought to users by the project, the environmental benefits, and the income of all parties participating in the project operation, the social benefit is

$$E(z_{s}) = u + E(V) + Q + E\pi_{s} = u + \varphi \alpha \rho V_{et} (T_{c} - t_{j}) + (T_{c} - t_{j})R + F - c_{0} - \frac{1}{2}\beta \alpha^{2} - \theta(t_{a} - \lambda \alpha t_{b})$$
(8)

The construction party seeks to maximize income by adjusting its effort level. When $\frac{\partial \pi_j}{\partial \alpha} = 0$, the optimal effort level is obtained, i.e.,

$$-\beta \alpha + \theta \lambda t_b = 0 \tag{9}$$

Solving for the construction party's optimal effort level, we obtain:

$$\alpha_s^* = \frac{\theta \lambda t_b}{\beta} \tag{10}$$

Substituting α_s^* into Equation (2) yields the optimal project duration:

$$t_s^* = t_a - \frac{\theta \lambda^2 t_b^2}{\beta} \tag{11}$$

The construction party's effort cost is

$$g_s = \frac{1}{2}\beta\alpha^2 = \frac{\theta^2\lambda^2 t_b^2}{2\beta}$$
(12)

The project company's profit is

$$Q_S = T_c R - t_a R + \frac{\theta \lambda^2 t_b^2 R}{\beta}$$
(13)

Therefore, the construction party's maximum expected income is

$$E(\pi_{s})^{*} = F - c_{0} - \theta t_{a} + \frac{\theta^{2} \lambda^{2} t_{b}^{2}}{2\beta}$$
(14)

The total environmental benefit is

$$E(V_{\rm s}) = \sum_{i=1}^{n} \rho \varphi \alpha \delta_i w_i (T_c - t_j) = \sum_{i=1}^{n} \rho \varphi \alpha \delta_i w_i \frac{\theta \lambda t_b}{\beta} (T_c - t_a) + \frac{\theta^2 \lambda^3 t_b^3}{\beta^2}$$
(15)

And the social benefit is

$$E(z_{s}) = u + T_{c}R_{2} - t_{a}R_{2} + \frac{\theta\lambda^{2}t_{b}^{2}R_{2}}{\beta} + F - c_{0} - \theta t_{a} + \frac{\theta^{2}\lambda^{2}t_{b}^{2}}{2\beta} + \sum_{i=1}^{n}\rho\varphi\alpha\delta_{i}w_{i}\left[\frac{\theta\lambda t_{b}(T_{c} - t_{a})}{\beta} + \frac{\theta^{2}\lambda^{3}t_{b}^{3}}{\beta^{2}}\right]$$
(16)

4.2. Value Model for Dual-Role Entity Scenario

When pure investors and professional companies jointly form an SPV company, the SPV company entrusts the project's construction to the professional company as a shareholder. In this case, the professional company, as the project contractor, acts as an agent and as a shareholder, becoming a Dual-Role subject. Then, in this scenario, the expected income of the construction party is given by

$$E(\pi_{d}) = E(F - C) + k\pi_{x} = F - c_{0} - \frac{1}{2}\beta\alpha^{2} - \theta(t_{a} - \lambda\alpha t_{b}) + k(T_{c} - t_{a} + \lambda\alpha t_{b})R_{2}$$
(17)

Similarly, the construction party adjusts its effort level to maximize income. When $\frac{\partial \pi_j}{\partial \alpha} = 0$, the optimal effort level is achieved, which is

$$-\beta \alpha + \theta \lambda t_b + kR_2 \lambda t_b = 0 \tag{18}$$

Solving for the construction party's optimal effort level α_d^* , we obtain

$$\alpha_d^* = \frac{(\theta + kR_2)\lambda t_b}{\beta} \tag{19}$$

Substituting α_d^* into Equation (2), we obtain the optimal project duration:

$$t_d^* = t_a - \frac{(\theta + kR_2)\lambda^2 t_b^2}{\beta}$$
(20)

The construction party's effort cost is

$$g_d = \frac{(\theta + kR_2)^2 \lambda^2 t_b^2}{2\beta} \tag{21}$$

The optimal revenue for the project company is

$$Q_d = T_c R_2 - t_a R_2 + \frac{(\theta + kR_2)\lambda^2 t_b^2 R_2}{\beta}$$
(22)

Therefore, the optimal revenue for the construction party is

$$E(\pi_d) * = F - c_0 - \theta t_a + \frac{(\theta + kR_2)^2 \lambda^2 t_b^2}{2\beta} + kR_2(T_c - t_a)$$
(23)

