Hindawi
Advances in Civil Engineering
Volume 2023, Article ID 2351910, 13 pages
https://doi.org/10.1155/2023/2351910

Research Article

Evaluating the Impact of Macroeconomic Policy Interventions and Recession on a Sewage Treatment PPP Project Using a System Dynamic Model

Qian Liu,[1] **Zaiyi Liao**,[2] **Qi Guo**,[1] **Dagmawi Mulugeta Degefu**,[2] **Liang Yuan**,[3] **Shenjun Jiang**,[3] **and Feihong Jian**[1]

[1]*College of Hydraulic and Environmental Engineering, China Three Gorges University, Yichang 443002, China*
[2]*Department of Architectural Science, Ryerson University, Toronto M5B2K3, Canada*
[3]*College of Economics and Management, China Three Gorges University, Yichang 443002, China*

Correspondence should be addressed to Zaiyi Liao; zliao@ryerson.ca and Qi Guo; guoqi@ctgu.edu.cn

Received 10 March 2022; Revised 20 November 2022; Accepted 1 December 2022; Published 16 February 2023

Academic Editor: Quoc-Bao Bui

The revenue of a public-private partnership (PPP) project is influenced by macroeconomic scenarios such as economic recession and policy adjustments. But these macrofactors and their dynamic relations with microfactors in PPP projects have not been thoroughly understood. In this article, system dynamics (SD) and real option (RO) are integrated to develop a novel model to investigate the impacts of the macro-risk factors on the revenue of PPP projects. Five scenarios were studied through simulation. The results indicate that the loan interest rate and tax rate are negatively correlated to the revenue, while the GDP growth rate and self-owned capital rate are positively correlated. This indicates that the government can stimulate the private sector to invest in PPP projects by providing lower loan interest and increasing the self-owned capital rate. This integrated approach has been proposed for use by decision-makers to evaluate the impact of economics and policies in the future. This study provides a comprehensive review and reliable theoretical analysis regarding the adoption of PPP by China's local governments, yielding to main policy implications for further promoting the efficiency of PPP development.

1. Introduction

Aquatic ecosystems have been seriously polluted with population growth and economic development. Statistics show that 85% of the urban water bodies in China are seriously polluted, increasingly restricting the development of China's economy and harming the health of residents and the ecological environment. However, insufficient sewage treatment facilities lead to a vast proportion of wastewater in aquatic ecosystems. To close the gap between the high demand for sewage treatment and underinvestment, the Chinese government has been actively promoting investment in sewage treatment projects, an important way to realize the coordinated development of the social economy and water resources. PPP has become a widely adopted cooperation scheme between governments and private sectors for the development and operation of public infrastructures. In a typical PPP project, the public sector shares the risks and rewards with the private partners. PPP contracts have been proven effective in arranging the finance for infrastructure projects, improving the supply efficiency of public services, and defusing local government debt risks. Tong et al. found that the financing capacity was improved, and the debt risk of local government was eased with the PPP mode [1]. In summary, it is a mutually beneficial way to balance the increasing demand and inadequate government budgets [2, 3]. However, the complex relationship of macro- and micro-risk factors and dynamic characteristics changes in these factors of PPP makes it very difficult, if not impossible, for all the stakeholders to make decisions with

sufficient certainty of success and may have a significant influence on the performance and sustainability of PPP projects [4, 5].

For the past decades, researchers have employed different quantitative methods to identify and investigate the risk factors involved in PPP projects. Malini used Monte Carlo simulation (MCS) to study the impacts of stochastic variables, such as toll rate, toll revision schedule, the extent of a government grant, and the duration of the concession period, on the economic performance of a PPP toll road project. The results showed that the toll rate, government grant, and concession period have a positive impact on the revenue of PPP projects [6]. Shen assumed that operation costs, traffic volumes, and discount rates were random variables and could be modeled by a normal distribution, and concession prices can be calculated by discrete distribution in the cash flow forecast. Their results indicated that the risk level is determined by the concession period [7]. Zhao et al. adopted a real options method for decision-making in highway development. They assumed that the traffic volume could be modeled by the Wiener process [8] and deployed geometric Brown motion (GBM) to model risks in future traffic demand, optimizing the decision-making process. This is a common practice in most of the literature on the topic [9]. Nevertheless, the above-mentioned studies focus on the micro-risk factors and the influences of macro-risk factors, such as GDP growth rate, loan rate, and policies of the sewage treatment PPP project in China, are scarce.

Since 2015, profound changes have taken place in China's economy and policies, which have marked impacts on the investment in PPP projects. China's economy grew sharply to 4.8% in the first quarter of 2022. A sustained economic downturn significantly impacts the revenue of PPP projects [10]. This is because private sectors have retained a cautious attitude toward investing in PPP projects [11, 12]. A series of supporting policies were carried out by the government from 2013 to 2016, and the implementation rate of PPP projects experienced a rapid rise to a stable process. The implementation rate declined suddenly from 2017 because of the policies such as the compliance review of the PPP project. Figure 1 shows the change trend of China's GDP growth rate and the implementation rate of sewage treatment PPP projects from 2013 to 2019. Private sector is encouraged to participate in infrastructure investment by the government. Some policy interventions have been implemented including tax reduction, preferential interest rate, and self-own capital rate.

Investment revenue is sensitive to both macro- and micro-risk factors, and unstable revenue hinders private sectors' participation [13]. This harms the environmental protection industry, quality of public service, and government credibility [14–16]. Furthermore, since the methods applied in these studies, including the traditional discounted cash flow (DCF) model, the real options model, and Monte Carlo simulation, do not consider dynamic features of PPP projects, they cannot reveal the dynamic changes of macro-risk factors on PPP revenue. Therefore, it is necessary to identify the relationships between macro- and micro-risk factors and evaluate the impacts of the macro-risk factors in the sewage treatment PPP project.

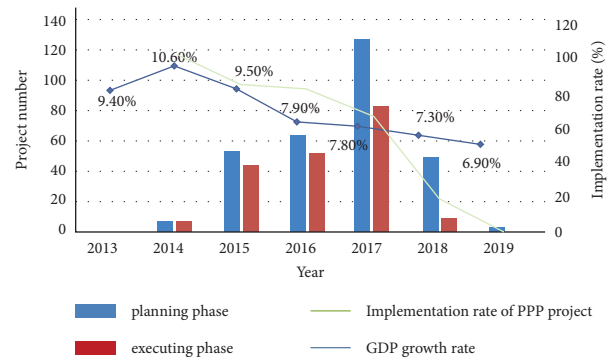

Figure 1: The change trend chart of China's GDP growth rate and the implementation rate of sewage treatment PPP projects from 2013 to 2019.

