

Article

Fiscal Shocks and Strategic Resilience Traps in Metro PPP Project Ecosystems: Scenario-Based Evidence from Post-Land-Finance China

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Abstract

Fiscal shocks in post-land-finance China are weakening the funding basis of capital-intensive metro public-private partnership (PPP) projects, but the system-level mechanism through which public fiscal stress becomes subcontractor-level financial viability pressure remains underexplained. This study examines a section-level metro PPP project ecosystem in a sub-provincial Chinese city to trace this transmission mechanism and its financial implications. The analysis combines de-identified audit evidence and interviews with a scenario-based structural NPV model and 800,000 model-generated Monte Carlo realizations under calibrated institutional scenarios. The evidence indicates that quasi-bureaucratic SPV internal capital-market arrangements convert fiscal shortfalls into vertical and horizontal cross-subsidization practices, preserving short-term project continuity while shifting cash-flow pressure downstream. This condition is defined as a strategic resilience trap: practices that preserve short-term project continuity while potentially eroding the project ecosystem's long-term adaptive capacity. Under calibrated assumptions, improving the contract-payment channel reduces model-generated losses by approximately 4%, suggesting that payment punctuality addresses only one part of the wider internal capital-market mechanism.

Keywords: PPP project; fiscal shocks; internal cross-subsidization; financial viability

1. Introduction

Mobilizing capital for urban transport infrastructure requires dedicated project-finance structures and supports broader economic-development objectives [1,2], yet major transport projects continue to face persistent implementation and institutional barriers [3,4]. In China, this challenge has long been mediated by land finance, a public-land-based financing arrangement through which local governments convert the future appreciation of urban land-use rights into present-day infrastructure revenue [5]. However, cyclical economic fluctuations and broader macroeconomic reorientation have sharply weakened this funding basis. The share of land finance revenue in total government revenue fell from a peak of 46% in 2020 to 19.2% in 2025, a level comparable to that observed roughly two decades earlier (Figure 1). Prior research has characterized this emerging setting as the post-land-finance era [6]. For capital-intensive metro public-private partnership (PPP) projects, the resulting fiscal contraction is not only a government-budget problem; it can propagate through the SPV-centered project system and reshape the financial viability of downstream participants [7].



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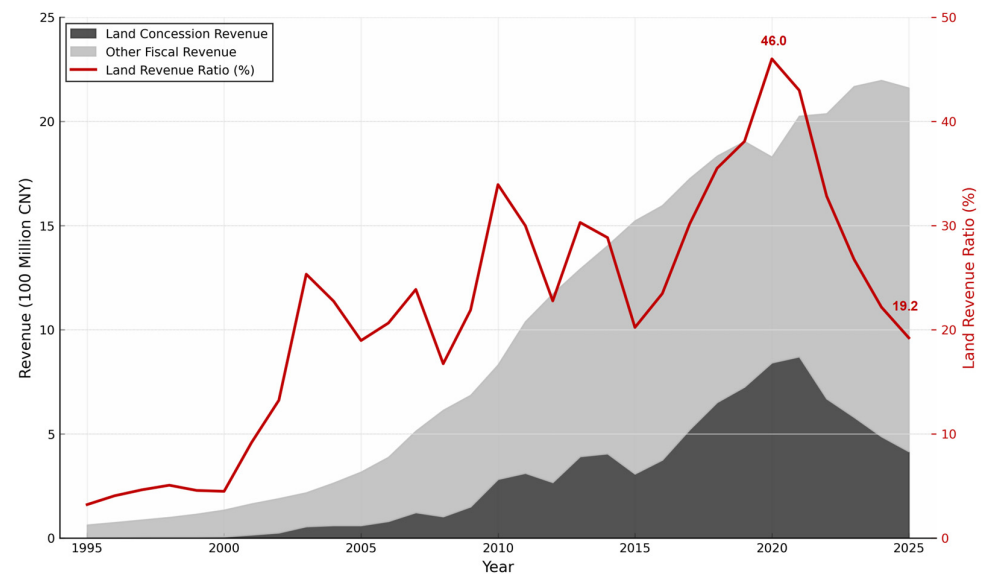


Figure 1. Share of land-finance revenue in total Chinese government revenue, 1995–2025. Note: Data are sourced from the Ministry of Finance of China and the China Land and Resources Yearbook.

Metro projects are highly capital-intensive and commonly require multi-billion-dollar investment commitments [8]. PPP arrangements have therefore been widely adopted to mobilize public and private capital for metro construction [9,10]. In such arrangements, the local government and private enterprises establish a Special Purpose Vehicle (SPV) as the project carrier, a structure intended to ring-fence financial risk and coordinate project-specific fundraising. Yet a metro PPP is not a bilateral financing contract alone. It is a complex project ecosystem, with feedback loops, delays, and cross-level effects linking public agencies, SPVs, construction enterprises, subcontractors, auditors and consultants, and interdependent financial flows [11]. When local fiscal capacity contracts, short-term stabilizing responses inside this ecosystem, such as delayed payment, payment prioritization, or internal fund reallocation, may keep construction moving while producing delayed and unintended financial viability losses at the subcontractor level. This tension, in which short-term project continuity is preserved while financial pressure is shifted downstream and long-term adaptive capacity may be weakened, is conceptualized here as a strategic resilience trap and forms the study's main link to systems thinking and strategic management.

Existing PPP and infrastructure-finance studies have identified financial risks, evaluated project-finance arrangements, and examined aggregate outcomes under fiscal stress [12,13]. Related work also points to gaps between formal rules and actual practice [14], intertemporal substitution through concession or payment arrangements [15,16], and cross-subsidization inside infrastructure organizations [17,18]. Less is known, however, about the institutional transmission mechanism through which a public fiscal shock is converted into subcontractor-level financial viability pressure through quasi-bureaucratic SPV internal capital-market practices. A related gap concerns the micro-level quantitative drivers of this distress: how do selected institutional and financial variables shape the resulting financial viability pressure?

This study addresses these gaps through two research questions. First, how does fiscal stress become subcontractor-level financial viability pressure through quasi-bureaucratic SPV internal capital-market arrangements in a metro PPP project ecosystem? Second, what financial viability consequences does this mechanism produce under calibrated scenarios? To address the first question, the analytical framework combines institutional layering, SPV internal capital markets, and vertical and horizontal cross-subsidization to trace how

fiscal stress is reallocated through the project ecosystem. To address the second question, the framework translates this transmission mechanism into a structural NPV model that illustrates its financial viability consequences under calibrated scenarios.

Empirically, the study examines a section-level metro PPP case in a sub-provincial Chinese city. Drawing on de-identified audit evidence and interviews from the project ecosystem, it traces how fiscal shortfalls are processed through SPV payment ordering, internal cross-subsidization, and subcontractor cash-flow pressure. The study then uses a scenario-based structural NPV model to illustrate the financial viability implications of the mechanism through 800,000 model-generated Monte Carlo realizations across calibrated institutional scenarios. These realizations explore the implications of model assumptions; they are not treated as independent empirical observations.

The study makes two closely related contributions. The core contribution is to identify and explain an institutional risk-transfer mechanism in which fiscal stress is transmitted through quasi-bureaucratic SPV internal capital-market arrangements and internal cross-subsidization, thereby shifting viability pressure to subcontractors. This mechanism-based account refines the application of internal capital markets to infrastructure PPP settings [19,20]. The supporting contribution is to illustrate the mechanism's financial viability implications through scenario-based structural NPV modeling, including a sensitivity analysis of the institutional and financial variables that shape mean NPV under calibrated assumptions. By specifying the institutional conditions under which internal-capital-market logic applies to SPV-based infrastructure ecosystems, the framework clarifies the scope of this theoretical extension. The case is treated as mechanism-tracing evidence from a single section-level project, not as a basis for universal parameter values, broad policy claims, or unrestricted cross-context generalization.

The remainder of this study is organized as follows. Section 2 reviews the literature on fiscal shocks, PPP project ecosystems, institutional layering, internal capital markets, and cross-subsidization. Section 3 describes the case background, audit evidence, and interviews. Section 4 specifies the scenario-based structural NPV model, calibration approach, Monte Carlo design, and sensitivity analysis. Section 5 reports the case mechanism and model-generated financial viability consequences. Section 6 discusses the resilience-eroding implications, system-level strategies, limitations, and future research. Section 7 concludes.

2. Literature Review and Conceptual Framework

2.1. Institutional Layering and Fiscal-Shock Transmission

As noted above, the focal metro project financed through an SPV faced a substantial start-up capital shortfall, producing a departure between the financing institutions originally designed under earlier capital conditions and those that actually govern day-to-day operation. This study interprets this departure through institutional layering: formal rules codified in policy and contract remain in place, while implementing actors develop informal practices to keep projects operating under new constraints [21,22]. Under pressure from shifting external conditions, formal institutions typically undergo partial or marginal adjustments rather than wholesale replacement. Informal institutions emerge as transitional practical rules that sustain, for a time, the stability of both the broader socioeconomic order and the specific engineering projects embedded within it [23]. This adjustment dynamic is particularly pronounced in metro projects, where large capital requirements, long project lifecycles, and strong institutional path dependence raise the cost of wholesale reform [24–26]. In the present setting, institutional layering therefore provides the explanatory lens for understanding why formal SPV rules persist while informal financing practices emerge to absorb fiscal shocks. The next subsection operationalizes this lens within the

SPV-centered project ecosystem by identifying the specific formal–informal institutional tensions through which fiscal stress is reallocated.