The total environmental benefit is

$$E(V_d) = \sum_{i=1}^n \rho \varphi \alpha \delta_i w_i (T_c - t_j) = \sum_{i=1}^n \rho \varphi \alpha \delta_i w_i \left[\frac{(\theta + kR_2)\lambda t_b (T_c - t_a)}{\beta} + \frac{(\theta + kR_2)^2 \lambda^3 t_b^3}{\beta^2} \right]$$
(24)

The social benefit is

$$E(z_d) = u + T_c R_2 - t_a R_2 + \frac{(\theta + kR_2)\lambda^2 t_b^2 R_2}{\beta} + F - c0 - \theta t_a + \frac{(\theta + kR_2)^2 \lambda^2 t_b^2}{2\beta} + kR_2(T_c - t_a) + \sum_{i=1}^n \rho \varphi \alpha \delta_i w_i \left[\frac{(\theta + kR_2)\lambda t_b(T_c - t_a)}{\beta} + \frac{(\theta + kR_2)^2 \lambda^3 t_b^3}{\beta^2} \right]$$
(25)

5. Results and Discussion

5.1. Comparison of Optimal Effort Levels of the Construction Party in Two Modes

Theorem 1. In the scenario in which the construction party serves as both a shareholder of the SPV company and an agent for the construction project, their effort level is higher than when they only serve as an agent for the construction project.

Proof of Theorem 1. $\Delta \alpha = \alpha_d^* - \alpha_s^* = \frac{(\theta + kR)\lambda t_b}{\beta} - \frac{\theta \lambda t_b}{\beta} = \frac{kR\lambda t_b}{\beta}$. Since revenue is generated only after completion, it can motivate the private parties to participate in the PPP project. Therefore, R > 0. Additionally, due to the conditions k, λ , β , and $t_b > 0$, we can conclude that $\frac{kR\lambda t_b}{\beta} > 0$. Hence, $\alpha_d^* > \alpha_s^*$.

According to Friedman's "four-level spending matrix" (the "Four-Level Spending Matrix" by the famous American economist Friedman: (a) spend your own money to do your own things, emphasizing both thriftiness and effectiveness; (b) spend your own money to do other people's things, emphasizing thriftiness without focusing on effectiveness; (c) spend other people's money to do your own things, emphasizing effectiveness without focusing on thriftiness; and (d) spend other people's money to do other people's things, emphasizing neither effectiveness or thriftiness), when the construction party becomes a shareholder in the SPV company, serving as both the principal and the agent (the first case), they are essentially spending their own money to handle their own affairs. This situation emphasizes both cost savings and effectiveness. In this case, the agent (construction party) bears all the risks and works entirely for themselves, so their effort level reaches the highest level. Furthermore, by investing in the SPV company, the construction party incurs a certain investment cost. To enhance their return on investment, the construction party pays greater attention to project construction process management. They actively introduce advanced technologies, and the design team optimizes the design to control costs and reduce overall project expenses, thus minimizing resource input. This, in turn, lowers costs. The value improvement pathway is shown in Figure 2.



Figure 2. The impact pathways of the construction party's effort levels on the value improvement of PPP projects in the two role modes: (a) construction party as a Dual-Role entity; (b) construction party as a single-role entity.

5.2. Comparison of Enterprise Income in Two Modes

k

Theorem 2. In the Dual-Role subject mode, the profits of all parties' enterprises are higher than the profits under the single-role subject mode.

Proof of Theorem 2. Comparing the project company's profits in both scenarios:

$$\Delta Q = Q_d - Q_s = T_c R - t_a R + \frac{(\theta + kR)\lambda^2 t_b^2 R}{\beta} - \left(T_c R - t_a R + \frac{\theta\lambda^2 t_b^2 R}{\beta}\right) = \frac{kR_2^2 \lambda^2 t_b^2}{\beta}.$$
 Since k and β are both greater than 0, it follows that $\frac{kR_2^2 \lambda^2 t_b^2}{\beta}$, indicating that $Q_d > Q_s$.
Comparing the construction party's effort costs in both scenarios:
$$\Delta g = g_d - g_s = \frac{(\theta + kR_2)^2 \lambda^2 t_b^2}{2\beta} - \frac{\theta^2 \lambda^2 t_b^2}{2\beta} = \frac{(2\theta kR_2 + k^2 R_2^2)\lambda^2 t_b^2}{2\beta}.$$
 Since θ , k, R_2 , and β are all greater than 0, it follows that $\frac{(2\theta kR_2 + k^2 R_2^2)\lambda^2 t_b^2}{2\beta} > 0$, indicating that $g_d > g_s$.