To fill the gap, we take both net present value (NPV) of the private sector and government subsidy as the proxies of decision-making. To further analyze the influencing mechanism of macro-risk factors on NPV and government subsidy, we use the SD model to establish the feedback relationships of macro- and micro-risk factors and simulate the variation trend of NVP and assistance of sewage treatment PPP projects under different economic and policy scenarios.

This paper contributes to the literature on evaluating PPPs in four ways. First, the existing scholarship in this field tends to overlook the impact of macro-risk factors (like economics and policy) and the relationships between these factors in PPP projects. Second, the integrated macro- and micro-risk factors theoretical analysis framework proposed is an extension of the existing analysis perspective. In this article, the authors combined real option, stakeholder, and system dynamic theories to evaluate the impact of macro-risk factors on the revenue of PPP projects to better understand the influencing mechanism of macro-risk factors on PPP revenue. Third, it is also worth noting that this article comes to different conclusions from previous research, which provides a reference for making correct decisions during an economic downturn. Fourth, the proposed method can evaluate the impact of policy interventions on the revenue of PPP project.

This article is organized as follows. Section 2 presents a literature review. Section 3 describes the method employed, outlines the formulation of the system dynamics model, and explains the modeling procedure. The data and scenarios for simulation studies are described in Section 4. Section 5 presents the simulation results and discussion. The conclusions and limitations of the present study and future research are discussed in Section 6.

2. Literature Review

2.1. PPP Risk Factor. Risk identification is a hot research focus for PPP-related studies. Li et al. pointed out that risks associated with PPP projects could be classified into macro-, medium, or microlevels, and each level is related

to several subrisks [17]. The media classified the risks in transport PPP projects into technical, commercial, political, and fiscal risks [18]. Xu et al. stated that the performance of PPP water projects was influenced by contract conditions, legislation, concession prices, inaccurate market forecasts, financing, policies and market demand changes, the macroeconomy, government credits, and technical risks [19]. The research, as mentioned above, concludes that successful PPP implication is significantly influenced by both micro- and macrorisks. However, they did not conduct deep investigations on macrorisks.

2.2. Macro-Risk Factors in PPP Projects. Macro-risk factors are mostly related to exogenous risks, including economic fluctuation, legal and policy adjustment, and force majeure. [20]. Ke and Ameyaw investigated macrorisks in a typical PPP project using questionnaire surveys [21, 22]. Economic fluctuation risks typically include economic downturn and inflation risk. An economic downturn impacts the external demand of the market to change enterprises' sales revenue and finally affects enterprises' investment expenditure [23]. A high degree of economic downturn brings high investment risks, and enterprises will decide to reduce investment [24, 25]. Most projects in China are mainly dependent on financing from banks. However, macroeconomic risks will distort the allocation of bank credit resources, thus affecting the ability of enterprises to obtain loans and borrow with a low-interest rate [26, 27]. Mane and Pimplikar studied the financing risk caused by the loan rate fluctuation during the postconstruction period. The case study results indicate that the concession period should be extended, corresponding to the change in loan rate [28].

Moreover, the exchange rate and inflation are dynamic and unstable for the PPP projects in the long operation period. Policy adjustment risks refer to the change in monetary policy (interest rate or exchange rate), tariff policy, industrial policy (minimum capital ratio change) [29], price adjustment, etc. Gaiotti et al. took the data of Italian companies as samples and found that monetary policy affects corporate investment through financing costs [30]. Tong studied the current tariff policy comprehensively and concluded that tax policy plays a significant role in regulation during the contract cooperation in PPP mode [31]. The above-mentioned researches focus on the impact of macrofactors on the investment decision of the manufacturing industry; however, there are few studies that pay attention to the quantitative analysis of the impact of economic and policy interventions on the investment decision of sewage treatment PPP projects.

The above researches focus on the influence of macrofactors on the investment decision of domestic and foreign manufacturing industry, and there are few types of research on the quantitative analysis of economic and policy adjustment on the investment decision of water environment management PPP projects. The above researches focus on the influence of macrofactors on the investment decision of domestic and foreign manufacturing industry, and there are few types of research on the quantitative analysis of economic and policy adjustment on the investment decision of water environment management PPP projects. The present study focuses on the macro-risk factors which can be quantitatively measured.

2.3. System Dynamics Model. Previous research has focused on the quantitative analysis of risks by using analytic hierarchy process (AHP), Monte Carlo simulation [32], real options method [33], binomial lattice [34], fuzzy set theory [35], etc. in PPP projects. These methods assume that macrovariables such as interest and tax rates are fixed. Few focus on the dynamic characteristics of macro-risk factors and explore the relationship between macro- and micro-risk factors.

Insight into this issue can be obtained using a system dynamics model of PPP projects. System dynamics [36] can incorporate macro- and micro-risk factors into one framework and present the feedback relationships of factors impacting PPP projects. It was first proposed by Forrester [37] and received increased recognition from a wide range of fields as an effective method to analyze complex systems. As a typical long-term, dynamic, and complex system [38–40], the revenue system of PPP projects can be investigated using an adopted analyzing tool based on SD. It can recognize the circular structure of a system and overcome the defect of linear causal models, which allows researchers to study the nonlinear interactions among various factors (endogenous and exogenous) [41]. It provides a possible way to simulate the behaviour of some key business variables when macroeconomic conditions change and policy measures are implemented. In this article, an SD-based method is proposed to identify the effect of government policies on the revenue of a sewage treatment PPP project. This approach intends to obtain an optimized policy scheme through analysis of macro- and micro-risk factors.

3. Research Methods

The proposed analytical approach takes a PPP sewage treatment construction project as a case study. It utilizes SD to dissect macro- and micro-risk factors that could influence the project's revenue. This approach includes three steps, as explained in the research framework in Figure 2.

