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Government–Enterprise–Public Game-Theoretic Strategies for Ecological Restoration in Smart City Development

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Abstract: Municipal engineering projects are of critical significance for advancing China's high-quality sustainable development, fostering harmonious coexistence between human society and the natural environment, and enabling the construction of smart cities. This study constructs an ecological restoration network involving three stakeholders—the government, enterprises, and the local labor force at restoration sites—and employs a Stackelberg game-theoretic framework to examine how the interplay between government procurement payments and subsidy policies affects tripartite collaborative governance. The findings reveal that: (1) Compared with the "procurement-first, subsidy-later" strategy, the "subsidy-first, procurement-later" approach entails higher upfront government expenditure but achieves greater fiscal efficiency and generates superior corporate profits; (2) Subsidizing enterprises facilitates long-term talent accumulation and more effectively addresses employment needs within the restoration-site labor force, whereas compensating the labor force directly yields higher short-term corporate profitability; (3) The effectiveness of government procurement payment ratios and subsidy schemes depends critically on the actual number of participating workers and the residual value of their labor. Moreover, an optimal procurement payment ratio and subsidy range exist, under which each unit of subsidy maximizes capital utilization efficiency and simultaneously optimizes corporate profit outcomes.

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1. Introduction

Ecological restoration—rehabilitating degraded ecosystems through natural or artificial interventions—is a critical dimension of smart city development and a key pathway to sustainable development. Unlike other sectors, most restoration projects are public or quasi-public goods with positive externalities, making them largely unmarketable and reliant on government investment. Thus, reducing costs while improving efficiency remains a strategic challenge requiring systematic coordination. China has adopted a "government–enterprise–public collaborative model" as a major approach. The government exercises preferential procurement to guide market forces, enterprises supply technologies and professional services, and local residents provide on-site labor. This tripartite synergy advances both ecological restoration and smart city construction, raising new theoretical and practical questions about regional operational models and policy-mix strategies.[1][2][3]

Domestic research on ecological restoration has largely employed fuzzy comprehensive evaluation and PVAR models, focusing on aquatic basins and mining areas. Wang Jinnan and Wang Zushan et al. addressed soil erosion and water pollution in the Yellow and Yangtze rivers, proposing spatial governance and regional coordination strategies. Li Jing, Yu Haochen, and Chen Jing et al., from a mountains–waters–forests–farmlands–grasslands perspective, evaluated mining restoration and called for integrating ecological principles into post-restoration efforts. International scholarship has emphasized technological advancement and practical on-site challenges, mainly in ecology and environmental science. Covington et al. studied post-fire ponderosa pine forest restoration, refining both evaluation and technical methods.[4] Altaghlibi introduced ecological compensation criteria to incentivize green technologies, while Lamqadem demonstrated biochar's effectiveness against desertification. Government incentives and penalties have also been widely examined. Hentati and Mondaca found that fishery subsidies can reduce poverty and protect marine resources but may cause overexploitation if excessive. Craig C. et al. identified optimal subsidy intervals for organic agriculture and new energy.[5][6]

In summary, international research tends to be technology-oriented and empirically grounded, while domestic studies emphasize institutional and evaluative frameworks. However, both lack sufficient attention to interactive dynamics among stakeholders. Despite China's practical experience, the sector still suffers from high costs, slow progress, prolonged timelines, delayed payments, and fragmented understanding, straining enterprises and labor. This calls for a tripartite game-theoretic approach to coordinate government, enterprises, and the local workforce.[7]

2. Materials and Methods

This study considers a setting where enterprises provide ecological restoration services to the government, which may adopt a hybrid procurement-and-subsidy strategy: exercising preferential procurement while simultaneously offering fiscal subsidies to incentivize enterprise participation. Under this scheme, only a preset portion of the transaction is paid upfront, with the remainder settled upon project completion. The government has two subsidy channels: (i) directing funds to enterprises while requiring them to absorb local labor; or (ii) providing direct payments to the local labor force based on a fixed rate per labor unit, as an ecological compensation measure. The model is formalized using the following parameters:

p_1 — Market-determined wage rate per unit of labor, i.e., the minimum compensation that a unit of labor receives for participation in restoration work in the absence of government subsidies.

p_2 — Wage rate per unit of labor offered by the enterprise, i.e., the compensation level acceptable to a unit of labor under the government subsidy scheme.

p_3 — Subsidy rate per unit of labor provided by the government.

p — Government procurement price per unit of restored area, i.e., the payment that the government makes to the enterprise for each unit of restored land area purchased.

$N(N \in N^+)$ — Total labor force that the enterprise is capable of employing.

$n(n \in N^+)$ — Actual number of labor units participating in ecological restoration work.

β — Capacity of each unit of labor to generate additional value. When the compensation received by a unit of labor exceeds the market wage rate p_1 , the surplus remuneration exerts a positive incentive effect, thereby enabling the labor unit to create extra value beyond its baseline contribution.

q — Volume of restored area transacted between the enterprise and the government, i.e., the quantity of restored land area traded under the procurement agreement.

c — Cost per unit of restored area, defined as the average cost borne by the enterprise for restoring each unit of land area.

α — Government subsidy spillover coefficient, defined as the ratio of additional profits generated by the subsidy to the subsidy amount itself. A larger value of this coefficient indicates greater subsidy effectiveness.

k — Sensitivity coefficient of market demand with respect to the subsidy price. The term kp_3 denotes the change in market demand attributable to the government subsidy, where k follows a uniform distribution over the interval $(0,1)$.