2.2. Formal and Informal Institutions in the SPV Project Ecosystem

To operationalize the institutional-layering perspective at the project-system level, this study distinguishes between the formal financing architecture of the SPV and the informal practices that govern cash-flow circulation under fiscal stress. The first is the formal institutional framework reviewed above, which forms the nominal financial architecture inherited from the land-finance era. The second consists of informal institutions that have emerged as the rules actually followed in practice. Motivated by the public-good character of metro services, and by firms' attention to cash flow and project-performance incentives [27], these informal institutions often retain the outward form of formal institutions. This helps keep the project running even under severe capital shortfalls.

This study focuses on the structural financial-viability dilemma that arises within SPV-carried metro projects when external socioeconomic conditions shift abruptly. Following the literature reviewed above and adapting analytical approaches from adjacent fields [28,29], this subsection organizes the analysis around four institutional tensions and, for each, characterizes the corresponding formal and informal institutions. As Figure 2 illustrates, the framework comprises four institutional tensions, each generating a point at which fiscal stress is reallocated within the SPV project ecosystem.

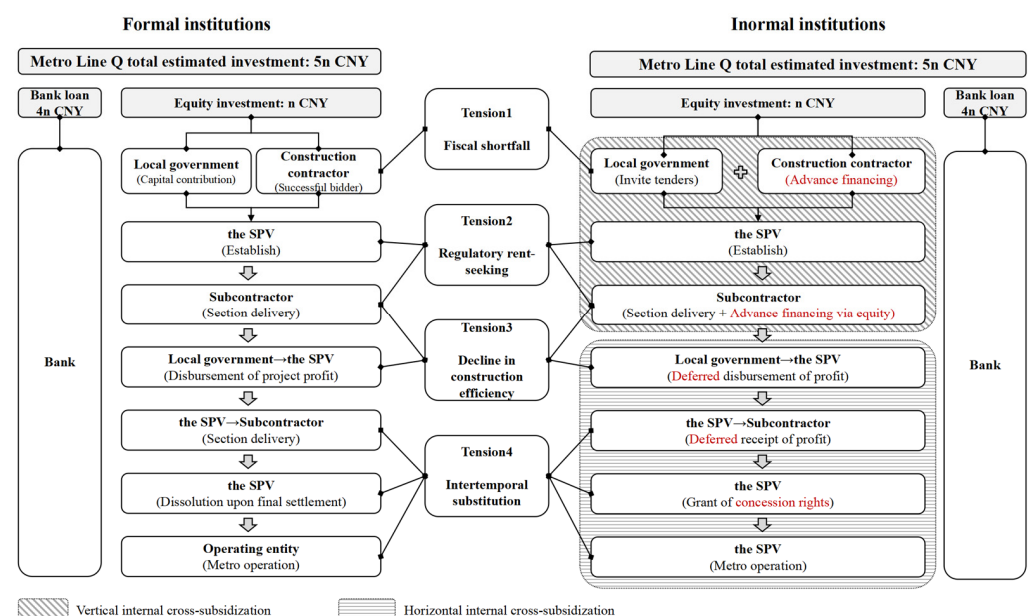


Figure 2. Formal and informal investment-and-financing frameworks of an SPV-carried metro PPP project in the post-land-finance era. Note: n denotes the de-identified monetary unit used to preserve the proportional investment structure.

2.2.1. Tension 1: Capital Shortfalls in Local Government Contributions

Formal institution 1 refers to the case-specific requirement that, during the investment phase of this metro project, the capital contribution of the local government should equal one-fifth of total project investment. In the focal case, however, the local government's fiscal resources were insufficient to meet the full capital commitment. As noted above, some construction enterprises pre-finance the capital contribution themselves, expecting to convert short-term financial pressure into long-term market-access rents, and thus display a tendency toward asymmetric risk-bearing [27,30].

Informal institution 1 emerges as the arrangement in which the capital contribution that the local government cannot deliver is advanced by the winning construction enterprise.

2.2.2. Tension 2: Rent-Seeking in Section Allocation

As illustrated in Figure 2, once the winning enterprise is selected, the local government and the construction enterprise jointly establish the SPV dedicated to this metro line. The SPV is governed by a Strategic Command Committee serving as its highest decision-making body, and references to “the SPV” throughout this study denote the SPV acting through this body. The SPV divides the project into several construction sections, subcontracting each to a subcontractor. Throughout this study, the term subcontractor refers to both the contract counterparty and the corresponding equity stakeholder within the SPV. At the same time, as a financing device, the SPV distributes the pre-financed portion of the capital contribution to the subcontractors in the form of equity shares.

Formal institution 2a stipulates that each subcontractor’s theoretical equity contribution should equal its contract share in the overall project. In practice, however, variation across sections in construction volume, technical difficulty, and projected passenger flow makes strict proportionality impossible, and the final equity allocation is set through negotiation. Because any gap between the contract share and the equity share represents a zero-sum reallocation among subcontractors, and because the SPV exercises administrative authority over this allocation, the process creates scope for discretion and potential rent-seeking.

Informal institution 2a emerges as the arrangement in which a subcontractor’s theoretical equity does not necessarily equal its contract share in the overall project.

Formal institution 2b stipulates that each subcontractor should fully remit its theoretical equity. In practice, however, reduced profit margins in the construction market have weakened the cash-flow position of most construction enterprises, leaving some subcontractors unable to pay the full amount.

Informal institution 2b emerges when the SPV advances the unpaid balance on behalf of the subcontractor and creates an internal claim. Once contract payments are later disbursed, the SPV deducts this outstanding debt before passing residual proceeds on to the subcontractor.

2.2.3. Tension 3: Suboptimal Construction Efficiency

Formal institution 3 assumes that, under ordinary operating conditions, a subcontractor’s construction efficiency tends to converge toward its standard efficiency level, and section-level construction cost tends to converge toward the standard construction cost benchmark. In practice, however, under capital shortfalls, organizational decline tends to emerge in forms such as flagging morale, talent attrition, and weakening operational management.

Informal institution 3 emerges as a state in which section-level construction efficiency typically falls below its expected level and section-level construction cost typically exceeds the standard benchmark.

2.2.4. Tension 4: Concession Rights as Intertemporal Substitution

Formal institution 4a stipulates that local governments should disburse scheduled contract payments to the SPV in installments so as to sustain the orderly progress of the project. In practice, however, fiscal shortfalls may prevent local governments from making these disbursements on schedule, thereby disrupting project implementation.

Informal institution 4a emerges as the need for subcontractors to secure alternative financing channels in order to ensure project completion.

Formal institution 4b stipulates that the SPV should naturally dissolve upon completion of the metro project, with operation subsequently transferred to a dedicated operating entity. In practice, however, to incentivize the construction enterprises to complete the build and to ensure adequate provision of public-service infrastructure, local governments commit, via a concession arrangement, to letting the SPV assume the role of the metro operator for a specified period. Chinese local governments commonly describe this intertemporal substitution as a strategy of “trading time for space” [31].

Informal institution 4b emerges as the arrangement in which the government grants the SPV a concession of a specified duration, allowing future operating returns to offset the current capital shortfall. This study terms this mechanism horizontal internal cross-subsidization: the redirection of current construction profits, financing capacity, or expected future returns to fill the fiscal contribution gap.

Taken together, the four tensions and their corresponding formal and informal institutions operationalize institutional layering as a sequence of observable reallocations within the SPV-centered financing framework. They identify where fiscal stress enters the SPV internal capital market, how it is redistributed through vertical and horizontal cross-subsidization, and which mechanism-specific variables must subsequently be evaluated in the subcontractor-level financial-viability analysis.

2.3. Research Gap and Conceptual Chain

The literature reviewed above reveals three limitations that are directly relevant to the two research questions. First, institutional-layering theory explains why formal rules and informal practices coexist, but does not sufficiently specify the micro-level mechanism through which fiscal pressure is transmitted inside SPV-organized PPP project ecosystems. Second, PPP and infrastructure-finance studies identify fiscal, contractual, and project-level financial risks, but do not trace the cash-flow pathway connecting public fiscal contraction, internal capital-market adjustment, cross-subsidization, and subcontractor-level distress. Third, existing financial-viability studies do not show how emerging informal institutional arrangements can be translated into mechanism-specific variables for section-level analysis. Taken together, these three research streams offer important but analytically differentiated insights. However, these streams rarely connect institutional change, cash-flow reallocation within the SPV, and subcontractor-level consequences within a single mechanism-based framework. These limitations therefore call for an integrated transmission chain linking fiscal shock, SPV internal-capital-market adjustment, internal cross-subsidization, and subcontractor-level financial viability pressure.

The first two limitations motivate the first research question concerning the institutional transmission of fiscal stress, whereas the third motivates the second research question concerning the financial viability consequences of that mechanism. Accordingly, the formal-informal institutional framework and conceptual chain trace the transmission mechanism, while the structural NPV model translates the identified mechanism into scenario-based financial variables.

As shown in Figure 3, the conceptual chain developed in this section addresses the first research question by linking fiscal shock to subcontractor-level financial viability pressure through a layered, feedback-mediated institutional mechanism. Fiscal contraction first creates a mismatch between formal SPV rules and actual funding conditions; institutional layering then allows formal rules to persist while informal financing practices emerge. Within the SPV internal capital market, the shortfall is reallocated through internal cross-subsidization, including the vertical and horizontal channels defined above. These practices transfer cash-flow pressure to subcontractors. Once that pressure reaches operating units, efficiency decay and agency-cost pressure help explain why a tempo-

rary financing adjustment becomes subcontractor-level financial viability loss. Internal cross-subsidization is therefore the key analytical thread for explaining how fiscal shock is translated from a public-budget problem into subcontractor-level financial viability pressure. The mechanism-specific cash-flow and efficiency variables derived from this chain also provide the analytical basis for examining its financial viability consequences under calibrated scenarios.