(1) The PPP revenue system is divided into the micro-private revenue subsystem and the macroeconomic-policy subsystem

(2) The SD-based simulation model is established by analyzing the parameters' feedback loop, and all parameters' equations are constructed to develop quantitative relationships between factors

(3) Different economic and policy scenarios are designed to identify the impacts of macro-risk factors on PPP projects and the dynamic influence process

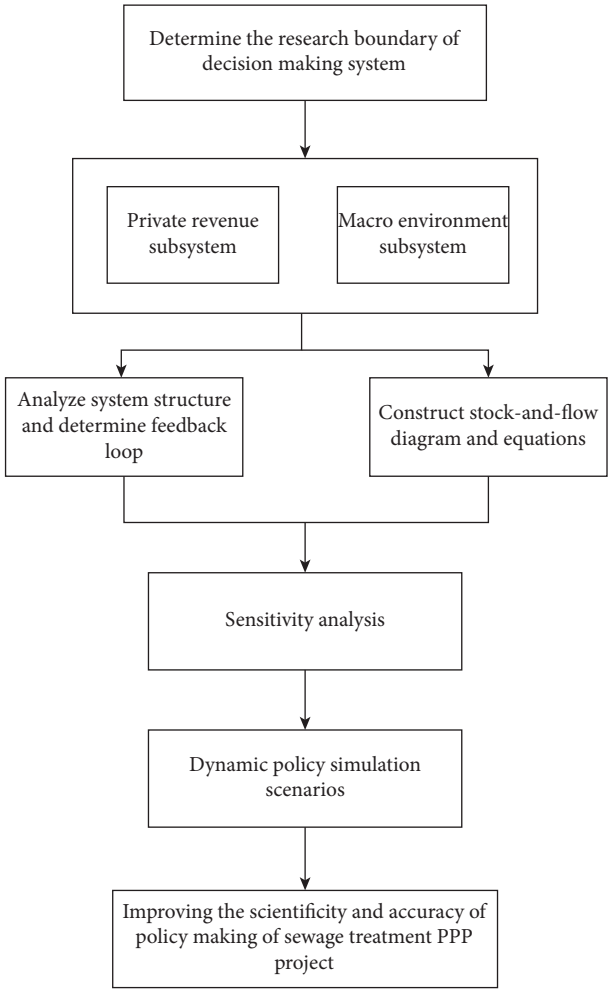

Figure 2: The research framework.

3.1. Research Scope. The proposed evaluation system consists of two subsystems: a private revenue subsystem and a macroenvironmental subsystem. The private revenue subsystem dominates financial feasibility and contains several elements that constitute cash inflows and cash outflows, according to Xu et al. [42]; while the macroenvironmental, a.k.a., the economic-policy subsystem, models economic environments by deploying gross domestic product (GDP) growth rate as a critical factor, given its ability to influence regulatory policies. The variables in each subsystem hold static or dynamic interrelationships.

3.2. System Dynamics Modelling. The SD model is designed to identify the influence of macroeconomic recession and regulatory policies on a typical sewage treatment PPP project. The model is implemented in Vensim P.L.E. software, a full-fledged platform that fits continuous simulation and supports discrete-event analyses and agent-based modeling.

Previous studies showed that system dynamics could depict relationships among variables within a system that comprises multiple subsystems. Hence, it is an ideal tool to model the interactions within PPP projects. Figure 3 depicts the SD conceptual visualization of the PPP project for sewage treatment, where arrows bridge from causes (variables at the tails of arrows) to effects (variables at the heads of arrows) [43], and the positive (+) signs represent positive reinforcement. In contrast, the negative (−) denotes the opposite.

Fourteen variables and 11 parameters are devised in this system: one level variable, two flow variables, and 11 auxiliary variables (see Table 1). The level variable is computed using an integrator. The rate variable measures the rate at which an influencing variable is applied to the level variable. This may include inflow and outflow variables.

After describing qualitative conceptualization, SD modeling needs to compute relationships between variables quantitatively. In this model, values of some variables are obtained from previous project experiences and public data, and the rest are calculated in this article. NPV and government subsidy are used to describe the logical relationships among the variables.

3.2.1. PPP Revenue Subsystem. NPV is the difference between the present value of cash inflows and the present value of cash outflows over a period of time. A positive NPV indicates that the project will be profitable. When the value is negative, it indicates otherwise. Therefore, NPV is the final output of the system, and its calculation involves several variables that are either cash-inflow-related or cash-outflow-related:

$$\begin{aligned} \mathrm{NPV} &= \sum (\mathrm{CI} - \mathrm{CO}), \\ \mathrm{CO} &= C_c + C_o + C_i + C_t, \\ \mathrm{CI} &= I_s + G_s, \end{aligned} \tag{1}$$

where CI represents the cash inflows including income from the sewage treatment (I_s) and the government subsidy for the project (G_s). Technically, the sewage treatment income is determined by concession price and sewage treatment volume [44–46]. Usually, the government sets the sewage treatment into a value that encourages the private sector to participate. CO is the cash outflows of the project, including the construction cost (C_c), the operation cost (C_o), the loan interest (C_i), and the total tax (C_t) [47]. The construction cost refers to the cost incurred during each year of the construction period [42]. The operation cost includes maintenance cost, wages, the welfare of the employer, energy cost, and raw material cost [48]. The loan cost is the interest generated from a bank loan.

In this model, the actual volume of the total sewage treatment Q_τ can be modeled through a lognormal stochastic process [49]:

$$\mathrm{d}Q_\tau = \mu Q_\tau \mathrm{d}\tau + \sigma Q_\tau \mathrm{d}W_Q, \tag{2}$$

where $\mathrm{d}Q_\tau$ is the increment of the sewage treatment volume during a short period of time d_τ. μ is the volume growth rate during d_τ, and σ is the long-term volatility of the annual growth rate of the volume. μ and σ are constants, and $\mathrm{d}W_Q$ is the incremental volume that is independently and identically

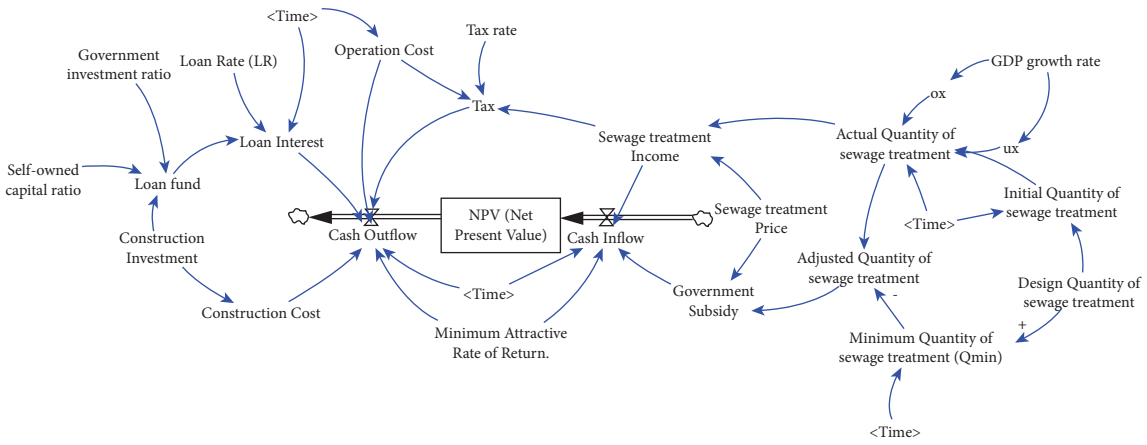

Figure 3: The feedback loop of the proposed system dynamic model.