$r[r \in (0,1)]$ — Coefficient representing the prepayment proportion under the government's preferential procurement policy. Specifically, after the procurement volume is determined between the government and the enterprise, the government settles r times the total transaction amount as an upfront payment, with the remaining balance disbursed upon successful completion of the restoration project. The term rpq denotes the amount of the government's upfront procurement payment.[8][9][10]

Based on the problem context described above, the following assumptions are imposed to formalize the model. In the hybrid government strategy combining procurement payments and subsidies, two distinct policy sequences are considered: (i) under the "subsidy-first, procurement-payment-later" strategy, the government and the enterprise jointly aim to maximize fiscal efficiency in terms of capital utilization; (ii) under the "procurement-payment-first, subsidy-later" strategy, the objective is instead set to maximize the enterprise's profit.

Assumption 1. While exercising preferential procurement, the government mandates that the enterprise address local labor employment issues as an integral part of its ecological restoration operations.

Assumption 2. When the government provides subsidies directly to the labor force, the condition $p_2 + p_3 > p_1$ must hold. Should this inequality fail, all subsidized labor units would decline to participate in ecological restoration work, and the subsidy would consequently lose its poverty-alleviation significance in terms of stimulating employment. Furthermore, the subsidy rate is assumed to be lower than the market-determined wage rate, i.e., $p_1 > p_3$, which implies that labor units retain the option to choose whether to engage in restoration work after receiving the subsidy. In contrast, when the government channels subsidies to enterprises, all available labor units are assumed to participate in the restoration work, subject to the constraint $N \geq n$.

Assumption 3. The capacity of each labor unit to generate additional value, denoted by β , is assumed to satisfy $\beta \geq 1$ and to follow a uniform distribution. When labor units do not receive any remuneration exceeding the market wage rate, i.e., when the total compensation does not surpass p_1 , we have $\beta = 1$. Drawing upon analogous studies in the literature, the additional profit captured by the enterprise due to the extra value created by each unit of labor is represented by $\frac{p_2 + p_3}{p_1} \beta$.

To distinguish between the two subsidy regimes, the superscript gD denotes the scenario in which the government directs subsidies to enterprises, whereas the superscript gLD denotes the scenario in which the government provides subsidies directly to the labor force. Accordingly, the superscripts gD^* and gLD^* are used to indicate the equilibrium values of the relevant variables under the enterprise-directed subsidy regime and the labor-directed subsidy regime, respectively. Furthermore, the subscripts mc and G are employed to denote the enterprise's profit and government expenditure, respectively.

We now examine the optimal behavioral decisions of the government, the enterprise, and the labor force under the hybrid strategy that combines government preferential procurement and subsidy policies. Given that the government's preferential procurement target is uniquely determined, whereas the subsidy recipients are not restricted to a single entity, we proceed to develop equilibrium models for distinct subsidy

regimes while accounting for the government's prepayment ratio coefficient r . The resulting models are solved via Stackelberg game-theoretic analysis.

The sequence of decisions is as follows. First, the government determines the subsidy rate p_3 based on the market-determined wage rate p_1 . Upon observing the government's policy choice, the enterprise then decides on the transaction volume q and the unit price p for the restoration area to be traded with the government. The demand function is specified as:

$$p = \beta N - (kp_3 - c) - q = \beta N + c - kp_3 - q$$

In the absence of government subsidies, the enterprise's profit function and the government's expenditure function are respectively given by:

$$\begin{cases} \pi_{mc}^w = q(p - c) - Np_1 \\ \pi_G^w = pq \end{cases} \quad (1)$$

where π_{mc}^w denotes the enterprise's profit in the absence of government subsidies, and π_G^w denotes the government's procurement expenditure under the same non-subsidy scenario.[11]

Government Subsidies Directed to Enterprises (gD Scenario)

When the government provides subsidies directly to enterprises as a priority, the enterprise is obligated, in accordance with the procurement agreement, to indirectly assume corporate social responsibility by employing the local labor force at the restoration site, thereby contributing to poverty alleviation through industrial development. Under this regime, the enterprise receives a prepayment portion of the government procurement expenditure, along with the additional value created by the labor force, while simultaneously bearing both the ecological restoration costs and the labor employment costs. The government, in turn, incurs expenditures comprising the subsidy disbursement and the procurement payment. Accordingly, the enterprise's profit function and the government's expenditure function are respectively given by:

$$\begin{cases} \pi_{mc}^{gD} = rpq - qc + \frac{p_2 + p_3}{p_1} \beta N - Np_2 \\ \pi_G^{gD} = Np_3 + pq \end{cases} \quad (2)$$

where π_{mc}^{gD} denotes the enterprise's profit under the enterprise-directed subsidy regime, and π_G^{gD} denotes the corresponding government expenditure. Substituting the demand function into Equation (2) yields the enterprise's profit function as follows:

$$\pi_{mc}^{gD} = q[r(\beta N - kp_3 - q) + (r - 1)c] + \frac{p_2 + p_3}{p_1} \beta N - Np_2$$

Accordingly, the Hessian matrix of the above profit function is obtained as follows:

$$H_{\pi_{mc}^{gD}}(p, q) = \begin{bmatrix} \frac{\partial^2 \pi_{mc}^{gD}}{\partial p^2} & \frac{\partial^2 \pi_{mc}^{gD}}{\partial q \partial p} \\ \frac{\partial^2 \pi_{mc}^{gD}}{\partial p \partial q} & \frac{\partial^2 \pi_{mc}^{gD}}{\partial q^2} \end{bmatrix} = \begin{bmatrix} -2r & 0 \\ 0 & -2r \end{bmatrix}$$

Since the first-order leading principal minor of the Hessian matrix $H_{\pi_{mc}^{gD}}(p, q)$ satisfies $-2r < 0$, and its second-order leading principal minor satisfies $4r^2 > 0$, the Hessian matrix is negative definite. Therefore, under the enterprise-directed subsidy regime, the enterprise's profit function attains a unique global maximum. Following the decision sequence specified in the model, we derive the first-order conditions of the enterprise's profit function π_{mc}^{gD} , which yield:

$$\begin{cases} q(p_3) = \frac{r(\beta N - kp_3) + (r - 1)c}{2r} \\ p(p_3) = \frac{r(\beta N - kp_3) + (r + 1)c}{2r} \end{cases} \quad (3)$$

Proposition 1. When the condition $\beta > \max(\frac{kp_3 + q}{N}, \frac{p_2 p_1}{p_3 + p_2})$ holds, we have $\pi_{mc}^{gD} > 0$.