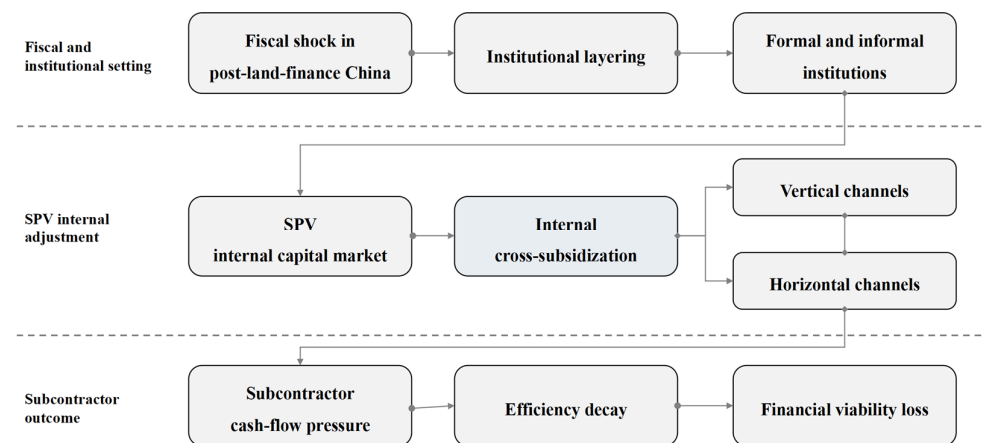


Figure 3. Conceptual chain of fiscal-shock transmission through internal cross-subsidization in the metro PPP project ecosystem.

3. Case Selection and Data

3.1. Case Selection

This study examines a section-level metro PPP project in a sub-provincial Chinese city. The project is referred to as Section A of Metro Line Q in City M, and the focal downstream actor is referred to as Subcontractor A. The SPV was jointly established by the local government of City M and Enterprise Group G for the construction of Metro Line Q. Section A is undertaken by Subcontractor A within the SPV project ecosystem, while its core operational team is formed by Construction Enterprise A, a wholly owned subsidiary of Group G.

Section A was selected for mechanism tracing rather than statistical generalization. First, the case presents the financial-viability dilemma in a severe form: the construction profit margin on Section A has reached -40% , indicating substantial downstream distress. Second, the case contains the main elements of the institutional transmission mechanism examined in this study, including external fiscal pressure, SPV-centered payment ordering, internal cross-subsidization, multi-actor bargaining, and subcontractor-level cash-flow pressure. Third, the focal subcontractor occupies a weak bargaining position within the SPV project ecosystem, making the case analytically suitable for tracing how fiscal stress is transferred to a section-level operating unit. Fourth, the financial records meet the quality threshold required for a scenario-based structural NPV model because the underlying entries were reviewed through multiple rounds of audit scrutiny.

3.2. Data Collection

The principal data source is the audit report for Section A, with a data cut-off date in 2024. The audit report covers the financial activities of Subcontractor A, including contractual obligations, capital contributions, contract receipts, construction expenditures, and outstanding internal claims with the SPV. Because the source material contains confidential project and firm information, the disclosed monetary inputs were de-identified through a common confidentiality-preserving transformation while retaining a consistent CNY

measurement scale. The transformation preserves the proportional relationships required for model calculation while removing identifiable original amounts, locations, and contract numbers. Consequently, the reported CNY results should be interpreted as de-identified monetary values rather than the undisclosed original contract amounts.

The study also uses interview notes from 34 anonymized professional participants: four SPV personnel, nine construction-enterprise personnel, twelve subcontractor personnel, and nine third-party professionals. The interviews were conducted in four rounds between 2024 and 2026. Among the third-party professionals, participants TP01–TP04 were core audit experts with direct knowledge of the audit process and parameter interpretation. Interview materials were not used to statistically estimate model parameters. Instead, they were used to identify institutional mechanisms, distinguish threshold-based from continuous responses, interpret audit-anchored observations, and assess the contextual plausibility of selected modeling assumptions.

Verifying the authenticity and interpretability of the underlying financial data is the central data-collection challenge in this setting. Ambiguous or inconsistent data reporting is common in empirical research on PPP projects [32–34]. Data cleaning followed the audit-scrutiny trail: concealed entries, misjudged classifications, and arithmetic miscalculations identified through cross-referencing between the audit report and the interview notes were excluded from the analytical sample. Where audited entries were incomplete but contextually interpretable in light of the interview notes and core-expert review, they were retained and documented in Appendix C; where they could not be reconciled, they were excluded. For variables without directly observed values, distributional assumptions were specified on the basis of the audit evidence and the core-expert interpretation described in Section 4.2 and were subsequently implemented in the simulation scripts.

To support replicability within these limits, Appendix A presents the anonymized interview evidence matrix, Appendix B reports selected model-generated results supporting the manuscript's numerical findings, and Appendix C provides the parameter-source mapping, source classifications, and principal transformation logic. The simulation code, de-identified parameter settings, and random-seed information are provided in the Supplementary Materials.

4. Methodology

4.1. Structural NPV Model

The model-variable selection follows the institutional transmission chain developed above: fiscal shock, SPV internal capital-market adjustment, internal cross-subsidization, subcontractor cash-flow pressure, and financial viability loss [35,36]. The first methodological step is to specify a dependent variable that can operationalize subcontractor-level financial viability loss. The second step is to identify the independent variables through which fiscal shocks and SPV internal capital-market practices enter the structural model.

For the dependent variable, this study adopts NPV as a scenario-based proxy for long-run financial viability. In accounting research and financial-management practice, prior work has used profit margin, balance-sheet position, net present value, total factor productivity, and internal rate of return to assess project performance [37,38]. In the present setting, NPV is suitable for three reasons. First, undiscounted cash flows cannot reconcile values over multi-decade horizons [39,40]. Second, back-loaded and constraint-bound cash flows make NPV trajectories informative about long-horizon project distress [41,42]. Third, NPV admits a continuous distribution amenable to simulation-based computation [43]. NPV is therefore used as a scenario-based measure of subcontractor financial viability in the model; it does not directly measure long-term ecosystem resilience.

For the independent variables, the model first retains financial factors already identified in PPP and urban rail studies. These include start-up capital shortfalls, weakening government support, cost and revenue uncertainty, risk-allocation conditions, passenger-flow and farebox stability, government subsidy or operating-cost compensation, public-private coordination, and cost-benefit appraisal quality [33,37,44–48]. Because this study focuses on a subcontractor within an SPV project ecosystem, these established variables are combined with mechanism-specific variables that capture downstream fiscal-shock transmission.

In addition to the financial variables identified in prior work, the present model incorporates three less visible mechanisms within the metro PPP project ecosystem. Internal cross-subsidization reallocates fiscal shortfalls and expected returns through the SPV's internal capital market [17,19,20,49,50]. It is represented by variables for government progress-payment arrival rate, construction-profit diversion, payment pre-emption or leakage, and operating-return realization. Agency-cost pressure captures the monitoring costs, bonding costs, and residual losses that arise when SPV hierarchy and subcontracting relations shift financial burdens toward downstream actors [51,52]. It is represented by variables for internal claims, deducted payments, financing burden, and subcontractor cash-flow pressure. The endogenous efficiency mechanism captures how internal rules, incentives, and managerial capacity affect construction efficiency under capital pressure [53–56]. It is represented by efficiency-response parameters, the probability of efficiency impairment, and the translation of cash-flow stress into financial viability loss [57].

The resulting model therefore incorporates capital shortfalls induced by external risk, accounting components of construction costs and modeled operating returns, efficiency impairment arising from performance volatility, and internal cross-subsidization.

Accordingly, this study develops a stochastic structural model that integrates project finance, internal capital markets, and endogenous efficiency response to estimate the NPV of a metro construction section. The core variables of the model, together with their calibration sources and transformation logic, are documented in Appendix C. The model distinguishes between construction-phase net cash flow and operating-phase net returns. The project NPV is calculated as:

$$NPV = NCF_{\text{const}} + \sum_{t=6}^T \frac{R_{\text{ops_net},t}}{(1+d)^t}, \quad (1)$$

where NCF_{const} denotes the realized net cash flow during the construction phase, $R_{\text{ops_net},t}$ denotes the modeled annual net operating return in year t ; the modeled operating period runs from year 6 through year T ; T denotes the end of the modeled concession horizon; and d denotes the social discount rate. The following equations are introduced to derive NCF_{const} .

When government capital contributions are not delivered in full, the SPV self-finances the resulting shortfall, which constitutes a critical premise for computing NCF_{const} . At the section level, this overall deficit of the SPV is distributed to Subcontractor A as part of its equity obligation.

According to the audit report, Subcontractor A fails to remit the required contribution in full, giving rise to an equity gap. Upon request, the SPV advances this equity on behalf of Subcontractor A and thereby holds an internal credit claim against it. This arrangement tends to leave Subcontractor A in a weaker bargaining position when negotiating equity terms with the SPV. As noted in Section 2.2, the SPV wields administrative authority over equity allocation among subcontractors, such that the equity share need not strictly equal the construction contract share. The SPV's internal credit claim on Subcontractor A is therefore denoted D_{SPV} and defined as:

$$D_{\text{SPV}} = (E_{\text{sub_req}} - E_{\text{sub_act}}) \times (1 + \theta), \quad (2)$$

where $E_{\text{sub_req}}$ denotes the theoretical equity contribution stipulated in the contract for Section A, $E_{\text{sub_act}}$ denotes the cash amount actually contributed by Subcontractor A, and θ denotes the discrepancy between the construction share and the equity share. Equation (2) establishes a multiplicative amplification mechanism. A positive θ not only adjusts the absolute magnitude of the equity gap but also amplifies the first-order budget constraint whereby the SPV directly intercepts contract payments owed to Subcontractor A. This mechanism corresponds to the vertical internal cross-subsidization ($\Delta L_{\text{vertical}}$) introduced in Section 2, computed as:

$$\Delta L_{\text{vertical}} = D_{\text{SPV}} \times \omega, \quad (3)$$

where ω denotes the construction progress coefficient, fixed at 1 for the present empirical instance.