distributed (i.i.d) in a standardized Wiener process. For convenience, equation (2) is modified as follows:

$$dQ_\tau = \left(\mu - \frac{1}{2}\sigma^2\right)d\tau + \sigma dW_Q. \tag{3}$$

Since the actual volumes of the sewage treatment in two adjacent years are strongly correlated, a stochastic evolution process can be used to express the process (see equation (4)):

$$Q_{\tau+1} = Q_\tau e^{\left(\mu - \frac{1}{2}\sigma^2\right)\Delta\tau + \sigma\epsilon\Delta\tau}. \tag{4}$$

This suggests that the logarithm of the volumes follows a normal distribution with a mean of $(\mu - 1/2\sigma^2)d_\tau$ and a variance of $\sigma^2 d_\tau$.

The subsidy for the project $G_s(t)$ is influenced by the actual volume of the sewage treatment Q_τ, the concession price P, and the minimum volume of the sewage treatment $Q_{\min}$. If Q_τ in year τ is below the lower the threshold $Q_{\min}$, the government will provide a subsidy to cover the shortfall, and the subsidy will be $(Q_{\min} - Q_\tau)$. Thus, the effective income for the private sector in year τ can be described as follows:

$$\begin{aligned} Q_\tau(\tau) &= \max\ (Q_\tau, Q_{\min}), \\ Q_{\min} &= \theta_{\min} \times Q_D, \end{aligned} \tag{5}$$

where Q_D is the quantity of sewage treated.

3.2.2. Macroenvironment Subsystem. Macroenvironments impact the annual income and the cost of the PPP sewage treatment construction project. The two main factors that influence the macroeconomic environment are the GDP growth rate and government policies.

In the proposed revenue model, two variables, μ and σ, are related to the GDP growth rate while monetary, fiscal, and industrial regulatory policies affect the project's revenue by influencing the capital structure and capital cost.

$$\begin{aligned} \mu &= 1 \times R_g, \\ \sigma &= 0.8 \times R_g. \end{aligned} \tag{6}$$

The loan interest L_i is influenced by two variables: the amount of loan L and the loan interest rate R_I. The amount of the loan is determined by the construction cost C_c, the self-owned capital ratio R_S, and the government investment ratio R_i. The self-owned capital ratio is a function of the type of industry. The tax is determined by the sewage treatment income and the tax rate.

$$\begin{aligned} L_i &= L \times R_i, \\ L &= C_c \times (1 - R_s - R_i), \\ C_t &= I_s \times R_t. \end{aligned} \tag{7}$$

4. Case Study

Sewage treatment is one of the most important application fields of the PPP model, and its decision-making is influenced by macro- and microrisks. A proactive policy will be implemented to resist the economic loss caused by an economic recession. The regulatory policies can be divided into three categories: operating cost reduction policies, tax policies that ease the tax burden and cut down the loan interest rate to decrease the capital cost of private sectors, and policies that improve cash inflow.

The authors applied the proposed SD model to a sewage treatment construction project to study the influences of economic conditions and government policies on the revenue of the PPP project. The authors designed four scenarios in addition to the base scenario, as listed in Table 2, to investigate and compare the function of each policy.

The simulation period of the model is set at 20 years starting from 2019, reflecting the PPP agreement with a 20-year concession period, including the construction period. The time step is half a year.

4.1. Base Scenario and Data Resource. The related data were extracted from a feasibility research report of the project, as shown in Table 1 [50]. The average GDP growth rate was set at 6.5%, according to the National Bureau of Statistics of China (NBS). The authors assumed that the impact coefficients were equal to one, which implied that the sewage treatment

Table 1: Model variables.

No.	Name	Symbol	Unit	Function/value
1	Net present value	NPV	Dollars	$\sum(\mathrm{CI}-\mathrm{CO})/(1+i)$To
2	Cash inflow	CI	Dollars/year	Sewage treatment income + government subsidy
3	Cash outflow	CO	Dollars/year	Construction cost + operation cost + loan interest
4	Construction cost	C_c	Dollars/year	1.456×10^7
5	Operation cost	C_o	Dollars/year	Operation cost = 0.29 million × (1 + annual growth rate)$^{}$time
6	Loan interest	C_i	Dollars/year	Loan fund × loan interest rate
7	Tax	C_t	Dollars/year	Sewage treatment income × tax rate
8	Minimum attractive rate of return	$R_{\min}$	%	8
9	Sewage treatment income	I_s	Dollars/year	Concession price × actual quantity of sewage treatment
10	Concession price	P	Dollars/T	0.14
11	Actual quantity of sewage treatment	Q_τ	T/year	$Q_{\tau+1}=Q_\tau e^{(\mu-1/2\sigma^2\Delta\tau+\sigma\varepsilon\Delta\tau)}$
12	Influence coefficient of GDP growth rate on volume growth rate	μ	Dimensionless	1
13	Influence coefficient of GDP growth rate on volume volatility	σ	Dimensionless	0.8
14	Design volume of sewage treatment	Q_d	T/day	1.15×10^4 T/Day
15	Minimum quantity of sewage treatment	$Q_{\min}$	T/day	0.7 × design volume of sewage treatment
16	Initial quantity of sewage treatment	Q_i	T/day	0.5 × design volume of sewage treatment
17	Adjusted volume	Q_{ad}	T/day	Min [max(Q_{ac}, $Q_{\min}$), $Q_{\max}$]
18	Government subsidy for this project	G_s	Dollars/year	Sewage treatment income-concession price × actual quantity of sewage treatment
19	Amount of loan	L		Construction investment × self-owned capital ratio
20	Loan interest	L_i		Amount of loan × loan interest rate
21	GDP growth rate	R_g	%	6.5
22	Loan interest rate	R_l	%	7.5
23	Government investment ratio	R_i	%	0
24	Self-owned capital ratio	R_s	%	30
25	Value-added tax rate	R_{t1}	%	17
	Enterprise income tax rate	R_{t2}	%	25

Table 2: Regulatory scenarios.