The condition specified in Proposition 1 serves a dual purpose: on the one hand, it guarantees the existence of a viable supply–demand relationship between the enterprise and the government; on the other hand, it ensures that the enterprise can obtain a positive level of profit under the enterprise-directed subsidy regime.

Substituting Equation (3) into Equation (2), we obtain the government expenditure function π_G^{gD} as follows:

$$\pi_G^{gD} = \frac{[r(\beta N - kp_3) + (r+1)c][r(\beta N - kp_3) + (r-1)c]}{4r^2} + Np_3 \quad (4)$$

Correspondingly, from Equation (4), and by applying the first-order condition of the government expenditure function, the equilibrium government subsidy rate is derived as follows:

$$p_3^{gD*} = \frac{kN\beta + ck - 2N}{k^2} \quad (5)$$

Subsequently, from Equation (5), the equilibrium transaction volume and the equilibrium transaction price between the government and the enterprise are obtained respectively as follows:

$$\begin{cases} q^{gD*} = \frac{2Nr - kc}{2kr} \\ p^{gD*} = \frac{2Nr + kc}{2kr} \end{cases} \quad (6)$$

Finally, substituting Equation (5) and Equation (6) into Equation (2) and Equation (4), respectively, yields the equilibrium enterprise profit π_{mc}^{gD*} and the equilibrium government expenditure π_G^{gD*} as follows:

$$\begin{aligned} \pi_{mc}^{gD*} &= \frac{k^2c^2(2r-1) + 4Nr^2(N-ck)}{4k^2} - \frac{\beta N(p_2^2k^2 + ck + Nk\beta - 2N)}{k^2p_1} - Np_2(7) \\ \pi_G^{gD*} &= \frac{k(4N^2 - k^2c^2) + 4Nr^2(kN\beta + ck - 2N)}{4k^2} \end{aligned} \quad (8)$$

Proposition 2. When the condition $\beta > \max(\frac{p_2^2k^2 + ck - 2N}{kN}, \frac{2N - ck}{kN})$ holds, it can be readily verified that $\begin{cases} \pi_{mc}^{gD*} > 0 \\ \pi_G^{gD*} > 0 \end{cases}$. Under this condition, in the enterprise-directed subsidy regime, the corresponding equilibrium outcomes for all stakeholders in the network are respectively given by Equations (5), (6), (7), and (8).

Government Subsidies Directed to the Restoration-Site Labor Force (gLD Scenario)

To fulfill the dual objectives of ecological restoration and poverty alleviation, the local government may adopt a strategy of providing direct subsidies to the restoration-site labor force. Under this regime, government subsidies directly raise the income of the local labor force, which can be characterized as either an ecological compensation measure or a poverty-alleviation intervention. In this context, the labor force retains the option to decide whether to participate in the restoration work. The enterprise's profit function and the government's expenditure function under this scenario are respectively given by:

$$\begin{cases} \pi_{mc}^{gLD} = rpq - qc + \frac{p_2 + p_3}{p_1}\beta n - np_2 \\ \pi_G^{gLD} = Np_3 + pq \end{cases} \quad (9)$$

where π_{mc}^{gLD} denotes the enterprise's profit under the labor-directed subsidy regime, and π_G^{gLD} denotes the corresponding government expenditure. By applying the Hessian matrix approach, it can be similarly verified that the enterprise attains an optimal profit level under the labor-directed subsidy regime. Following the same solution procedure as in the preceding section, we obtain:

$$p_3^{gLD*} = \frac{kN\beta + ck - 2N}{k^2} \quad (10)$$

$$\begin{cases} q^{gLD*} = \frac{2Nr - kc}{2kr} \\ p^{gLD*} = \frac{2Nr + kc}{2kr} \end{cases} \quad (11)$$

$$\pi_{mc}^{gLD*} = \frac{k^2 c^2 (2r - 1) + 4Nr^2 (N - ck)}{4k^2} - \frac{\beta n(p_2^2 k^2 + ck + Nk\beta - 2N)}{k^2 p_1} - np_2 \quad (12)$$

$$\pi_G^{gLD*} = \frac{k(4N^2 - k^2 c^2) + 4Nr^2 (kN\beta + ck - 2N)}{4k^2} \quad (13)$$

Proposition 3. Under the labor-directed subsidy regime, the corresponding equilibrium outcomes for all stakeholders in the ecological restoration network are respectively given by Equations (10), (11), (12), and (13).

3. Results and Discussion

Based on the equilibrium results derived in the preceding section, this part analyzes the effects of the hybrid government strategy combining procurement payments and subsidy policies on the tripartite game-theoretic equilibrium among the government, the enterprise, and the labor force, with particular emphasis on the subsidy spillover coefficient and the government's preferential procurement prepayment ratio. To distinguish between the two policy sequences, we use the subscripts z and j to denote the "subsidy-first, procurement-payment-later" strategy and the "procurement-payment-first, subsidy-later" strategy, respectively. The four policy scenarios are summarized in Table 1 below.[12]

Table 1. Policy Scenarios of Government Procurement Payment and Subsidy Strategies.