Comparing the profits of the construction company in both scenarios:

 $\Delta E\pi^* = E\pi_d^* - E\pi_s^* = F - c_0 - \theta t_a + \frac{(\theta + kR_2)^2 \lambda^2 t_b^2}{2\beta} + kR_2(T_c - t_a) - (F - c_0 - \theta t_a + \frac{\theta^2 \lambda^2 t_b^2}{2\beta}) = \frac{(2\theta kR_2 + k^2 R_2^2) \lambda^2 t_b^2}{2\beta} + kR_2(T_c - t_a).$ Since $T_c > t_a$, it follows that $T_c - t_a > 0$, $\frac{(2\theta kR_2 + k^2 R_2^2) \lambda^2 t_b^2}{2\beta} > 0$, and k and R_2 are both greater than 0, indicating that $\frac{(2\theta kR_2 + k^2 R_2^2) \lambda^2 t_b^2}{2\beta} + kR_2(T_c - t_a) > 0$, implying that $E(\pi_d^*) > E(\pi_s^*)$. \Box

Although the construction party incurs higher effort costs when participating in the formation of the SPV company, the expected returns are higher, indicating that the construction company is motivated to take on this dual role. According to transaction cost theory, the SPV company, as a vertically integrated temporary organizational structure formed by different participants in the PPP project construction chain, reconciles different interests and takes joint actions, thus improving constraint efficiency and reducing transaction costs and agency costs in engineering transaction activities. In other words, when the professional company acts solely as an agent, each construction contractor is segmented, allowing the owner maximum control; however, this control does not provide incentives to the contractors to optimize services and contribute to the subsequent phases of the project. Conversely, when the professional company acts as both an agent and a principal, a close integration among professional companies exists, where each step of delivery considers future activities, resulting in cost savings and consequently increases the profits of both the SPV and the professional company. The value improvement pathway is shown in Figure 3.



Figure 3. The impact pathways of costs on value improvement in two role modes: (**a**) construction party as a Dual-Role entity; (**b**) construction party as a single-role entity.

5.3. Comparison of Environmental Benefits in Two Modes

Theorem 3. In the Dual-Role subject mode, the environmental benefits achieved by the green PPP project in the Yangtze and Yellow River regions are higher than those in the single-role subject mode.

Proof of Theorem 3.

$$\begin{split} \Delta E(V_i) &= E(V_d) - E(V_s) = \sum_{i=1}^N \rho \varphi \alpha \delta_i w_i (T_c - t_j) \\ &= \sum_{i=1}^N \varphi \rho \delta_i w_i \left[\frac{(\theta + kR)\lambda t_b}{\beta} (T_c - t_a) + \lambda t_b \frac{(\theta + kR)^2 \lambda^2 t_b^2}{\beta^2} \right] \\ &= \sum_{i=1}^N \varphi \rho \delta_i w_i \left[\frac{\lambda t_b [\theta + k(P - kc_2)](T_c - t_a)}{\beta} \right. \\ &+ \lambda t_b \frac{[\theta + k(P - kc_2)]^2 \lambda^2 t_b^2}{\beta^2} \right] \\ &- \sum_{i=1}^N \rho \varphi \delta_i w_i \frac{\theta \lambda t_b}{\beta} \left(T_c - t_a + \frac{\theta \lambda^2 t_b^2}{\beta} \right) \end{split}$$

The correlation analysis of the PPP project value improvement model in this study will not be affected as long as the selected parameters fall within a realistic and economically meaningful range. To conduct a numerical analysis, this study referenced an actual project and selected the basic parameters shown in Table 2. \Box

Table 2. Parameter setting of PPP project value improvement model.
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Parameter	Assigned Value	Value Basis
Contract amount	F = 10	Reference case, simplified unit value (trillion/billion, etc.)
Influence coefficient of the construction party's effort level on the major river green PPP project	arphi=0.1	Hypothetical base value
Influence coefficient of time	heta=2	Hypothetical base value
Efficiency coefficient of reducing variable construction periods	$\lambda = 5$	Hypothetical base value
Basic standard for each water environmental management assessment indicator	$\delta_i = [1,5]$	Refers to the "14th Five-Year Plan for the Development of Urban Sewage Treatment and Resource Utilization" by the National Development and Reform Commission of China
The weight for each indicator	$w_i = [0, 1]$	Reference case
Quantity of indicators	i = [1, 5]	Reference case
The concession period	$T_{c} = 3.6$	Reference case, simplified unit value (year/month, etc.)
Predicted completion time	$t_a = 0.24$	Reference case, simplified unit value (year/month, etc.)
Variable construction time	$t_{b} = 0.5$	Reference case, simplified unit value (year/month, etc.)
Influence coefficient of agent's cost	$\beta = 3$	Hypothetical base value
The revenue generated per unit time after the construction project is completed	P = 0.6	Reference case, simplified unit value (trillion/billion, etc.)
Fixed cost	$c_0 = 0.2$	Reference case, simplified unit value (trillion/billion, etc.)