No.	Scenarios	Description
1	Base scenario	GDP growth rate is 6.5%, self-owned capital rate is 30, and concession price is 0.14 dollars/t
2	GDP growth rate decreases	GDP growth rate decreases from 6.5% to 4.55%
3	Self-owned capital rate decreases	Self-owned capital rate decreases from 30% to 10%
4	Tax rate decreases	Enterprise income tax rate decreases from 25% to 15%
5	Loan interest rate decreases	Loan interest rate decreases from 7% to 5.6%

demand's growth rate and volatility rate held positive relationships with the GDP growth rate according to the Notice on Strengthening Investment and Construction Management of PPP Projects in Accordance with Laws and Regulations issued by the National Development and Reform Commission in 2017. The minimum capital ratio of PPP water environmental governance projects is 0.3 [51], and enterprise income tax is exempted from the sewage treatment income according to the tax regulations released by the State Taxation Administration of China (STA) [52]. According to the stipulation of the Administration of Taxation of the Ministry of Finance, the PPP project that meets the requirements can enjoy the tax preference of exemption from income taxation for the first three years, reduction half for next three years. The enterprise income tax rate is 25% of sewage treatment plants. The enterprise income tax rate is the only tax incorporated in this study because it was based on long-term income. It was set as 25% as the National Development and Reform Commission of China (NDRC) [53]. According to the stimulation of the National Development and Reform Commission in 2015, the minimum sewage treatment price is 0.95 yuan/t which is 0.14 dollar/t in line with the average exchange rate between China Yuan and US dollars in 2019. By referring to Zhang et al.'s study, the average discount rate of the sewage treatment industry was set at 8% [54]. According to the People's Bank of China, the benchmark interest rate for long-term loans will be set at 4.9% in 2019. However, during the implementation of the project, the actual loan interest rate is higher than the benchmark interest rate based on the strength of social capital and the nature of the project. The authors assumed that the loan interest rate of long-term PPP projects is 7.5%.

4.2. Economic Recession Scenario. Some studies found that macroeconomic recession could influence corporate earnings and cash flows. For example, when most corporations cut down the expenses on environmental protection, the demand for sewage treatment would decrease. To clarify the mechanism behind this influence, the authors created an economic recession scenario with a GDP growth rate dropping from 6.5% to 4.55% for 20 years, according to Ward K's prediction, which indicated that China's economy would decline in the following decades [55].

4.3. Self-Owned Capital Rate Decrease Scenario. Self-owned capital rate is one of the most critical regulatory policies. In the base scenario, the self-owned capital rate was set at 30%. The authors referred to the practices in the UK [29] and set the self-owned capital rate as 10% to reduce the initial investment of the private sector. A self-owned capital rate decrease scenario was devised where the self-owned capital rate ranged from 30% to 10% over 20 years.

4.4. Tax Rate Decrease Scenario. Tax policies in PPP projects can also reflect regulatory policies. Given their essence for public welfare, PPP projects would be more likely to succeed if specific tax policies [56] favor them. Usually, governments recognize this and enact tax reduction policies to encourage private sectors to participate, primarily when NPVs cannot ensure the projects' feasibility or sustainability. Numerous tax schemes apply to work on PPP sewage treatment projects. Therefore, the authors took enterprise income tax as an example and altered its value from 25% to 15% [57].

4.5. Loan Interest Rate Decrease Scenario. Over the project period, the interest rate follows random uniform distribution [58], and directly decreasing the loan interest rate would lead to inflation, even though it cuts down the capital cost of the private sector. Therefore, the authors presumed the market as an agent and designed an interest rate decrease scenario [59, 60] where the bank determines the loan interest rate by considering the debt ratio of the company: the lower the debt ratio, the lower the loan interest rate. As a result, the loan interest rate ranged from 7% to 5.6% [61].

4.6. Sensitivity Analysis. A sensitivity test was conducted to assess the validity and availability of the developed model. According to the above analysis, four macrovariables (i.e., GDP growth rate, self-owned capital ratio, tax rate, and loan interest rate) contribute to cash flow. Detailed parameters for the four variables are shown in Table 3. Simulations were performed with 200 values for each variable randomly chosen from its probability distribution to represent realistic conditions. As forecasted, all the economy and policy variables were assumed to follow a random uniform distribution between the minimum and the maximum values. The results shown in Figure 4 indicated that although the value of NPV changes with the macroeconomic variables, the trend of VPN change is not altered by these variables. It means that the SD model developed can model the impacts of these variables on the VPN of PPP projects with reasonable sensitivity.

5. Results and Discussion

The SD model described above has been used to investigate the influence of macrorisks and their dynamic relations with

Table 3: Input parameters of the four variables for the sensitivity test.

Category	Variables	Distribution	Min	Max
Macroenvironment	GDP growth rate	Uniform	0.04	0.07
	Self-owned capital ratio	Uniform	0.1	0.3
	Tax rate	Uniform	0.15	0.25
	Loan interest rate	Uniform	0.04	0.08