Scenario No.	Subsidy Recipient	Sequence of Government–Enterprise Actions
1	Enterprise	Subsidy first, procurement payment later
2	Enterprise	Procurement payment first, subsidy later
3	Labor force	Subsidy first, procurement payment later
4	Labor force	Procurement payment first, subsidy later

Government Subsidies Directed to Enterprises: Scenario 1 (Subsidy First, Procurement Payment Later)

Proposition 4. When the subsidy spillover coefficient and the government's preferential procurement prepayment ratio satisfy the following conditions:

$$\begin{cases} \alpha_z^{gD*} = \frac{\beta}{p_1} + \frac{4Nk^4 r^2 [p_1(p_1 - p_2) + \beta p_2] + p_1(r - 1)(4N^2 r^2 - k^2 c^2)}{4p_1 N k^2 r^2 (kN\beta + ck - 2N)} \\ r_z^{gD*} = \frac{k[2N + \sqrt{4N^2 + 2c^2(k - 2)(3k - 4)}]}{4N(3k - 4)} \end{cases}$$

the tripartite game among the government, the enterprise, and the labor force reaches equilibrium under Scenario 1.

Under this scenario, the subsidy spillover coefficient should be controlled at the level of α_z^{gD*} , at which the leverage effect of government subsidy funds is maximized, and the capital utilization efficiency per unit of subsidy attains its optimum.

To further investigate the determinants of the equilibrium spillover coefficient α_z^{gD*} , we present Figure 1. The coefficient α_z^{gD*} is primarily influenced by the market-determined wage rate p_1 and the labor force's capacity to generate additional value β . Specifically, as p_1 increases, the spillover coefficient α_z^{gD*} decreases, implying that the marginal utility of each unit of government subsidy diminishes. This can be interpreted as follows: when the market wage rate p_1 rises while the subsidy intensity remains unchanged, the extra remuneration received by each unit of labor decreases, which in turn reduces the labor force's capacity to generate additional value β . Consequently, the additional profit captured by the enterprise, given by $\frac{p_2 + p_3}{p_1} \beta N$, declines, which is precisely

reflected in the reduction of the spillover coefficient. This finding suggests that, in the process of subsidy implementation, the government should closely monitor variations in p_1 and β so as to maintain a relatively high subsidy effectiveness.[13]

Having examined the effectiveness of the subsidy policy, we proceed to explore the relationship between the equilibrium spillover coefficient α_z^{gD*} and the government transaction payment coefficient r_z^{gD} . As shown in Figure 2, when the subsidy spillover coefficient is maintained at its optimal level, there exists an optimal government transaction payment coefficient r_z^{gD*} .

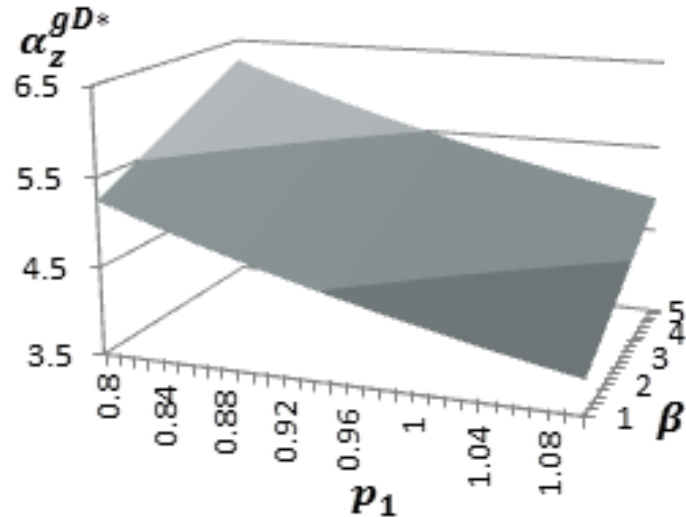


Figure 1. Determinants of the Subsidy Spillover Coefficient α_z^{gD*} .

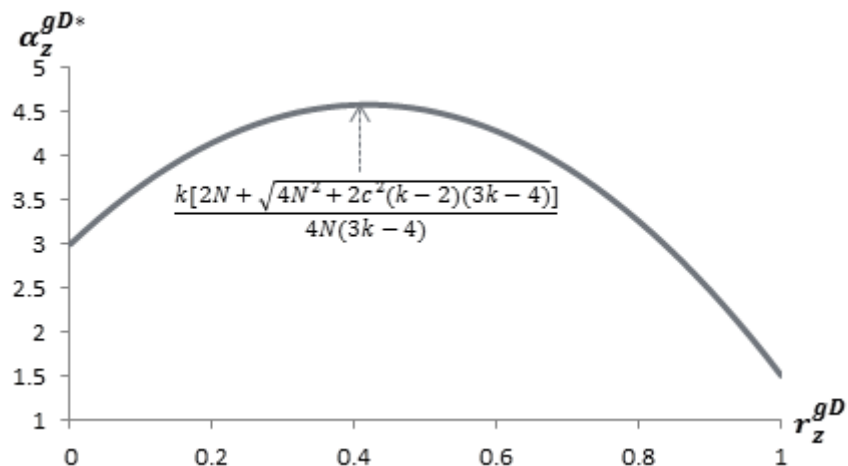


Figure 2. Relationship between α_z^{gD*} and r_z^{gD} .

When the subsidy spillover coefficient and the government's preferential procurement prepayment ratio satisfy the following conditions:

$$\left\{ \begin{array}{l} \alpha_j^{gD*} = \frac{\beta}{p_1} + \frac{4Nk^4[p_1(p_1 - p_2) + \beta p_2]}{4p_1Nk^2(kN\beta + ck - 2N)} \\ + \frac{[c^2 - 16(ck - N)[c^4 - 64k^2c^2(ck - N)^2]}{256Nk^2c^2(kN\beta + ck - 2N)(ck - N)^2} \\ r_j^{gD*} = \frac{c^2}{16N(ck - N)} \end{array} \right.$$

the tripartite game among the government, the enterprise, and the labor force reaches equilibrium under Scenario 2.