Parameter	Assigned Value	Value Basis
The management costs incurred by the professional company when participating as a shareholder in the role of the principal	$c_2 = 0.1$	Reference case, simplified unit value (trillion/billion, etc.)
Influence coefficient of government's emphasis on environmental benefits	ho = 1.5	Hypothetical base value
Social benefit	u = 0.5	Hypothetical base value

The study randomly selected five values for δ and w and then plugged these values into ΔEV_i . We used MATLAB R2022b software to plot the comparison of the environmental benefits in the two modes (Figure 4).



Figure 4. Comparison of environmental benefits in two modes: (a) relationship between *P*, *k*, and ΔEV_d (3D); (b) relationship between *P*, *k*, and ΔEV_d (2D).

The point k^* on the graph is the critical point. When $k^* < 0$, the environment benefits do not increase under the Dual-Role subject mode. According to Figure 4, k^* is related to *P*, and as *P* increases, k^* increases. In this context, even when *P* is very small, k^* remains greater than 0. This means that under the Dual-Role subject mode, the level of environmental benefits is higher than that under the single-role subject mode.

When the construction party only assumes the role of a builder, operational risks (such as operational performance, operation and maintenance costs, and demand or revenue risks) are irrelevant. The primary goal of the construction party is to minimize costs for higher returns, resulting in a significantly lower quality of project construction, barely meeting minimum acceptance standards. However, when the construction party acts as both an investor and a builder, it bears a portion of the operational risks. If the construction quality is subpar (for example, the sewage treatment project adopts lower standards, barely meeting acceptance criteria, and during operations, increasing environmental standards necessitate costly rework, resulting in lower returns), the frequency and costs of maintenance become excessive, leading to severe operational losses. This reduces the project's return on investment, resulting in operational and market risks. These risks, in turn, lead to inadequate operating profits, where the cash flow is insufficient to meet debt obligations, thereby causing debt repayment risks. In cases where financing parties face operational or debt repayment risks and cannot fulfil contract conditions, it results in defaults, causing a considerable amount of non-performing assets in banks or among investors, significantly diminishing the financing party's credit and integrity, thus escalating credit risks. Subsequently, the occurrence of credit risks leads to credit rating downgrades, unavoidably

Table 2. Cont.

increasing financing costs and thus raising financing expenses. Therefore, the construction party will strive to maximize project quality during the construction period, as indicated by the value improvement path in Figure 5.



Figure 5. The impact pathways of quality on value improvement in two role modes: (**a**) construction party as a dual-role entity; (**b**) construction party as a single-role entity.

5.4. Comparison of Social Benefits in Two Modes

Theorem 4. *In the dual-role entity mode, the project achieves higher social benefits than in the single-role entity mode.*

Proof of Theorem 4.

$$\begin{split} \Delta E(\boldsymbol{z}_{i}) &= E(\boldsymbol{z}_{d}) - E(\boldsymbol{z}_{s}) \\ &= \boldsymbol{u} + T_{c}\boldsymbol{R} - t_{a}\boldsymbol{R} + \frac{(\boldsymbol{\theta} + \boldsymbol{k}\boldsymbol{R})\lambda^{2}t_{b}^{2}\boldsymbol{R}}{\beta} + \boldsymbol{F} - \boldsymbol{c}_{0} - \boldsymbol{\theta}\boldsymbol{t}_{a} \\ &+ \frac{(\boldsymbol{\theta} + \boldsymbol{k}\boldsymbol{R})^{2}\lambda^{2}t_{b}^{2}}{2\beta} + \boldsymbol{k}\boldsymbol{R}(T_{c} - t_{a}) \\ &+ \sum_{i=1}^{N} \varphi\rho\delta_{i}\boldsymbol{w}_{i} \bigg[\frac{(\boldsymbol{\theta} + \boldsymbol{k}\boldsymbol{R})\lambda t_{b}}{\beta} (T_{c} - t_{a}) + \lambda t_{b} \frac{(\boldsymbol{\theta} + \boldsymbol{k}\boldsymbol{R})^{2}\lambda^{2}t_{b}^{2}}{\beta^{2}} \bigg] \\ &- \boldsymbol{u} + T_{c}\boldsymbol{R} - t_{a}\boldsymbol{R} + \frac{\boldsymbol{\theta}\lambda^{2}t_{b}^{2}\boldsymbol{R}}{\beta} + \boldsymbol{F} - \boldsymbol{c}_{0} - \boldsymbol{\theta}\boldsymbol{t}_{a} + \frac{\boldsymbol{\theta}^{2}\lambda^{2}t_{b}^{2}}{2\beta} \\ &+ \sum_{i=1}^{N} \rho\varphi\delta_{i}\boldsymbol{w}_{i}\frac{\boldsymbol{\theta}\lambda t_{b}}{\beta} \Big(T_{c} - t_{a} + \frac{\boldsymbol{\theta}\lambda^{2}t_{b}^{2}}{\beta}\Big) \\ &= \frac{\boldsymbol{k}\boldsymbol{R}^{2}\lambda^{2}t_{b}^{2}}{\beta} + \frac{(2\boldsymbol{\theta}\boldsymbol{k}\boldsymbol{R} + \boldsymbol{k}^{2}\boldsymbol{R}^{2})\lambda^{2}t_{b}^{2}}{2\beta} + \boldsymbol{k}\boldsymbol{R}(T_{c} - t_{a}) \\ &+ \sum_{i=1}^{N} \frac{\boldsymbol{\varphi}\rho\delta_{i}\boldsymbol{w}_{i}\lambda t_{b}}{\beta} \bigg[\boldsymbol{k}\boldsymbol{R}(T_{c} - t_{a}) + \frac{(\boldsymbol{k}^{2}\boldsymbol{R}^{2} + 2\boldsymbol{\theta}\boldsymbol{k}\boldsymbol{R})\lambda^{2}t_{b}^{2}}{\beta} \bigg] \end{split}$$