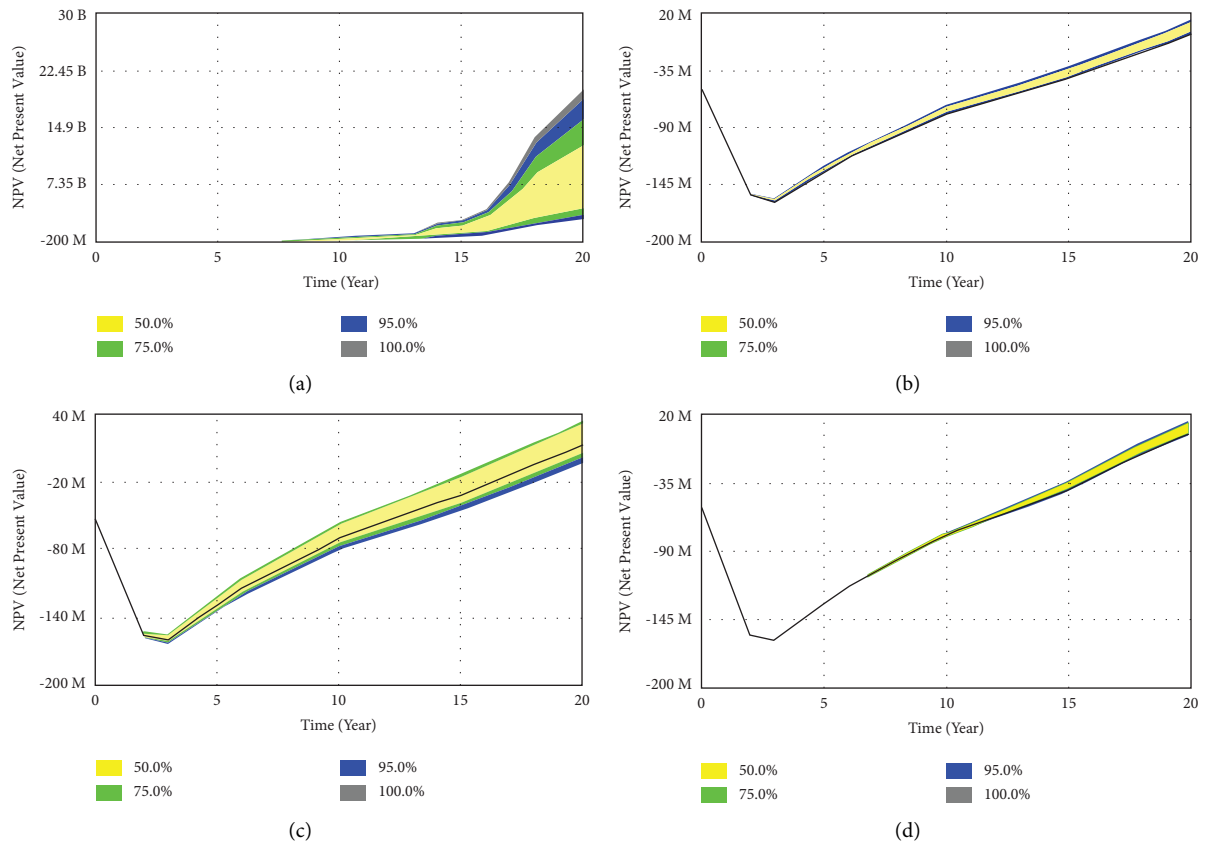

Figure 4: The impact of macro-risk variables on NPV: (a) GDP growth rate vs NPV. (b) Self-owned capital ratio vs NPV. (c) Loan interest rate vs NPV. (d) Tax rate vs NPV.

the microrevenue for a PPP sewage treatment construction project. Five scenarios were defined according to the most likely change in macro- and microvariables.

5.1. Impact of GDP Growth Rate. To evaluate the impact of GDP growth rate decline, we assumed that the GDP growth rate is decreased to 4.55% in an economic recession scenario. Figure 5 shows how the GDP growth rate impacts the performance of the PPP project. The direct consequence of the fast GDP decline, from 6.5% to 4.55%, was the decreased volume of sewage treated. In the first 3–10 years, the demand for sewage treatment declined slightly but plunged by 15%–28% from the 11th to the 20th year (Figure 5(a)). The sewage treatment income followed the same trend with a drop from 20% to 30% during the last ten years (Figure 5(b)). This can be explained because the effect of GDP decrease on manufacturing enterprises is delayed. The widening gap in the actual volume of sewage treatment and income indicates that manufacturing enterprises gradually cut back their production, and the demand and revenue of survival enterprises have stabilized in the last few years.

As the GDP acceleration slowed, the annual government subsidy increased significantly, as depicted in Figure 3(c). Especially in the 8th and the 11th years, when the government in the basic scenario paid nothing, the government in this scenario had to provide much more. That is because the government partly compensates the insufficient revenue according to the concession agreement. The less the income is, the more the government pay. These results suggest that a GDP decrease will increase the financial burden on the government.

As shown in Figure 3(d), NPV is the most influenced factor, dropping more than 240%, from 1.07Î106 dollars in the basic scenario to −1.53Î106 dollars. That is because NPV is an accumulative value controlled by the annual income. The significant drops in income lead to a decrease in NPV.

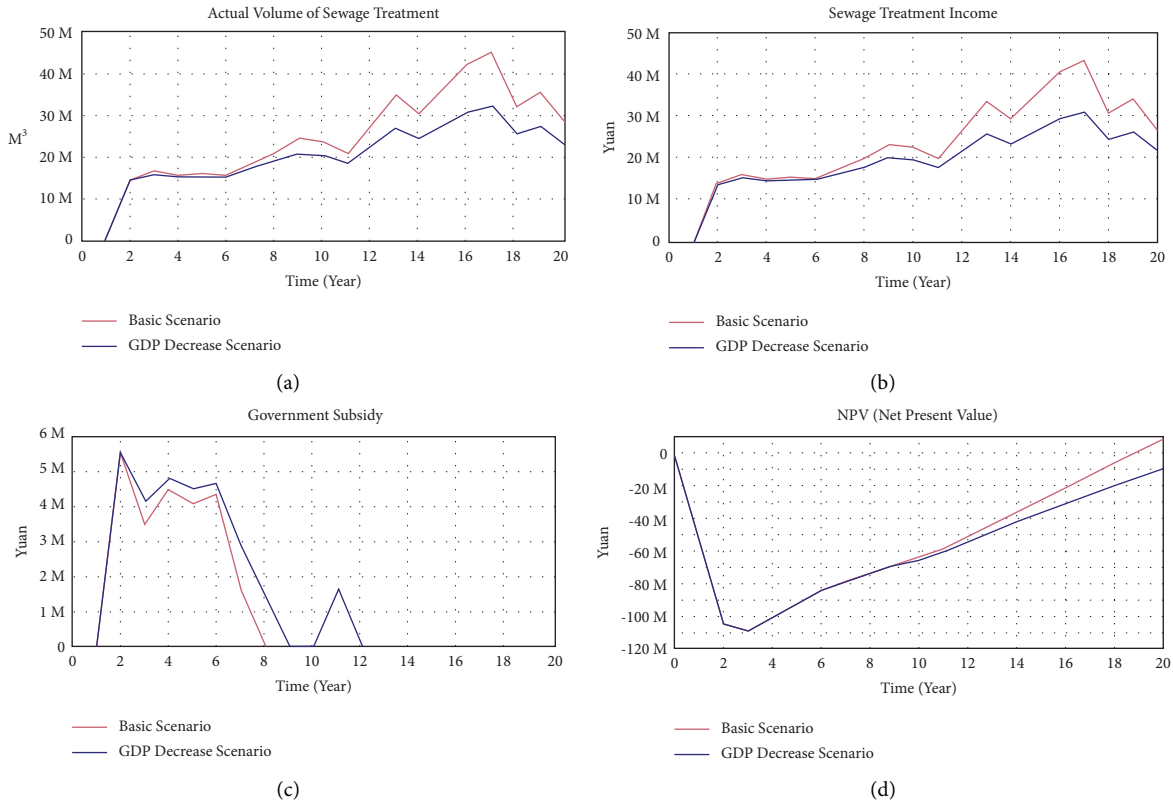

Figure 5: Impact of GDP decreases on the actual volume of sewage treatment, sewage treatment income, government subsidy, and NPV.