Beyond the passive component captured by $\Delta L_{\text{vertical}}$, Subcontractor A additionally diverts construction profits from its own section and prospective operating returns to offset the capital shortfalls identified above. These actively reallocated intertemporal funds correspond to the horizontal internal cross-subsidization ($\Delta L_{\text{horizontal}}$) introduced in Section 2, computed as:

$$\Delta L_{\text{horizontal}} = V_{\text{cont}} \times \pi_{\text{exp}} \times \alpha + R_{\text{fare}} \times \beta, \quad (4)$$

where V_{cont} denotes the contract value, π_{exp} denotes the targeted markup rate, and R_{fare} denotes the modeled baseline annual expected net operating-return proxy associated with farebox operations. R_{fare} is calibrated at 0.05 V_{cont} as an author-operationalized baseline net cash-flow proxy informed by the interview. It is not an observed annual farebox return or gross farebox revenue. In addition, α denotes the construction-profit diversion multiplier, and β denotes the operating-return diversion multiplier.

Having specified the internal-capital-market components, this study next computes NCF_{const} by drawing on agency cost theory and the endogenous efficiency mechanism, synthesizing the cash-flow modeling framework of Zayed and Liu [58] and the risk-management framework of Zhang and Fan [59]. On the inflow side, construction-phase cash flow includes the realized contract value. On the outflow side, it includes adjusted actual construction expenditure, vertical and horizontal internal cross-subsidization, and the receivables-related loss exposure R_{receiv} . NCF_{const} is accordingly defined as:

$$NCF_{\text{const}} = (V_{\text{cont}} \times \omega) - R_{\text{receiv}} - \left(\frac{C_{\text{base}}}{\eta} + \Delta L_{\text{vertical}} + \Delta L_{\text{horizontal}} \right), \quad (5)$$

where R_{receiv} denotes a receivables-related loss-exposure term that captures the transmission of government payment risk along the supply chain. In the computational implementation, C_{base} is calculated as $V_{\text{cont}} (1 - \pi_{\text{exp}})c$, where c denotes a dimensionless construction-cost multiplier. The adjusted actual construction expenditure is then represented by C_{base}/η .

Informed by prior research and the interview material, this study specifies R_{receiv} as a stepwise response function [60], expressed as:

$$R_{\text{receiv}}(g) = V_{\text{cont}} \times f(g), \quad (6)$$

where $f(g)$ is given by:

$$f(g) = \begin{cases} 0.05, & \text{if } g > 0.8 \\ 0.15, & \text{if } 0.5 \leq g \leq 0.8. \\ 0.30, & \text{if } g < 0.5 \end{cases} \quad (7)$$

That is, when the government progress-payment arrival rate (g) exceeds 0.8, the risk coefficient within R_{receiv} is set to 0.05, reflecting a corresponding leakage of verified output value; when g lies in the interval $[0.5, 0.8]$, the output-value leakage risk is set to 15%; and when g falls below 0.5, the leakage risk rises to 30%. The government progress-payment arrival rate (g) here denotes the share of contractually scheduled progress payments that the local government delivers to the SPV against verified construction output, and is distinct from the initial equity-contribution channel discussed in Section 2.2. The two breakpoints and the three associated leakage coefficients are anchored in the interview material. The regime below the 0.5 threshold is operationalized using a 30% leakage coefficient; above the 0.8 threshold, by contrast, payment delays are routinely absorbed without material operational consequences. The stepwise form is adopted because the interview material describes payment-delay regimes as qualitatively distinct thresholds rather than a continuous gradient; the breakpoints, not the within-regime functional form, are the principal object of identification. The parameter values adopted in this function are further discussed in Section 4.2.

To connect construction-stage financial pressure to management efficiency, the model defines the construction-phase cash-flow pressure gap as:

$$\text{Gap} = \Delta L_{\text{vertical}} + R_{\text{receiv}} + \Delta L_{\text{horizontal}}, \quad (8)$$

where Gap is a modeled construction-phase pressure measure rather than an independently observed accounting deficit. It combines vertical internal cross-subsidization, receivables-related loss exposure, and the consolidated horizontal internal cross-subsidization burden.

Building on agency-theoretic logic [61] and drawing on two studies of managerial efficiency measurement [62,63], this study defines the adjusted actual construction expenditure as the ratio of construction cost (C_{base}) to the management efficiency factor (η). η is specified as a piecewise linear decay function, expressed as:

$$\eta = \begin{cases} 1, & \text{if } \text{NCF}_{\text{const}}^{(\eta=1)} \geq 0 \text{ or } \text{Gap} \leq \delta \times V_{\text{cont}} \\ \max\left(\eta_{\min}, 1.0 - \sigma \times \frac{\text{Gap} - \delta \times V_{\text{cont}}}{V_{\text{cont}}}\right), & \text{if } \text{NCF}_{\text{const}}^{(\eta=1)} < 0 \text{ and } \text{Gap} > \delta \times V_{\text{cont}} \end{cases} \quad (9)$$

where $\text{NCF}_{\text{const}}^{(\eta=1)}$ denotes construction-phase net cash flow evaluated at full management efficiency. Management efficiency remains at 1 when the pre-impairment construction cash flow is non-negative or when Gap does not exceed the safety threshold ($\delta \times V_{\text{cont}}$). When the pre-impairment construction cash flow is negative and Gap exceeds this threshold, efficiency declines linearly with the excess pressure. The parameter σ captures the rate of efficiency deterioration, while $\eta_{\min}$ denotes the minimum residual efficiency. The resulting condition is interpreted as efficiency impairment.

Finally, the annual operating-return term entering Equation (1) is defined as:

$$R_{\text{ops_net},t} = R_{\text{fare}} \xi, \quad t = 6, \dots, T \quad (10)$$

where ξ denotes a dimensionless operating-return scaling factor applied uniformly over the modeled operating period from year 6 through year T . Its stochastic specification is provided in Section 4.2.

Certain sources of variation are not incorporated into the economic model because they bear only an indirect relationship to the research focus. These include the negotiability and periodic adjustment of the contract value, the possibility that the agreed concession period is not fully honored, and the additional financing risk associated with borrowing against prospective operating returns. Accordingly, the model directly evaluates cash-flow pressure

and subcontractor financial viability loss. Any implications for long-term adaptive capacity or ecosystem resilience are theoretically derived rather than directly modeled outcomes.

4.2. Monte Carlo Simulation Design

In recent years, transportation economics research has increasingly used Monte Carlo methods to address the difficulty of obtaining continuous cash-flow data over several decades [64,65]. This approach uses large-scale random sampling to examine how uncertainty affects long-horizon project outcomes.

To operationalize the NPV model developed in Section 4.1, the simulation is implemented in a standard scientific computing environment. The model distinguishes audit-anchored inputs, calculated model quantities, interview-informed or expert-reviewed assumptions, and illustrative comparative settings. The audit-based inputs V_{cont} and $E_{\text{sub_req}}$ are reported on a de-identified basis; θ is set at 0.01, π_{exp} at 0.18, and T at 20 years. Following the Methods and Parameters for Economic Evaluation of Construction Projects published by China's National Development and Reform Commission [66], the social discount rate d is set at 0.08. The stochastic inputs are specified as follows. In Scenarios 1 and 2, the government progress-payment arrival rate g follows a triangular distribution with a minimum of 0, a mode of 0.2, and a maximum of 1. The bounds represent the feasible proportional range, while the mode is jointly anchored in the audit report, the interview interpretation, and the review of the core audit experts. Construction-cost uncertainty is represented by the dimensionless multiplier $c \sim \text{Triangular}(0.9, 1.0, 1.3)$, with $C_{\text{base}} = V_{\text{cont}}(1 - \pi_{\text{exp}})c$. Because Section A has not yet entered operation, R_{fare} is treated as a modeled baseline annual expected net operating-return proxy and is fixed at $0.05 V_{\text{cont}}$, rather than being modeled as a random variable. Operating-return uncertainty is instead represented by the dimensionless scaling factor $\xi \sim N(1.0, 0.1)$. The mean of 1.0 denotes full realization of the modeled baseline, while the standard deviation of 0.1 represents the interview-informed and expert-reviewed dispersion scale; the exact normal form is an author-specified parsimonious approximation. One value of ξ is drawn for each Monte Carlo realization and applied uniformly throughout the modeled operating period. The baseline values of α and β are both normalized to 1.0, indicating no scaling of the corresponding baseline exposure terms. All monetary calculations are performed directly in CNY; values reported in billion CNY and million CNY are obtained by dividing the corresponding CNY outputs by 10^9 and 10^6 , respectively.