As illustrated in Figure 3, we first examine the relationship between r_j^{gD*} and π_{jmc}^{gD*} . As r_j^{gD} increases, the relationship between the government procurement prepayment ratio and the enterprise's profit exhibits an inverted U-shaped pattern—first rising and then declining. This indicates that a higher government prepayment ratio is not necessarily

preferable. Once the procurement prepayment ratio reaches a certain threshold, the enterprise can fully leverage the capital leverage effect and enhance capital utilization efficiency, without requiring the full transaction amount to be settled upfront. When the procurement prepayment ratio attains its optimal level, the subsidy spillover coefficient is maximized, capital utilization efficiency reaches its peak, and the enterprise achieves its strongest profitability. However, when the government procurement prepayment ratio becomes excessively high, in conjunction with government subsidies, the enterprise receives subsidy funds that exceed its maximum capacity to utilize capital effectively. Consequently, the marginal capital utilization efficiency declines, which in turn erodes the enterprise's profitability.

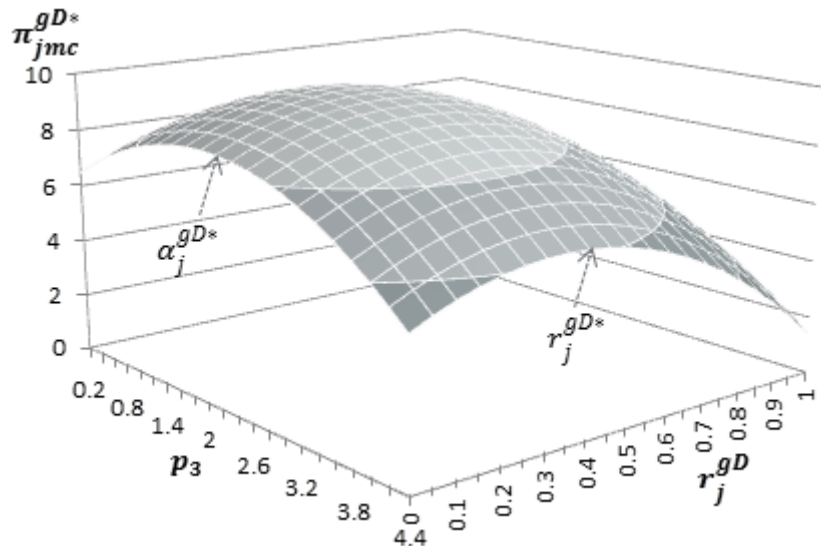


Figure 3. Relationships among Government Subsidy Rate p_3 , Transaction Payment Coefficient r_j^{gD*} , and Enterprise Profit π_{jmc}^{gD*} .

Furthermore, from $\frac{\partial r_j^{gD*}}{\partial c} > 0$ and $\frac{\partial r_j^{gD*}}{\partial N} > 0$, it follows that the government procurement prepayment ratio is positively correlated with both the cost per unit of restored area and the total labor force that the enterprise is capable of employing. Specifically, when the restored area is relatively large, the enterprise must commit substantial upfront capital to the ecological restoration work, which in turn justifies a higher government prepayment ratio. Similarly, when the enterprise has access to a larger pool of potential labor, it faces higher prospective employment costs, thereby necessitating a higher level of government startup funding through the procurement prepayment mechanism.

Government Subsidies Directed to the Labor Force: Scenario 3 (Subsidy First, Procurement Payment Later)

Proposition 6. When the subsidy spillover coefficient and the government's preferential procurement prepayment ratio satisfy the following conditions:

$$\begin{cases} \alpha_z^{gLD*} = \frac{k(r-1)(4N^2r^2 - k^2c^2) - 4k^2r^2(Np_1 + np_2 - n\beta k^2)}{4Nr^2(kN\beta + ck - 2N)} + \frac{n\beta k^2}{Np_1} \\ r_z^{gLD*} = \frac{1 + 2\sqrt{[1 + (k^2c^3 + 1)(N^2 - k(Np_1 + np_2 - n\beta k^2))]} }{4[N^2 - k(Np_1 + np_2 - n\beta k^2)]} \end{cases}$$

the tripartite game among the government, the enterprise, and the labor force reaches equilibrium under Scenario 3.

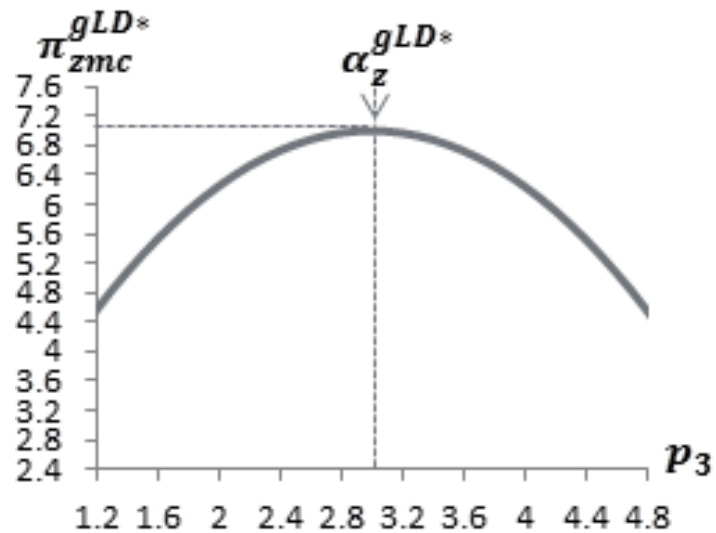


Figure 4. Relationship between Government Subsidy Rate p_3 and Enterprise Profit π_{zmc}^{gLD*} .