When NPV reached negative values, the project became infeasible.

The results indicate that decreasing GDP growth rate leads to reductions in the volume of sewage treatment, the income of the project, the government subsidy, and the NPV and ultimately reduces the wiliness to invest in the private sector, which is consistent with the influencing path in Figure 2. The impact on the revenue of sewage treatment PPP projects could be manifested in many ways ranging from reduced investment to bankruptcy [62]. This is consistent with Yoon's research which concluded that macroeconomic fluctuations generally reflect the changes in external demand. This will directly affect the enterprise's operating income, increasing or decreasing business investment expenditure [63]. This demonstrates that the ability of a PPP project to survive in the presence of a significant economic recession mainly depends on sufficient and appropriate interventions from the government (the public part of PPP). This is further explored in the policy scenario simulation reported in Section 5.2.

5.2. Impact of Regulatory Policies. The impact of each macroregulatory policy on the six outputs, NPV, the actual sewage treatment volume, the government subsidy, the sewage treatment income, the tax, and the loan interest, was simulated. The results are presented in Figure 6.

5.2.1. The Impact of a Self-Own Capital Rate Decrease. When the self-own capital rate decreases from 30% to 10%, the NPV is dropped to −3.13Î106 dollars from the 3rd to the 20th year, a 105% cut compared to its value in the GDP decreasing scenario. At the same time, the loan interest is increased from 7.64Î105 dollars/year in the base scenario to 9.83Î106 dollars/year, and a jump of 151% for the NPV can be observed. These findings imply that a decrease in self-own capital rate leads to a higher loan and a higher loan interest expense, ultimately decreasing the NPV of PPP projects. This finding concurs with the result obtained by Ban that capital ratio reduction increased the financial burden of real estate companies [64].

5.2.2. The Impact of a Tax Rate Decrease. The total tax declined by about 50% when the tax rate decreased, while NPV has risen 69% higher than that in the GDP decrease scenario. These data show that the low tax rate exhibited is declining tax expenditure. That is because the tax decrease policy reduced the operation cost of the private sector. NPV is larger than the base scenario from the 4th to 12th year and then declined for the rest of the simulation period (see Figures 6(a) and 6(e)). Tax cuts can improve the NPVs of PPP projects because of the tax expense drops faster than the income. The result is consistent with the evidence reported by Bloom that the government adopts tax policy to adjust the

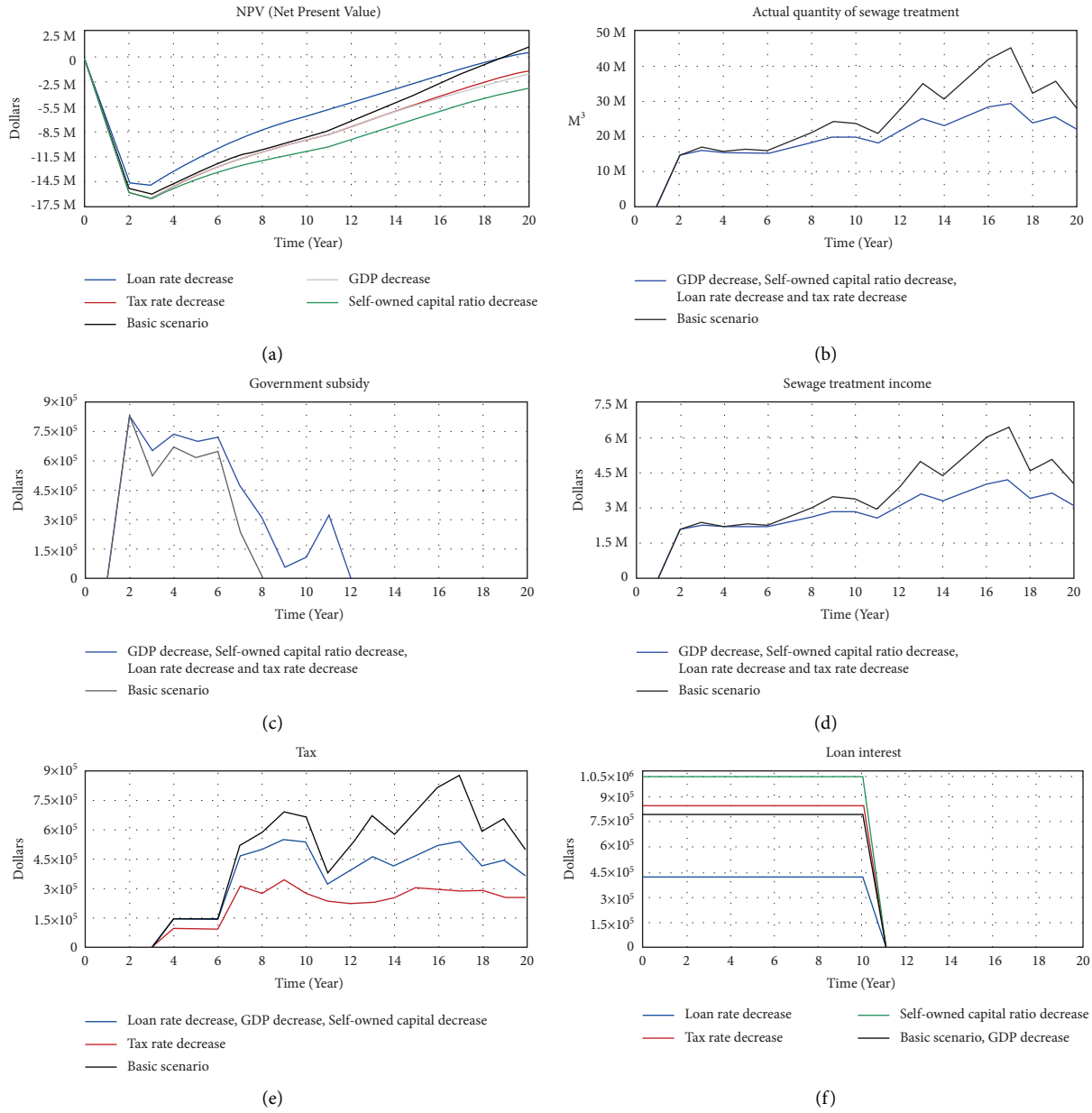

FIGURE 6: Impact of different scenarios on the six key outputs: (a) NPV, (b) actual volume of sewage treatment, (c) government subsidy, (d) sewage treatment income, (e) tax, and (f) loan interest.

demand and supply of capital and sends a message about a future investment to firms [65].