We used the data mentioned earlier in the text and plugged these values into ΔEz_i . The comparison of social benefits between the two modes is shown in Figure 6. \Box

According to Figure 6, in this scenario, when P = 0.1, $k^* < 0$, and as *P* increases, k^* also increases. This indicates that when the total project investment is very small, the increase in social benefits under the dual-role subject mode is not significant, and it may not even generate any increases.

In practical projects, the government is typically most concerned with social benefits. The objectives of the government and the construction party are inconsistent. When the construction party acts solely as a builder, it is only concerned about its own profit during the construction phase, leading to lower service quality. If penalties cannot be executed, this results in a loss of social benefits. In large-scale green PPP projects in major river basins, low-yield projects are often paired with high-yield projects for contracting purposes. When the construction party realizes that an immediate start on the low-yield project is not its

optimal choice and delaying the start would bring greater benefits to the enterprise, the project start might be delayed, causing a loss in social benefits, even if the net present value of the project is evident. However, after the construction party becomes a shareholder in the SPV company, it not only receives supervision from the government but also assumes operational risks. Neglecting social benefits by the construction party will inevitably lead to the government reducing subsidies or imposing penalties on the project, resulting in reduced profits for the SPV company. In order to ensure their own return on investment and achieve a long-term stable relationship within the project, the construction party can only seek higher profits after meeting the government's requirements by improving the social benefits through promptly initiating construction, shortening the project duration, ensuring better governance, and enhancing the social benefits.



Figure 6. Comparison of social benefits in two modes: (a) relationship between *P*, *k*, and ΔEz_d (3D); (b) relationship between *P*, *k*, and ΔEz_d (2D).

5.5. The Relationship between the Participating Entity's Benefits and the Equity Participation Ratio in the Dual-Role Entity

We utilized the previously mentioned data to examine the correlation between the returns of various stakeholders and the equity participation ratio of the dual-role entity. Subsequently, we created a graphical representation illustrating this relationship, which is shown in Figures 7–9.



Figure 7. Relationship between k and enterprise economic earnings.



Figure 8. Relationship between T_c , k, and EV_d for different ρ : (**a**) relationship between T_c , k, and EV_d (3D); (**b**) relationship between T_c , k, and EV_d (2D).



Figure 9. Relationship between T_c , k, and Ez_d for different P: (**a**) relationship between T_c , k, and $Ez_d(3D)$; (**b**) relationship between k and Ez_d (2D).

According to Figure 7, the income of the SPV company increases as the shareholding percentage of the dual-role entities increases. There is a critical point, denoted as k^* , in the equity ratio between the dual-role entities such that when $k < k^*$, the income increases as the equity ratio grows larger, and when $k > k^*$, the income decreases as the equity ratio increases. This is because after the professional company participates as a shareholder in the SPV, it needs to invest additional resources in the principal role, such as assigning more personnel to carry out project management, quality control, safety, and progress monitoring within the SPV company. Consequently, this increases the overall costs of management. However, in general, the income for the construction party is higher when it participates in the SPV compared to not participating. This indicates that the construction company has the motivation to invest in the SPV while undertaking the construction and operations of the major river water environment governance PPP project.