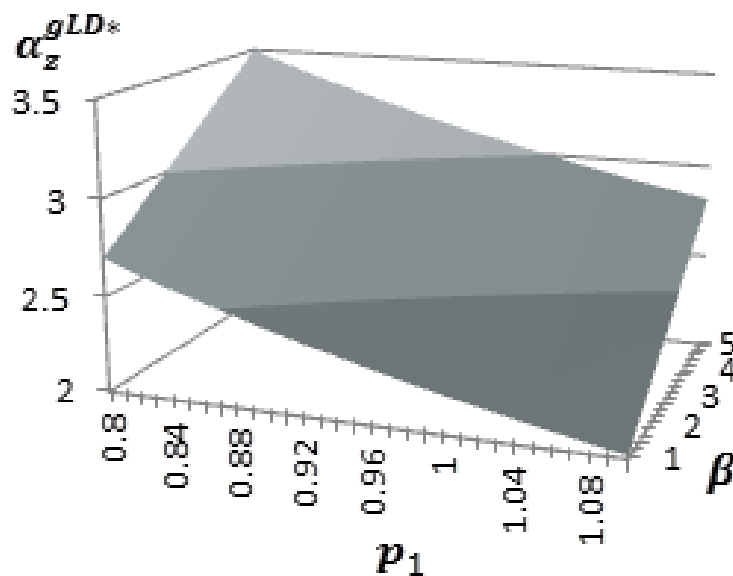


Figure 5. Determinants of the Spillover Coefficient α_z^{gLD*} .

The relationships among enterprise profit, government subsidies, and the spillover coefficient are illustrated in Figures 4 and 5.

As shown in Figure 4, the subsidy rate p_3 and the enterprise's equilibrium profit π_{zmc}^{gLD*} exhibit an inverted U-shaped concave relationship, first increasing and then decreasing. This indicates that there exists an optimal interval for the government subsidy per unit of labor, and that a higher subsidy is not necessarily better. When $\frac{\partial \pi_{zmc}^{gLD*}}{\partial \beta} > 0$ ($p_3 < \alpha_z^{gLD*}$), the labor force, in pursuit of higher remuneration, enhances its capacity to generate additional value, which in turn drives up enterprise profit. As shown in Figure 5, the labor force's capacity to generate additional value β is positively correlated with the subsidy spillover coefficient. This implies that a higher capacity of the labor force to generate additional value leads to greater capital utilization efficiency per unit of subsidy for the enterprise, thereby boosting enterprise profit.[14]

However, after enterprise profit surpasses its optimal point, as the subsidy amount received by the labor force continues to increase, we have $\frac{\partial \pi_{zmc}^{gLD*}}{\partial \beta} < 0$ ($p_3 > \alpha_z^{gLD*}$), and enterprise profit exhibits a gradually declining trend. This suggests that when the remuneration for the labor force's additional value creation exceeds expectations, the marginal labor productivity declines. Consequently, both the government and the

enterprise should maintain the wage and subsidy levels for the labor force within a reasonable range to avoid wasteful allocation of funds.

We next examine the impact of government procurement payments on the equilibrium of the supply chain. When the procurement payment coefficient is set at r_z^{gLD*} , the spillover coefficient α_z^{gLD*} attains its optimum, at which government subsidies are most effective. The relationships among the equilibrium parameters are shown in Figures 6 and 7.

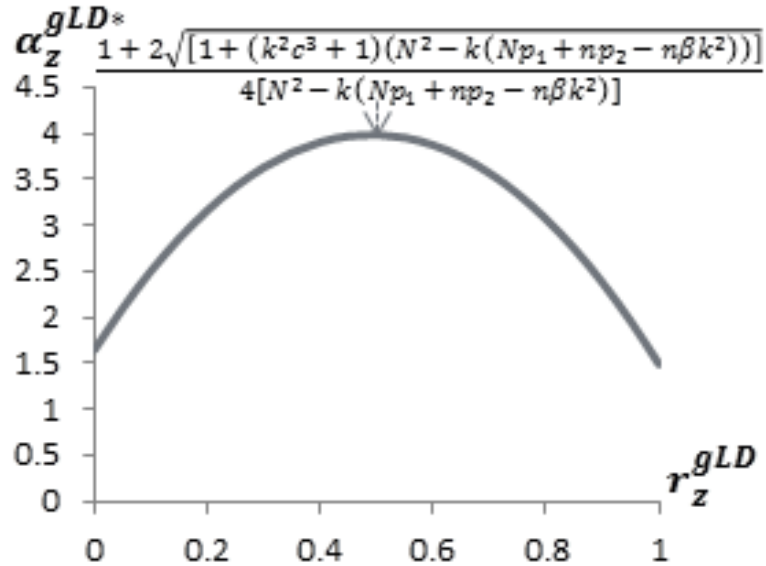


Figure 6. Relationship between the Subsidy Spillover Coefficient α_z^{gLD*} and the Government Transaction Payment Coefficient r_z^{gLD} .

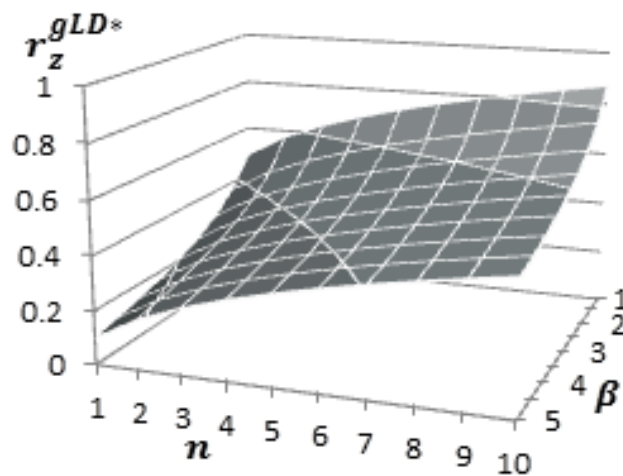


Figure 7. Determinants of the Government Transaction Payment Coefficient r_z^{gLD} .