The financial position of a section-level project lies at the terminal node of macroeconomic transmission, while its operating model, managerial capacity, and informal arrangements negotiated with the SPV vary across institutional conditions. Accordingly, this study constructs four progressively more favorable scenarios, namely the Stress scenario (Scenario 1), the Enhanced-Capacity scenario (Scenario 2), the Support scenario (Scenario 3), and the Privileged scenario (Scenario 4), to trace the project's survival margin under different conditions. Scenario 1 is case-calibrated, whereas Scenarios 2–4 are illustrative comparative settings. Scenario 1 approximates the audited stress condition facing Subcontractor A: its parameter settings are anchored in the audit evidence, interpreted through the interview material, and reviewed by the core audit experts for contextual plausibility, with $\delta = 0.05$, $\sigma = 12.5$, and $\eta_{\text{min}} = 0.3$. The interview evidence and expert review therefore support the contextual plausibility of the Scenario 1 calibration rather than the external validity of its parameter values, which should not be transferred directly to other projects. Scenario 2 represents a subcontractor with greater endogenous risk-bearing capacity: δ is raised to 0.3, σ is reduced to 3, and η_{min} is raised to 0.7, thereby attenuating the effect of capital-shortfall pressure on production-management efficiency. Scenario 3 represents joint support from the SPV and the local government: δ is further raised to

0.5, the mode of g is increased to 0.5, shifting the most likely payment-arrival ratio to 50%, and the SPV grants Subcontractor A a 50% waiver of its required equity contribution. Scenario 4 represents a subcontractor with a stronger bargaining position in equity negotiations. All other parameters remain identical to those in Scenario 3, but θ is adjusted to -0.01 , meaning that the subcontractor benefits from the mismatch between its equity share and contract share, thereby reducing its capital burden through a more favorable vertical internal cross-subsidization arrangement. The parameter configurations of the four scenarios are reported in Table 1, and their principal source types and transformation rules are summarized in Appendix C.

Table 1. Parameter configurations across the four simulation scenarios.

Parameter	Scenario 1	Scenario 2	Scenario 3	Scenario 4
δ	0.05	0.3	0.5	0.5
σ	12.5	3	3	3
$\eta_{\min}$	0.3	0.7	0.7	0.7
$g(\text{mode})$	0.2	0.2	0.5	0.5
$E_{\text{sub_act}}$	$E_{\text{sub_req}} \times \text{equity ratio}$	$E_{\text{sub_req}} \times \text{equity ratio}$	$E_{\text{sub_req}} \times \text{equity ratio} \times 0.5$	$E_{\text{sub_req}} \times \text{equity ratio} \times 0.5$
θ	0.01	0.01	0.01	-0.01

In addition to the four formal scenarios, a separate payment-arrival counterfactual holds the Scenario 1 parameters constant while increasing only the mode of g from 0.2 to 0.95. The counterfactual uses the same 20 equity-contribution levels and 10,000 draws per level and is not included in the 800,000 formal-scenario realizations.

Random samples of the stochastic variables are drawn independently from their specified distributions. Within each scenario, 20 equally spaced levels of subcontractor equity-contribution ratio are specified across the range from 0% to 100%. The study generates 10,000 random draws at each level, yielding a cumulative total of 800,000 model-generated NPV realizations across the four scenarios. The iterations are not empirical observations or external validation samples; they are model-generated realizations used to explore the implications of calibrated assumptions.

The simulation yields the NPV distribution under each equity-contribution ratio. The efficiency impairment regime is defined as the event of $\eta < 1.0$, which occurs when the conditions specified in Equation (9) are met. Its probability is operationalized as the Monte Carlo frequency of this event within a given scenario and equity-contribution ratio.

4.3. Stress-Sensitivity Testing

In the tradition of prior work, a sensitivity-testing procedure is employed to examine NPV variation within the selected perturbation design [63,67,68]. The stress-sensitivity tests identify the relative span generated by the variables included in the sensitivity loop; they do not rank all possible determinants of NPV. Building on the simulation evidence generated by the 800,000 Monte Carlo realizations, the study conducts a supplementary local sensitivity analysis by perturbing selected model inputs and examining the resulting variation in NPV.

Using the model specified in Section 4.1, four core variables are subjected to perturbation in the single-factor sensitivity analysis. Subcontractor A's actual equity-contribution ratio is varied over a common local interval from 0.4 to 0.6 around a baseline value of 0.5. The ratio is applied to the scenario-specific equity obligation, including the 50% waiver assumed in Scenarios 3 and 4. The parameters α and β are each allowed to vary within the range 0.8 to 1.2, in order to probe the adverse effects of alternative channels of horizontal internal cross-subsidization on project financial viability. The government progress-payment arrival rate g is varied over the common comparative interval from 0.4 to 0.6 across all four

scenarios. This interval supports within-design comparison. Construction cost remains part of the baseline NPV calculation, but it is not included in the sensitivity loop, tornado chart, or ranked driver table. The discrepancy coefficient θ has been found to exert a negligible influence in stress-sensitivity testing and is therefore excluded from the experiment.

This sensitivity design is organized around the institutional transmission pathway rather than around a broad inventory of accounting inputs. The equity-contribution ratio, α , β , and g capture how capital obligations, profit diversion, and government payment reliability reshape subcontractor cash flow inside the SPV project ecosystem. By contrast, construction cost is retained in the structural NPV calculation as an accounting component but is not interpreted as a focal transmission variable in the sensitivity experiment.

The perturbation ranges chosen above represent author-defined local sensitivity settings within a case-relevant and expert-reviewed perturbation space. The ranges are used to test stability within the sensitivity design and should not be interpreted as empirical confidence intervals, observed real-world bounds, or a complete parameter space for the case.

Taken together, these procedures address the two questions that motivate the analysis. The first is how capital shortfalls in the post-land-finance era, operating through internal cross-subsidization, shape the financial viability of Subcontractor A. The second is how the selected institutional and financial variables affect the modeled financial viability of Subcontractor A within the specified local perturbation design.

5. Results

5.1. Case Mechanism of Institutional Risk Transfer

In the focal case, the audit evidence and interview notes indicate a sequence in which a local fiscal shock entered the SPV-centered project ecosystem and was reallocated internally rather than remaining only at the government level. Under fiscal contraction, the SPV sought to preserve project continuity by adjusting internal capital-market arrangements, including equity obligations, payment ordering, and internal claims. This adjustment created two cross-subsidization channels. In the vertical channel, SPV payment pre-emption or delayed payment reduced the cash available to the subcontractor. In the horizontal channel, construction profits, financing capacity, or expected operating returns were redirected to absorb part of the shortfall. The resulting cash-flow pressure compressed the subcontractor's disposable funds and constrained its capacity to support construction activities. This sequence constitutes the empirically documented component of the analysis; its efficiency and financial viability consequences are examined separately through the structural NPV model.

5.2. Model-Generated Scenario Consequences

The scenario results do not independently validate the mechanism; rather, they illustrate its financial consequences under calibrated assumptions (Figure 4). In Scenario 1, which approximates the audited stress condition, mean NPV remains negative across the full equity-contribution range, rising from approximately −1.31 to −1.16 billion CNY while the efficiency-impairment probability remains at 100%. Scenario 2, which represents greater endogenous risk-bearing capacity, narrows the mean NPV loss to approximately −0.39 to −0.22 billion CNY, with the efficiency-impairment probability declining from 100.00% to 94.80% over the tested range. Scenarios 3 and 4 further reduce the simulated NPV loss to approximately −0.20 to −0.04 billion CNY and lower the efficiency-impairment probability at higher equity-contribution ratios, but neither scenario produces a non-negative mean NPV across the tested range.

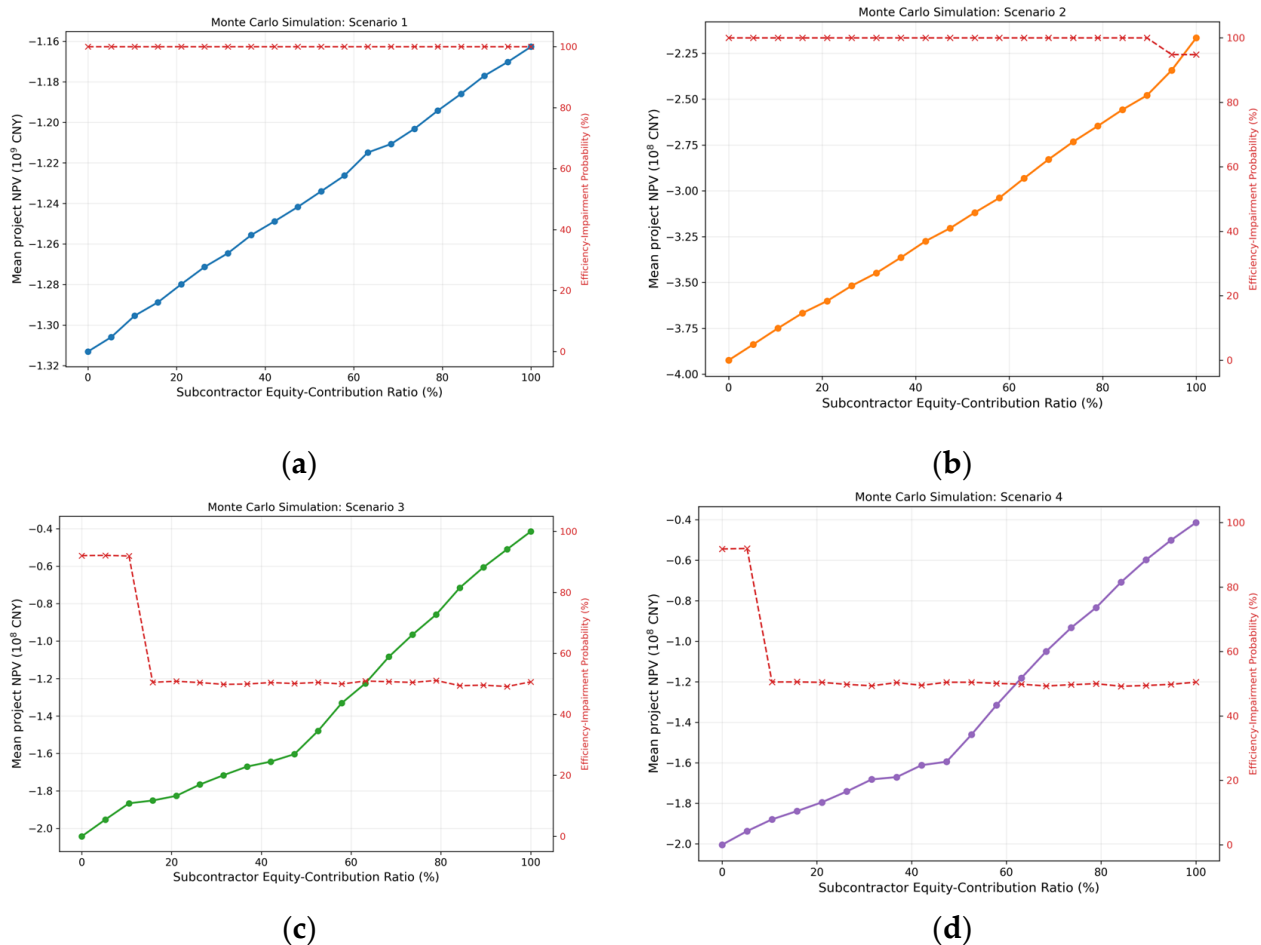


Figure 4. (a) Monte Carlo simulation results across scenario 1; (b) Monte Carlo simulation results across scenario 2; (c) Monte Carlo simulation results across scenario 3; (d) Monte Carlo simulation results across scenario 4. Note: Solid colored lines with circular markers indicate mean NPV (left axis), while red dashed lines with cross markers indicate the efficiency-impairment probability (right axis). Blue, orange, green, and purple represent Scenarios 1–4, respectively.