According to Figure 8, the environmental benefits generally increase as the shareholding percentage of the dual-role entities increases. When k > 0.5, significant environmental benefits are generated. When the ρ value is relatively high, the influence of k on the environmental benefits becomes more apparent, indicating that the government places more emphasis on environmental benefits. The shareholding proportion of the dual-role entities has a greater impact on environmental and social benefits. Moreover, the social benefits generated by the PPP project become more pronounced. This is related to the characteristics of major river basin green PPP projects in which, due to limited revenue sources, the government, as the primary payer, participates not only as a regulator but also as a service purchaser. As such, the government has higher involvement in a major river basin green PPP project and places increased demands on the project to ensure a balanced financial outcome. Due to the importance the government places on environmental benefits, this is manifested in the actual policy environment and the level of support. As a result, the policy environment significantly influences the optimal equity ratio in major river basin green PPP projects. Moreover, the more the government prioritizes environmental benefits, the more receptive it is to construction companies participating in the SPV.

According to Figure 9, there is also a critical point, denoted as k^* , concerning the social benefits that depends on the shareholding percentage of the dual-role entities. When $k < k^*$, both environmental and social benefits increase as the shareholding percentage grows. Conversely, when $k > k^*$, the benefits decrease with an increasing shareholding percentage. This is due to the marginal effect of the constructor's efforts. With an excessively high equity ratio, the associated risk is also higher, resulting in a larger risk premium. In this scenario, the increased efforts of the constructor will not yield proportional returns, leading to higher costs for the government. Additionally, the critical shareholding percentage, k^* , increases with the project revenue, P, indicating that the range of shareholding percentages preferred by the government for construction companies will be influenced by the total project investment. This is because high-investment major river green PPP projects typically combine low-yield projects with high-yield projects. A higher equity ratio for the constructor assists in undertaking more specific social responsibilities and ensuring the effectiveness of low-yield green projects.

When construction parties invest in the SPV, they become both investors and builders. According to Theorem 1, as dual-role entities, construction parties demonstrate more willingness to exert effort. However, according to Theorem 2, the cost of this effort is also higher. But at the same time, construction parties can achieve greater economic benefits by augmenting shareholder profits. This implies that constructors are motivated to undertake such dual roles, and the principal–agent relationship in dual-role entities can enhance the efficacy of PPP projects. Previous studies have not considered the advantages of dual roles in their quantitative analyses [44].

According to the conclusions drawn from the research by Shi et al. [24], increasing the equity share and enhancing rewards can effectively ensure that the operating company exerts effort for the benefit of the project. Our study validates this viewpoint from the perspective of transaction costs and further elucidates the relationship between the critical point of equity share, "political support", and changes in the total project investment.

According to research by Askar M., some collaborators participate not for future profits from the project but to secure construction or equipment supply contracts, without considering their social performance [18]. Hence, to avoid such speculative behaviors, constraints on equity and incentive mechanisms should be designed [45]. Based on Theorems 3 and 4, our study, through numerical simulation, found that a higher equity share for the private sector is not always better. Within a reasonable range, it can achieve improved environmental and social benefits.

After becoming a dual-role entity, the construction party assumes a portion of the operational risks and debt repayment risks. Therefore, during construction, the constructor must consider not only construction profits but also the consequences of frequent maintenance and excessive costs due to poor project quality. To prevent serious operational losses or low returns on project investment, the constructor will endeavor to maximize project quality during construction. This means that when the agent acts as a dual-role entity, the project governance is more effective, potentially enhancing the environmental benefits. If the constructor neglects social benefits, it may lead to reduced government subsidies or even penalties, resulting in decreased earnings for the SPV company. To ensure their own investment return and maintain a long-term stable cooperative relationship in the project, constructors need to first meet government requirements for social benefits before

seeking higher returns for themselves. Timely commencement of work, shortening the construction period, and ensuring better governance outcomes also contribute to improved social benefits.

He et al.'s [46] research suggests that excessive government regulation may violate the principle of contractual freedom, thereby dampening the enthusiasm of private enterprises to participate in projects. The results of our study can be used to extend He et al.'s research and provide an explanation for the range of government shareholding ratios. Our study posits that when the private sector's share exceeds 0.5, the effect of environmental benefit enhancement is significant, implying that when the government's shareholding in the project company is less than 50%, the resulting enhancement in environmental benefits is greater. This aligns with the "PPP Project Contract Guidelines" issued by the Chinese Ministry of Finance [47], which stipulate that a project company can be established either solely by a private party or jointly by the government and a private party. However, the government's shareholding in the project company should be less than 50% and should not have actual control and management rights. This indicates that excessive government oversight and control should be avoided in PPP projects to fully leverage the advantages of the private sector.