The results indicate that, similar to the enterprise-directed subsidy regime, under the labor-directed subsidy regime, as the government procurement payment coefficient r_z^{gLD} increases, the spillover coefficient first rises and then declines. This suggests that under the subsidy-first strategy, the government should carefully control the procurement prepayment ratio to ensure a relatively high level of capital utilization efficiency. Furthermore, the government procurement payment coefficient r_z^{gLD*} is primarily influenced by the actual number of labor units participating in ecological restoration work and the additional value created by each unit of labor. When the number of labor units increases, the enterprise faces higher employment costs, which necessitates a larger amount of startup funding and consequently leads to an increase in the procurement prepayment ratio. Conversely, when the additional value created by each

unit of labor increases, the enterprise can capture more extra profit, which enables it to undertake the ecological restoration tasks even when only a relatively low proportion of the transaction amount is settled upfront.

Proposition 7. When the subsidy spillover coefficient and the government's preferential procurement prepayment ratio satisfy the following conditions:

$$\left\{ \begin{array}{l} \alpha_j^{gLD*} = \frac{16N^3c^2(kN\beta + ck - 2N)[c^2 - 64k^2(ck - N)^2]}{[16N^2(ck - N)^2]^2} \\ \quad + \frac{n\beta k^2}{Np_1} - \frac{k^2(Np_1 + np_2 - n\beta k^2)}{N(kN\beta + ck - 2N)} \\ r_j^{gLD*} = \frac{c^2}{16N(ck - N)} \end{array} \right.$$

the tripartite game among the government, the enterprise, and the labor force reaches equilibrium under Scenario 4.

The relationships among the cost per unit of restored area, the total labor force that the enterprise is capable of employing, and the transaction payment coefficient are illustrated in Figure 8.

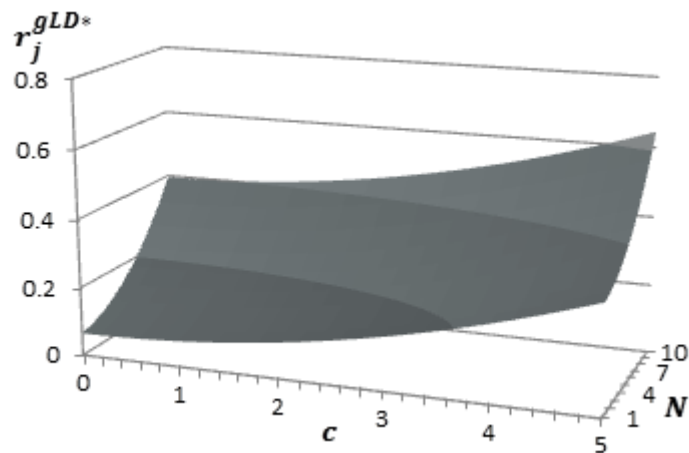


Figure 8. Determinants of the Government Transaction Payment Coefficient r_j^{gLD*} .

First, as the cost per unit of restored area increases, the government transaction payment coefficient rises correspondingly. Second, the total labor force that the enterprise is capable of employing is also positively correlated with the government transaction payment coefficient. Finally, from the first-order condition of π_{jmc}^{gLD*} , setting $\frac{\partial \pi_{jmc}^{gLD*}}{\partial N} = 0$ yields the equilibrium labor force level $N^* = \frac{\beta n(k\beta - 2) + ckr^2p_1}{2r^2p_1}$. This implies that under the labor-directed subsidy regime, if the total available labor force is less than N^* , the enterprise should consider employing the entire labor force; conversely, if the total available labor force exceeds N^* , full employment is not advisable.[15]

Analysis of Government Subsidy Elements

As demonstrated in the preceding analysis, the numerical values of the same equilibrium parameter vary considerably across different policy scenarios. A comparative analysis of the equilibrium parameters under alternative strategies thus provides valuable references for strategic decision-making among the government, the enterprise, and the labor force.

In this study, the government subsidy elements primarily include the subsidy spillover coefficient α and the government preferential procurement prepayment ratio coefficient r . The comparative analysis is summarized in Table 2.

Table 2. Comparison of Equilibrium Parameters under Different Government Strategies.

Equilibrium Parameter	Comparative Analysis
α	$\alpha_z^{gD*} > \alpha_j^{gD*} > \alpha_z^{gLD*} > \alpha_j^{gLD*}$
r	$r_z^{gLD*} > r_z^{gD*} > r_j^{gLD*} = r_j^{gD*}$

(1) Subsidy Spillover Coefficient

The spillover coefficient is higher under enterprise-directed subsidies than under labor-directed subsidies. This is mainly because some labor recipients receive payments without actually working, reducing fund utilization efficiency. In addition, under the subsidy-first strategy—which targets capital efficiency—the marginal utility of subsidy funds is higher, further raising the spillover coefficient.

(2) Procurement Payment Coefficient

Under the procurement-first strategy, the payment coefficient is relatively low, as the objective is enterprise profit maximization, requiring less upfront funding to incentivize participation. The coefficient is higher when subsidizing labor, since non-participating workers reduce enterprise surplus and leverage-generated benefits, necessitating greater government prepayment. Notably, under the procurement-first strategy, the coefficient remains the same regardless of subsidy recipient.

Enterprise Equilibrium Profit Analysis

It is straightforward to show that $\pi_{zmc}^{gLD*} > \pi_{jmc}^{gLD*} > \pi_{zmc}^{gD*} > \pi_{jmc}^{gD*}$. The difference in the sequencing of procurement payments and subsidies leads to variations in both the initial capital obtained by the enterprise and the associated capital utilization efficiency, which in turn generates disparities in enterprise profits.

Labor-directed subsidies yield higher enterprise profits than enterprise-directed subsidies. This is because: (i) under labor-directed subsidies, firms pay only for actively engaged workers; and (ii) participating workers tend to have higher value-creation capacity, generating greater extra profits. Moreover, given the same subsidy recipient, the subsidy-first strategy outperforms the procurement-first strategy in terms of enterprise profits. This is because the subsidy-first approach achieves optimal capital utilization efficiency and provides higher upfront procurement payments, both of which jointly boost enterprise profitability.