Across the four scenarios, improved support or bargaining position reduces the severity of the simulated loss but does not remove the underlying viability pressure. The model-generated mean difference between Scenarios 3 and 4 is largest around the 63.16% equity-contribution ratio, reaching approximately 4.42 million CNY; the difference is approximately 3.79 million CNY at the 0% ratio and becomes negligible at the 100% ratio. Because Scenarios 3 and 4 are generated using separate Monte Carlo streams, these point-wise differences should be interpreted as descriptive comparisons between the two complete scenario configurations rather than as isolated estimates of the effect of θ . Overall, the comparison indicates that more favorable internal allocation may relieve part of the subcontractor's cash-flow burden, but the magnitude of this effect remains limited within the wider SPV internal capital-market structure.

The counterfactual exercise isolates the contract-payment channel by holding Scenario 1 parameters constant while raising the mode of the government progress-payment arrival rate (g) from 0.2 to 0.95. All other elements of the internal capital-market arrangement, including Subcontractor A's actual equity contribution, the SPV's internal credit claim, and the vertical and horizontal cross-subsidization channels, are held at their Scenario 1 values (Figure 5). This design asks whether near-on-time contract payments alone would materially alter the model-generated loss profile.

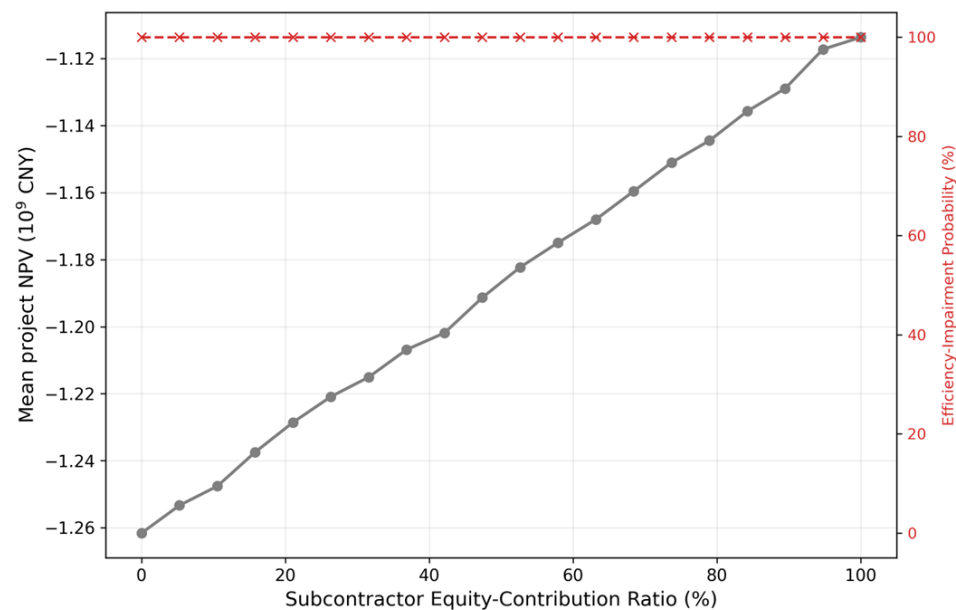


Figure 5. Counterfactual Monte Carlo simulation results. Note: The gray solid line with circular markers indicates mean NPV (left axis), while the red dashed line with cross markers indicates the efficiency-impairment probability (right axis).

Under calibrated assumptions, increasing the modeled progress-payment arrival rate reduces model-generated losses by approximately 4%, indicating that payment punctuality is insufficient when other internal capital-market obligations remain unchanged. Mean NPV improves only from approximately -1.31 to -1.26 billion CNY at the 0% equity-contribution ratio and from approximately -1.16 to -1.11 billion CNY at the 100% ratio. The efficiency-impairment probability remains at 100% throughout the tested range. This relative result indicates that payment punctuality is relevant, but insufficient by itself to offset the cross-subsidization architecture embedded in the calibrated scenario.

5.3. Sensitivity Results

This study conducts a single-factor sensitivity analysis of the model-generated Monte Carlo results (Figure 6). The analysis also serves as a robustness check within the selected perturbation design. The four perturbed variables are the government progress-payment arrival rate, Subcontractor A's actual equity-contribution ratio, the construction-profit diversion multiplier (α), and the operating-return diversion multiplier (β). Across the tornado diagrams, the government progress-payment arrival rate produces the widest NPV span, especially in Scenarios 3 and 4. The construction-profit diversion multiplier is the next most visible source of variation, while the operating-return diversion multiplier and the equity-contribution ratio produce narrower spans.

This ranking is limited to the variables included in the sensitivity design and does not compare their influence with construction-cost variation or other excluded determinants. In the Stress and Enhanced-Capacity scenarios, government payment reliability and construction-profit diversion account for much of the selected-variable NPV variation. In the Support and Privileged scenarios, government payment reliability becomes more visually dominant, while the equity-contribution ratio has a smaller local effect around the baseline. These patterns are consistent with the paper's mechanism-focused interpretation that fiscal stress affects subcontractor financial viability through internal capital-market arrangements rather than ordinary payment timing alone.

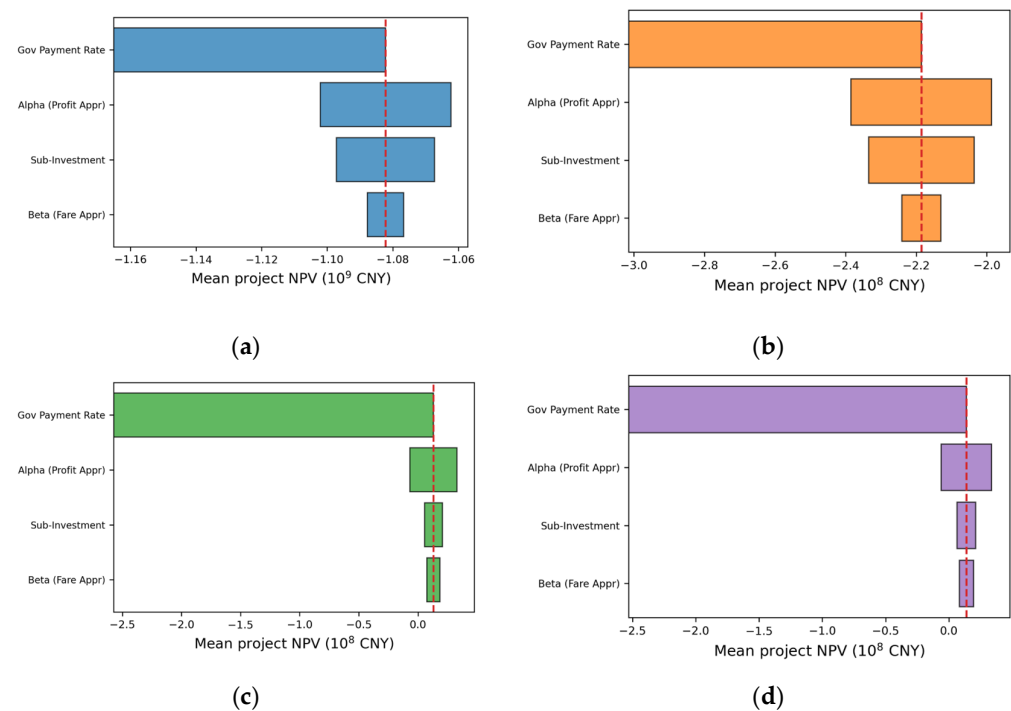


Figure 6. (a) Stress-sensitivity tornado diagram, scenario 1; (b) Stress-sensitivity tornado diagram, scenario 2; (c) Stress-sensitivity tornado diagram, scenario 3; (d) Stress-sensitivity tornado diagram, scenario 4. Note: Horizontal bars indicate the NPV ranges generated by perturbing each variable. Blue, orange, green, and purple represent Scenarios 1–4, respectively, while the red dashed vertical line indicates the baseline mean NPV.

6. Discussion

6.1. Why Fiscal Stress Becomes Subcontractor Distress

The analytical framework addresses the first research question by showing that fiscal stress becomes subcontractor distress when the SPV-centered project ecosystem combines administrative dependence with market-based contracting. In the audited case, subcontractors do not operate as fully autonomous market actors once project funding becomes unstable. They depend on the SPV for payment ordering, equity-allocation arrangements, future work opportunities, and access to the local infrastructure project network. This administrative dependence gives the SPV quasi-bureaucratic capacity to reorder cash flows when public funding becomes uncertain, while the formal PPP and subcontracting structure remains in place [27,30].