5.6. Model Validation

Given the nature of this study, face and content validity were selected as the most appropriate non-statistical validation techniques [48,49]. To secure face validity of the research endeavor, in a practical field such as the PPP management and value improvement, the appropriate approach is through interviewing industry practitioners and seeking their opinion regarding the correctness of the study's underlying logic, and the soundness of the value improvement relationships [49]. If the content of a study is found to fairly reflect reality, content validity is satisfied as well [48]. To achieve this, the authors conducted in-depth, semi-structured interviews with five practitioners in the PPP industry. A total of five interviews were conducted using both face-to-face and online meeting systems. The interviewees included one chairman of a professional contracting company with over 15 years of experience in PPP project investment and construction management; two consulting engineers from PPP consulting firms, each with an average of 10 years of consulting experience in the PPP field and specifically in the PPP field of environmental management in major river basins; one PPP project manager from the China Three Gorges Group with 8 years of experience in environmental management of major river basins; and one government officer with over five years of experience in PPP management. The primary purpose of the interviews was to seek expert opinions on five aspects: (1) the effectiveness of parameters influencing the value enhancement model of company income, environmental benefits, and social benefits in PPP projects, (2) the extent to which the value enhancement expression model under the two modes reflects the actual situation of the parties involved, (3) the validity of the findings, and (4) the practical implications of the work. The interviewees had the flexibility to express their opinions and provide reflections based on their own experiences.

Regarding the influencing parameters in the value enhancement model, the company revenue parameter was based on existing research outcomes to demonstrate the validity of the model. However, concerning the parameters for environmental and social benefits, the experts suggested that, on one hand, both types of benefits involve numerous parameters, and many of these are challenging to quantify. On the other hand, the environmental benefit parameters are subject to variation due to the diverse nature of specific projects. Hence, selecting the most representative parameters is considered a reasonable and feasible approach.

The chairman of the private-sector construction contracting company and the PPP project manager of the China Three Gorges Corporation both expressed that, on one hand, when taking on projects, their primary concerns are risk factors. They are reluctant to bear operational risks since they exceed their scope of control. In particular, in PPP projects

involving significant operational risks, they prefer to hold fewer shares. Rather than cash flows over 20–30 years, they prefer to obtain construction profits over 2–3 years and then exit. On the other hand, many major river environmental management projects generate minimal or no profits. Balancing management effectiveness with economic returns is a pressing issue. However, with government policy support, their participation enthusiasm would be higher. The aforementioned views imply that if the private sector invests in the SPV, they will assume more risks, subsequently increasing their efforts to obtain profits as shareholders, rather than speculative profits through their role as contractors. This aligns with the perspectives expressed in Theorems 1 and 2.

When it comes to the extent to which the model reflects reality and the research outcomes, the consulting engineers opined that for projects requiring high technical and integrated operational capabilities (such as waste management and water treatment), a combination of operators and technical vendors is indeed pivotal for project success. On the other hand, the government official indicated that although the government recognizes the necessity of imposing some control over the SPV's equity structure, its primary focus is to limit changes in the equity structure during various project stages to prevent equity participants from prematurely selling their shares within the concession period. Furthermore, the government official noted that generally, improving service quality could be achieved through performance measurement and penalty clauses stipulated in PPP contracts. However, adverse social impacts of private sector investments (such as user satisfaction) are often challenging to describe in contracts. Additionally, the sustainability and stability of service provision are significant concerns, meaning that larger equity stakes held by companies in SPVs might not necessarily be better, and appropriate government oversight is still required.

Furthermore, from practical cases, we can also verify the correctness of the model's deduction results. In the Scottish water treatment PPP project, the SPV framework involved SWA holding 51% ownership, while the remaining shares were evenly divided between two consortia: Stirling Water, comprising Thames Water, KBR, Alfred McAlpine, and MJ Gleeson, and UUGM, which included United Utilities, Galliford Try, and Morgan Est. The SPV incorporated the involvement of construction and operational expertise firms. This project was successfully implemented, leading to a substantial increase in industry efficiency. This effective initiative resulted in a notable 20% reduction in operational costs within just two years, generating significant cost savings of approximately GBP 80 million between 2002 and 2006 [50].