Analysis of Labor Force Factors

As demonstrated in the preceding section, labor force factors—including the number of labor units actually participating in restoration work and their capacity to generate additional value—exert a significant influence on the hybrid government strategy combining subsidies and procurement payments. It is therefore necessary to further investigate the effects of these labor force factors on the equilibrium of the tripartite network comprising the government, the enterprise, and the labor force.

(1) Relationship between $\frac{n}{N}$ and the Difference in Enterprise Equilibrium Profits under Alternative Government Strategies

The relationship between the proportion of labor units actually participating in restoration work, denoted by $\frac{n}{N}$, and the ratio of enterprise equilibrium profits under different government strategies, denoted by $\frac{\pi_{mc}^{gD*}}{\pi_{mc}^{gLD*}}$, is illustrated in Figure 9. When the number of labor units participating in restoration work is uncertain, enterprise equilibrium profits exhibit significant disparities. Specifically, when $n < 0.4N$, subsidizing enterprises yields superior enterprise equilibrium profits; when $n > 0.4N$, subsidizing the labor force yields superior enterprise equilibrium profits. This outcome is primarily attributable to the varying residual value of labor. As the number of participating labor units increases,

holding other parameters constant, the residual value of labor gradually rises, thereby enabling the creation of greater economic value for the enterprise.

Generally speaking, an increase in the number of participating labor units reduces the marginal utility of value creation by labor, leading to a decrease in the subsidy spillover coefficient. However, under the labor-directed subsidy regime, the presence of labor units that receive subsidies without actually participating in work attenuates the impact of labor quantity on marginal utility. Moreover, from the enterprise's perspective, the number of labor units actually participating in restoration work is positively correlated with the subsidy spillover coefficient ($\frac{\partial \alpha^{L^*}}{\partial n} > 0$), indicating that a larger labor force implies greater profit potential for the enterprise.

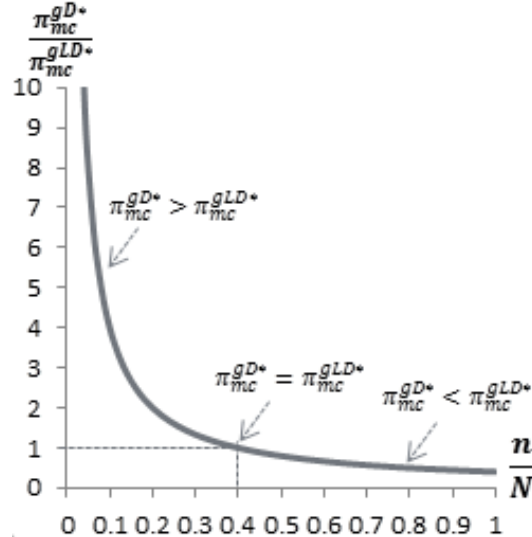


Figure 9. Impact of $\frac{n}{N}$ on the Difference in Enterprise Equilibrium Profits under Alternative Government Decisions

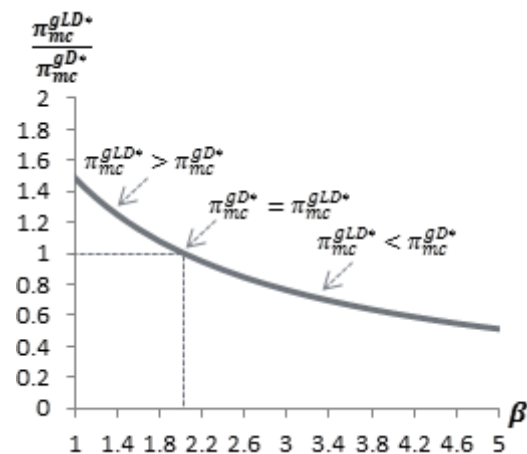


Figure 10. Impact of β on the Difference in Enterprise Equilibrium Profits under Alternative Government Decisions.

(2) Relationship between β and the Difference in Enterprise Equilibrium Profits under Alternative Government Decisions

Figure 10 illustrates the relationship between the labor force's capacity to generate additional value, denoted by β , and the ratio of enterprise equilibrium profits under alternative government decisions, denoted by $\frac{\pi_{mc}^{gLD*}}{\pi_{mc}^{gD*}}$. When the labor force lacks the capacity to generate additional value (i.e., when no extra remuneration is received, corresponding to $\beta = 1$), the enterprise equilibrium profit under the enterprise-directed subsidy regime is lower than that under the labor-directed subsidy regime, owing to differences in employment costs. At this baseline, the profit ratio is approximately 1.5. As

the labor force's capacity to generate additional value increases, the residual value of labor rises correspondingly. In this case, the disparity in enterprise equilibrium profits is primarily driven by the number of labor units actually participating in the restoration work, and consequently, subsidizing enterprises yields higher enterprise equilibrium profits. When the capacity of each unit of labor to generate additional value reaches approximately 2.05, the two subsidy strategies yield identical enterprise equilibrium profits.

4. Conclusion

The sequencing of procurement payments and subsidies yields three main findings. First, the subsidy-first strategy requires higher initial government outlays. Second, the procurement-first strategy involves a lower prepayment ratio, leaving fiscal room for concurrent projects. Third, under the procurement-first strategy, the prepayment ratio does not vary with the subsidy recipient.

Regarding subsidy effectiveness: (1) Both strategies enhance enterprise performance and human resource supply in the long run. (2) Labor-directed subsidies directly alleviate poverty regardless of work participation, while enterprise-directed subsidies better address site-specific employment. (3) An optimal subsidy level exists that maximizes fund utilization.

Policy guidance: To maximize subsidy efficiency, subsidize enterprises under the subsidy-first sequence within specified parameter intervals, or adopt the procurement-first sequence in other intervals. To maximize enterprise profit, subsidize labor under the subsidy-first sequence.

Labor factors β and n significantly affect enterprise profits. Wage-based subsidies outperform direct transfers in poverty reduction. Future research may explore micro-level labor dynamics and workforce typologies.

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