Several expectations make this transfer of pressure workable in the short run. Soft budget expectations encourage participants to assume that a public-service metro project will not be allowed to stop abruptly. Future project expectations and market-access concerns make downstream actors reluctant to resist temporary financing arrangements, even when those arrangements reduce their own liquidity. The SPV can therefore use informal internal capital-market practices to stabilize construction continuity: vertical cross-subsidization pre-empts or delays payments to recover internal claims, while horizontal cross-subsidization redirects construction profits, financing capacity, or expected operating returns. These practices do not merely redistribute cash within a neutral accounting system; they move fiscal pressure toward the subcontractor's cash-flow constraint. Taken together, institutional layering explains why formal rules persist, the internal-capital-market perspective explains how the SPV reallocates cash flows, and the cross-subsidization framework identifies how that pressure reaches the subcontractor.

6.2. Strategic Resilience Trap and Systems Contribution

This mechanism can be interpreted as a strategic resilience trap: informal financing practices preserve short-term project continuity while shifting financial pressure downstream and potentially eroding the project ecosystem's long-term adaptive capacity. In the present case, these practices directly weaken subcontractor financial viability by converting public fiscal stress into downstream cash-flow pressure. The scenario results illustrate the financial side of this tension: more favorable support or bargaining conditions reduce simulated losses, but they do not remove the viability pressure created by the SPV internal capital-market architecture.

The core contribution of this study is therefore not that it applies a more elaborate simulation tool, but that it identifies and explains an institutional risk-transfer mechanism inside a metro PPP project ecosystem. Existing PPP studies have identified financial risks and risk-management strategies at the project or contract level [13,46]. This study adds a mechanism-level account of how fiscal stress is processed through quasi-bureaucratic SPV internal capital markets and converted into subcontractor-level financial viability pressure.

The systems contribution lies in showing how risk transfer is feedback-mediated and can generate delayed, cross-level consequences in a project ecosystem. A response that appears stabilizing at the SPV level can create delayed losses at the subcontractor level, potentially weakening the operational capacity on which system continuity depends. This feedback structure links PPP fiscal uncertainty to business strategic management. The study directly examines cash-flow pressure and financial viability loss; the possibility that accumulated downstream losses weaken long-term adaptive capacity and ecosystem resilience is a theoretically derived implication that requires dynamic validation [36,69].

The scenario-based structural NPV model provides a supporting contribution by illustrating the financial viability implications of this mechanism under calibrated assumptions. Within the selected perturbation design, the sensitivity analysis compares the NPV spans generated by the four perturbed institutional variables. The limited counterfactual reduction is best read as a calibrated indication that contract-payment punctuality alone may miss a deeper internal capital-market channel, not as a standalone causal test.

6.3. System-Level Strategic Implications

For SPV-centered metro PPP systems operating under comparable fiscal and internal-allocation conditions, the relevant strategic question is how short-term stabilizing practices can be prevented from silently weakening downstream viability.

Strategy 1. Increase the transparency of SPV internal transfers. SPV payment pre-emption, equity offsets, internal claims, and temporary reallocations should be recorded as explicit internal capital-market transactions rather than left as opaque payment-ordering practices. Transparent records would make it easier to distinguish ordinary payment delay from vertical or horizontal cross-subsidization and would provide an audit trail for evaluating subcontractor exposure.

Strategy 2. Clarify project-level risk-sharing rules before fiscal stress is reallocated. The case suggests that ambiguity over equity obligations, payment priority, and internal claims allows quasi-bureaucratic discretion to substitute for formal risk sharing. A narrower and evidence-matched response is to specify how fiscal shortfalls, SPV advances, and subcontractor obligations are recognized, capped, and reviewed within the project ecosystem.

Strategy 3. Build early-warning indicators for subcontractor viability. Because the model links government progress-payment arrival rate, profit diversion, and equity-contribution pressure to NPV and efficiency-impairment probability, these variables can serve as case-informed candidate monitoring indicators [7]. Early-warning thresholds

should focus on downstream cash-flow pressure, deducted payments, internal claims, and efficiency-decay signals rather than only on aggregate project continuation.

Strategy 4. Establish subcontractor viability safeguards. When informal financing arrangements are used to maintain project continuity, the SPV should also define safeguards for the downstream actors absorbing the pressure. Such safeguards could include limits on payment pre-emption, review points for accumulated internal claims, and procedures for reassessing equity obligations when fiscal shortfalls persist. These measures do not eliminate fiscal stress, but they reduce the risk that resilience at the project level is achieved by exhausting subcontractor viability.

6.4. Limitations and Future Research

This study has four main limitations. First, it is based on a single section-level metro PPP case. The identified mechanism may be analytically relevant to SPV-based infrastructure ecosystems where public-service obligations constrain project suspension, fiscal shortfalls separate formal commitments from actual funding, and SPVs possess sufficient discretion to reallocate cash-flow burdens toward dependent downstream actors. However, its parameter values and effect sizes should not be transferred across contexts without additional evidence. Second, the 800,000 model-generated Monte Carlo realizations depend on calibrated assumptions, audit evidence, interview notes, and script settings; they illustrate financial viability consequences but do not independently prove or externally validate the mechanism. Third, the study directly examines cash-flow pressure and financial viability loss rather than dynamically measuring long-term adaptive capacity or ecosystem resilience; those implications remain theoretically derived and require longitudinal validation. These three limitations arise from the current data structure, which consists of construction-phase evidence from a single section-level case and lacks comparable cross-case or longitudinal operating-phase observations, while future access to comparable multi-project longitudinal data on government payment arrivals, SPV internal transfers, subcontractor cash flows, management efficiency, and realized operating returns would support these analyses. Fourth, NPV captures only one financial-viability dimension and does not quantify the public-welfare value of metro systems as quasi-public goods. Future studies should compare multiple SPV project ecosystems, test alternative calibration assumptions, and dynamically examine whether accumulated subcontractor viability losses translate into weakened system resilience under fiscal uncertainty.

7. Conclusions

This study identifies a fiscal-shock transmission mechanism in a metro PPP project ecosystem. The case analysis traces how a start-up capital shortfall and subsequent fiscal stress are processed through quasi-bureaucratic SPV internal capital markets, creating vertical and horizontal cross-subsidization channels that transfer pressure to the subcontractor. This mechanism is interpreted as a strategic resilience trap: informal financing practices preserve short-term project continuity while weakening subcontractor viability and potentially creating conditions that erode the project ecosystem's long-term adaptive capacity.

The findings indicate that, in the focal metro PPP project, subcontractor financial viability pressure is partly associated with institutional financing arrangements. Within the selected perturbation design, the government progress-payment arrival rate and the construction-profit diversion multiplier generate the largest NPV spans among the four perturbed variables. The counterfactual result further illustrates, under calibrated assumptions, that improving payment arrival alone reduces model-generated losses by approximately 4%. This suggests that focusing only on payment punctuality may miss the deeper SPV internal capital-market channel. Governance responses should therefore focus on transparent

internal transfers, clearer risk-sharing rules, early-warning indicators, and subcontractor viability safeguards rather than broad claims of regulatory overhaul.

Future work should test the fiscal-shock transmission mechanism and its scope conditions across additional metro PPP cases and institutional settings, and should dynamically examine whether subcontractor viability losses and corresponding safeguards affect long-term system resilience under fiscal uncertainty.

Supplementary Materials: The following supporting information can be downloaded at: <https://www.mdpi.com/article/10.3390/systems14070861/s1>. File S1: parameter_settings_and_seed.xlsx, de-identified parameter settings and random-seed information used in the simulations; File S2: simulation_code.py, Python code used for the Monte Carlo simulations, payment-arrival counterfactual analysis, and stress-sensitivity tests.

Author Contributions: Conceptualization, Y.W. and H.Z.; methodology, R.W. and Y.H.; investigation, Y.W. and Y.Z.; writing—original draft preparation, Y.W.; writing—review and editing, R.W. and H.Z. All authors have read and agreed to the published version of the manuscript.

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Institutional Review Board Statement: The study was conducted in accordance with the Declaration of Helsinki and was approved by the Ethics Committee of Tianjin University (protocol code TJUE2026-H-S-123; date of approval: 15 July 2026).

Informed Consent Statement: Verbal informed consent was obtained from all participants involved in the study. Participants were informed of the study purpose, the use of interview notes, anonymization and confidentiality arrangements, voluntary participation, and their right to withdraw.

Data Availability Statement: The simulation code, de-identified parameter settings, and random-seed information are provided in the Supplementary Materials. The underlying audit report and original case-specific financial records cannot be publicly shared because they contain confidential organizational and financial information. Appendix A provides an anonymized interview evidence matrix, Appendix B reports selected model-generated simulation results, and Appendix C documents the principal parameter values and transformation rules.

Conflicts of Interest: The authors declare no conflicts of interest.

Appendix A. Interview Evidence Matrix

Table A1. Interview evidence supporting parameter and mechanism specification.

Parameter	Core Interview Finding	Interviewee ID
$E_{\text{sub_act}}$	If a subcontractor is unable to make the required equity contribution in full, the SPV may advance the shortfall and convert the unpaid amount into an internal credit claim against the subcontractor.	CE02; SUB01; TP01; TP02; TP03
$\theta; \Delta L_{\text{vertical}}$	A subcontractor's construction-contract share does not necessarily coincide with its equity or capital-contribution obligation. A party with stronger bargaining power may obtain a more favorable equity allocation.	SUB01; SUB05; TP01
$\Delta L_{\text{horizontal}}; \alpha; \beta$	To maintain project continuity, construction enterprises or subcontractors may use profits from the focal section and other available funds to cover cash-flow shortfalls. Such intertemporal and cross-project reallocation weakens the firm's own cash reserves and subsequent risk-bearing capacity.	TP01; TP02; TP03; TP04

Table A1. Cont.