6. Conclusions

This study, based on the principal-agent theory, examined the relationship between capital providers and value enhancement in the major river green PPP projects. A value improvement model for PPP projects was established by considering the scenario in which construction companies participate in SPV companies as dual-role entities. This model was used to compare the value enhancement of PPP projects under two different modes. The following conclusions can be drawn from the results: (1) The varying role structure of constructors significantly impacts the value enhancement of major river basin green PPP projects. Reasonable equity distribution effectively compensates for the incompleteness of PPP project contracts, making it a crucial factor to consider when establishing an SPV company. (2) The dual-role mode of construction companies increases their effort levels, shortens project duration, and enhances the economic benefits of the project company. However, the level of economic benefit for construction companies is related to their shareholding percentage in the SPV. Overall, the income of construction companies is higher when they invest in an SPV compared to not investing. (3) The dual-role mode of construction companies can enhance the environmental benefits generated by PPP projects. The more the government values environmental benefits, the more it welcomes construction companies to invest in SPVs. (4) The increase in social benefits is related to the shareholding percentage of construction companies, and the critical shareholding percentage increases

with project revenue. This means that the preferred range of shareholding percentages for construction companies, as favored by the government, will be influenced by the total project investment.

This study bears several practical implications. Firstly, it aids governments in understanding how the composition structure of SPV companies effectively addresses the incompleteness of PPP project contracts, essentially functioning as a form of relationship governance. During procurement, it is recommended for governments to prioritize the inclusion of participants with specialized knowledge, like constructors and operators. Their professional expertise not only amplifies the efficiency of public service facility construction but also motivates them to invest higher levels of effort due to their dual roles, thereby reducing the government's governance costs. For instance, incorporating an equity structure as an evaluation criterion in the bidding process could be considered.

Secondly, this research supports the government in making informed decisions regarding SPV equity percentages. The degree of value enhancement in PPP projects is intricately tied to the distribution of SPV equity. In the practice of PPP projects, "political support" plays a significant role in enhancing the value improvement potential of PPP projects [2]. However, it is essential to avoid excessive government regulation and control [46]. The government's ownership stake in project companies should be less than 50%, allowing for a greater allocation of control rights to private entities, thereby leveraging the advantages of private sector participation to the fullest extent.

Thirdly, the allocation of ownership stakes in the SPV should be adjusted based on specific circumstances. Various factors such as project investment amounts and regulatory environments can influence the optimal ownership distribution among the dual-role entities in PPP projects. By implementing this dual-role entity model, green PPP projects tend to emphasize relational governance over contractual constraints, channeling value addition toward long-term overall project benefits. This approach helps to prevent short-term, suboptimal, and opportunistic behaviors, thereby creating higher economic, environmental, and social benefits and achieving better governance outcomes for green projects like the treatment of major rivers and water environments.

However, this study has some limitations that deserve further research. Firstly, it should consider more macroeconomic variables, for instance, whether differences in the economic development level of project sites will affect the distribution of equity percentages, and whether differences in capital allocation experience will impact the value improvement of PPP projects under the dual-role participant model. Secondly, the selection of more representative water environmental evaluation parameters should be considered for inclusion in the model. As there are numerous water environmental evaluation parameters, and different river basins have varying water quality conditions, selecting more representative evaluation parameters will lead to more accurate value improvement results. Thirdly, the theoretical analysis in this paper suggests that the dual-role entity mode can be further divided into five modes. Investigating whether these five modes exhibit differences in value-added levels is worth further research.

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Abbreviations

The following symbols are used in this paper:

- PPP Public-private partnership
- SPV Special Purpose Vehicle
- *F* Contract amount
- *R* Net income generated per unit time after the construction project is completed
- Q Profit of the project company
- φ Influence coefficient of the construction party's effort level on the major river green
- Ψ PPP project
- θ Influence coefficient of time
- λ Efficiency coefficient of reducing variable construction periods
- δ_i Basic standard for each water environmental management assessment indicator
- w_i The weight for indicator *i*
- *i* Number of indicators
- T_c The concession period
- t_a Predicted completion time
- t_b Variable construction time
- β Influence coefficient of agent's cost
- *P* The revenue generated per unit time after the construction project is completed
- C Construction cost
- c_0 Fixed cost
- *c*₁ Variable cost
- The management costs incurred by the professional company when participating c_2
- as a shareholder in the role of the principal
- ρ Influence coefficient of government's emphasis on environmental benefits
- *u* Social benefit
- α Agent's effort level
- α^* Agent's optimal effort level
- g Agent's effort cost k Shareholding perce
 - Shareholding percentage of the professional company in SPV
- $E(\pi_s)$ Expected profit for the construction party in Single-Role Entity Scenario
- $E(\pi_d)$ Expected profit for the construction party in Dual-Role Entity Scenario
- $E(V_s)$ Expected total environmental benefit in Single-Role Entity Scenario
- $E(V_d)$ Expected total environmental benefit in Dual-Role Entity Scenario
- $E(z_s)$ Social benefit in Single-Role Entity Scenario
- $E(z_d)$ Social benefit in Dual-Role Entity Scenario

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