Parameter	Core Interview Finding	Interviewee ID
R_{fare}	The relevant enterprise uses an approximate 5% net operating-return benchmark in general project screening. This benchmark informs, but does not directly estimate, the modeled annual operating-return proxy.	TP01; TP02
ξ	For long-run realized net operating returns, a deviation of approximately $\pm 10\%$ from the baseline is regarded as common and reasonable, while a deviation of $\pm 20\%$ represents a wider but still plausible range.	TP01; TP03; TP04
g	Government progress payments or contract payments do not always arrive according to the original schedule. The SPV must adjust payments, advances, and internal fund allocation in response to actual receipts. This progress-payment channel is distinct from the SPV's internal equity-contribution channel.	SPV01; SPV02; SPV04; SUB03; SUB06; SUB08; TP01; TP04; TP06
$R_{receiv(g)}/f(g)$	Delayed payments by the government or the SPV are transmitted downstream through uncertain receivables collection, delayed payments to suppliers and labor, compressed procurement, and increased financing needs. Interviewees described these effects as threshold-based rather than continuously linear: high payment-arrival rates can be absorbed internally, whereas medium or low arrival rates produce substantially greater output-value leakage and cash-flow loss exposure.	TP03; TP04; TP05; TP06; TP09
Gap	Vertical payment pre-emption, uncertainty in receivables collection, and the diversion of construction profits or future returns jointly compress the subcontractor's disposable cash flow and create pressure on wages, material procurement, supplier payments, and working capital.	SUB01; SUB07; TP01; TP02; TP03; TP04; TP05
η	Financial pressure affects material procurement, personnel stability, labor organization, equipment allocation, and on-site coordination. It may also blur responsibility boundaries, raise monitoring costs, and generate resource misallocation, thereby reducing construction-management efficiency.	TP04; TP07; TP09
δ	The effects of payment delays and funding shortfalls are nonlinear. At low pressure levels, the project can absorb the disruption through internal coordination; once pressure exceeds a certain level, on-site organization, procurement, and working-capital circulation deteriorate markedly, indicating a safety threshold for efficiency impairment.	TP04; TP06; TP09; TP01; TP02
σ	Once cash-flow pressure exceeds the threshold, procurement, staffing, equipment use, and organizational efficiency may deteriorate rapidly. Differences in managerial capacity and risk-bearing capacity cause the speed of efficiency deterioration to vary across project actors.	TP04; TP07; TP09; TP01; TP02
η_{min}	After cash-flow pressure has triggered a decline in management efficiency, the project organization may still retain a minimum level of managerial and production-organizing capacity.	SUB03; SUB08; TP01; TP02

Note: Interviewees were anonymized by role category. SPV denotes personnel from the special purpose vehicle; CE denotes construction-enterprise personnel; SUB denotes subcontractor personnel; and TP denotes third-party professionals. The two-digit suffix indicates the anonymized sequence within each role category. TP01–TP04 were the four core audit experts. Multiple IDs separated by semicolons indicate that a finding was supported by more than one interviewee.

Appendix B. Selected Model-Generated Simulation Results

Table A2. Efficiency-Impairment Probabilities across Equity-Contribution Levels.

Equity Contribution Ratio (%)	Scenario 1 Efficiency-Impairment Probability (%)	Scenario 2 Efficiency-Impairment Probability (%)	Scenario 3 Efficiency-Impairment Probability (%)	Scenario 4 Efficiency-Impairment Probability (%)
0.00	100.00	100.00	92.08	91.83
5.26	100.00	100.00	92.16	91.98
10.53	100.00	100.00	91.95	50.54
15.79	100.00	100.00	50.54	50.56
21.05	100.00	100.00	50.87	50.42
26.32	100.00	100.00	50.44	49.79

Table A2. Cont.

Equity Contribution Ratio (%)	Scenario 1 Efficiency-Impairment Probability (%)	Scenario 2 Efficiency-Impairment Probability (%)	Scenario 3 Efficiency-Impairment Probability (%)	Scenario 4 Efficiency-Impairment Probability (%)
31.58	100.00	100.00	49.85	49.35
36.84	100.00	100.00	49.97	50.34
42.11	100.00	100.00	50.45	49.50
47.37	100.00	100.00	50.13	50.45
52.63	100.00	100.00	50.50	50.45
57.89	100.00	100.00	49.97	50.11
63.16	100.00	100.00	50.96	49.84
68.42	100.00	100.00	50.73	49.29
73.68	100.00	100.00	50.50	49.70
78.95	100.00	100.00	51.13	50.01
84.21	100.00	100.00	49.42	49.21
89.47	100.00	100.00	49.60	49.45
94.74	100.00	94.83	49.15	49.80
100.00	100.00	94.80	50.68	50.49

Appendix C. Parameter Calibration and Transformation Table

Table A3. Parameter values, calibration sources, and transformation rules.

Parameter	Variable Name	Equation No.	Value/Range	Source Type
NPV	Net Present Value	(1)	Calculated	model output
NCF_{const}	Realized Net Cash Flow during the Construction Phase	(1) and (5)	Calculated	model output
$Rops_{net,t}$	Net Operating Return in Year t	(1) and (10)	$R_{fare} \times \xi$ for years 6 through T	calculated from fixed R_{fare} and one ξ , draw per realization
T	Total Duration of the Concession Agreement	(1)	20 years	audit observation
d	Social Discount Rate	(1)	0.08	National Development and Reform Commission & Ministry of Construction
D_{SPV}	SPV's Internal Credit Claim on Subcontractor A	(2)	Calculated	model calculation
E_{sub_req}	Theoretical Equity Contribution Stipulated in the Contract for Section A	(2)	De-identified CNY input	audit observation
E_{sub_act}	Cash Amount Actually Contributed by Subcontractor A	(2)	E_{sub_req} for Scenarios 1–2; $0.5 E_{sub_req}$ for Scenarios 3–4	Scenario-varying model input derived from the audit-based E_{sub_req}
θ	Discrepancy between the Construction Share and the Equity Share (Misalignment Coefficient)	(2)	$0.01(S1/S2/S3)$; $-0.01(S4)$	audit observation; scenario setting; core audit-expert explanation
$\Delta L_{vertical}$	Vertical Internal Cross-Subsidization	(3)	Calculated	model calculation; core audit-expert explanation
ω	Construction Progress Coefficient	(3)	1	audit observation
$\Delta L_{horizontal}$	Horizontal Internal Cross-Subsidization	(4)	Calculated: $V_{cont} \times \pi_{exp} \times \alpha + R_{fare} \times \beta$	calculated model quantity; interview-supported mechanism
V_{cont}	Contract Value	(4)	De-identified CNY input	audit observation
π_{exp}	Targeted Markup Rate	(4)	0.18	audit observation
R_{fare}	Modeled Baseline Annual Expected Net Operating-Return Proxy	(4)	$0.05V_{cont}$ (fixed baseline)	interview-informed project-screening heuristic; author operationalization
α	Construction-Profit Diversion Multiplier	(4)	baseline 1.0; local sensitivity range 0.8–1.2	author-defined local perturbation reviewed by TP01 and TP02 for contextual plausibility
β	Operating-Return Diversion Multiplier	(4)	baseline 1.0; local sensitivity range 0.8–1.2	author-defined local perturbation reviewed by TP01 and TP02 for contextual plausibility

Table A3. Cont.

Parameter	Variable Name	Equation No.	Value/Range	Source Type
R_{receiv}	Risk Exposure of Accounts Receivable	(5)–(7)	Calculated	model calculation
C_{base}	Baseline Construction Cost	(5)	$V_{\text{cont}}(1 - \pi_{\text{exp}})c$, where $c \sim \text{Triangular}(0.9, 1.0, 1.3)$	audit observation; author-specified stochastic input implemented in the simulation script
ξ	Operating-Return Scaling Factor	(10)	$N(1.0, 0.1)$; one draw per realization	Interview-informed and expert-reviewed dispersion scale; author-specified normal approximation
Gap	Construction-Phase Cash-Flow Pressure Gap	(8)	$\Delta L_{\text{vertical}} + R_{\text{receiv}} + \Delta L_{\text{horizontal}}$	Calculated model quantity
η	Management Efficiency Factor	(5) and (9)	Calculated	model calculation
g	government progress-payment arrival rate	(6) and (7)	$\text{Triangular}(0, m_g, 1)$, where $m_g = 0.2$ (S1–S2), 0.5 (S3–S4), and 0.95 (counterfactual); $g_{\text{sens}} \in [0.4, 0.6]$.	audit-anchored observation; interview-informed assumption; core audit-expert explanation
δ	Safety Threshold Coefficient	(9)	$S1 = 0.05$; $S2 = 0.3$; $S3/S4 = 0.5$	Scenario 1 case-calibrated setting; Scenarios 2–4 illustrative comparative settings
σ	Slope of the Response Function (Speed of Efficiency Decay)	(9)	$S1 = 12.5$; $S2/S3/S4 = 3$	Scenario 1 case-calibrated setting; Scenarios 2–4 illustrative comparative settings
η_{min}	Minimum Residual Efficiency	(9)	$S1 = 0.3$; $S2/S3/S4 = 0.7$	Scenario 1 case-calibrated setting; Scenarios 2–4 illustrative comparative settings

Note: Monetary variables are calculated on the de-identified CNY measurement scale described in Section 3.2, whereas ratios, multipliers, thresholds, and distribution parameters are dimensionless.

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