5.2.3. Impact of Loan Interest Rate Decrease. In the scenario where the loan interest rate decreases to 5.6%, the NPV value is −1.05Î105 dollars, a 93% increase when compared to the value obtained by simulating the GDP decrease scenario. Specifically, during the period between the 2nd year to 16th year, NPV is higher than that in any other scenario; while from the 17th to the 20th year, it drops to the second position, lower than that in the base scenario and higher than that in the tax decrease scenario. This can be explained that the decrease rate of the cash outflow (like loan interest) is slower than that of cash inflow (like sewage treatment income). These findings imply that a loan interest rate decrease policy can improve the cash flow in an early stage, but from the long-term perspective, it cannot carry back losses. These results are consistent with the findings of Taylor and Cheng that depicted investment as negatively related to the real interest rate [66].

Overall, macroeconomic downward will lead to a significant reduction of NPV due to low and declining cash flows. The growth rate of cash inflow and outflow determines the value of NPV. The improving effect of the loan rate decrease is better than the tax rate decrease. However, the self-own capital rate decrease hurts the revenue of PPP

projects. Using the model proposed in this paper, the influencing path of different macrorisks can be identified.

Therefore, any decision in PPP projects must consider the macrorisks and their dynamic relations, as well as microenterprise revenue. In a nutshell, the central government should improve the tax policy to ease the tax burden; thus, the private sector can decrease the cash outflow. Interest rate marketization should be promoted because it will relieve companies' financing constraints, reduce the loan interest rate by exacerbating the competition between banks, and force the private sector to reduce the debt rate to obtain lower loan interest rates.

5.3. Suggestions. Based on our analysis, the following four suggestions are proposed:

(1) The private sector should monitor the macroeconomic situation and government regulation policies. To make scientific investment decisions, stakeholders should conduct extensive statistical analyses of the macrofactors affecting PPP projects.

(2) Taxes schemes need to be improved by incorporating tax incentives to motivate the private sector by reducing their tax burden.

(3) The high financing cost puts a restraint on the participation of the private sector. The monetary policies should be designed to create ease for the potential private stakeholders.

(4) The self-owned capital reduction can relieve the initial financial pressure; however, it will increase the operation cost. Therefore, a self-owned capital reduction policy should be implemented together with other complementary measures, such as a loan rate decrease policy. These findings provide a reference for private sectors and local governments to implement appropriate policy measures for improving the sustainability of PPP projects.

6. Conclusions and Limitations

6.1. Conclusions. Research on the macro-risk factors (GDP growth rate and policy interventions) on the revenue is essential for the sustainable development of sewage treatment PPP projects. An SD-based policy analytical model was established to simulate the changing trends and values of fiscal variables. The following conclusions can be drawn from the results: (1) macroeconomic recession hurts the revenue of PPP projects which prevents the investment of the private sector, and incentive regulatory policies have different influencing paths; (2) the proposed SD model can be used to analyze possible changes in PPP projects and provides references for investment decision or policy making. The proposed approach can also be applied to study PPP projects in other sectors. For instance, subway and waste-to-energy incineration PPP projects can be investigated using the proposed method because they are quasi-operational urban infrastructures where the wild fluctuation of macrorisks influences revenue.

This paper has the following innovations: first, it is among the first attempts to develop an integrated analytical framework of macro- and microfactors and establish the feedback relationship between macro- and microfactors; second, it integrates real option, stakeholder, and system dynamics theories, which is an extension of the existing evaluation theory.

6.2. Limitations. This study has some limitations that deserve further research. First, more macroeconomic variables need to be considered. For instance, many studies reported that the inflation rate and exchange rate impact investment; however, their results are conflicting. For example, the work by Ahmed and Rogers states that the investment rate increases as the inflation rate rises [67]. On the other hand, Fama and Schwert have shown that the inflation rate hurts the investment rate [68]. The exchange rate should be considered in the foreign capital importing PPP project. The exchange rate fluctuation will lower the expected profits of enterprises and investment rates, according to George's opinion [69]. However, Darby et al. state that whether the investment rate will be discouraged or encouraged depends on the conditions of the companies involved [70]. Therefore, the influences of the inflation rate and exchange rate risk are yet to be universally agreed upon, and the topic is worthy of further research. Second, more specific parameter values should be incorporated into the model to obtain more accurate predicted results. Given the lack of relevant empirical study data, the parameter values of the impact of GDP on the growth rate and volatility of the annual growth rate of sewage treatment volume were assumed based on the industrial experience. Third, the SD method provides a novel perspective to analyze the complicated reality but is still far away from a final solution to macroeconomic influences, given the more complex economic conditions in practice.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Acknowledgments

This research was funded by the Mitacs Globalink Research Award (No. IT14938).

References

[1] T. Yang, R. Long, X. Cui, D. Zhu, and H. Chen, "Application of the public–private partnership model to urban sewage treatment," *Journal of Cleaner Production*, vol. 142, pp. 1065–1074, 2017.

[2] E. E. Ameyaw and A. P. C. Chan, "Risk ranking and analysis in PPP water supply infrastructure projects," *Facilities*, vol. 33, no. 7/8, pp. 428–453, 2015.

[3] M. Lilley and C. Giorgio, "A private-sector perspective," *Australian Accounting Review*, vol. 14, no. 33, pp. 34–41, 2004.

[4] B. Deng, D. Zhou, J. Zhao, Y. Yin, and X. Li, "Fuzzy synthetic evaluation of the critical success factors for the sustainability of public private partnership projects in China," *Sustainability*, vol. 13, no. 5, pp. 2551–2621, 2021.

[5] J. Tamošaitienė, H. Sarvari, D. W. M. Chan, and M. Cristofaro, "Assessing the Barriers and risks to private sector participation in infrastructure construction projects in developing countries of Middle East," *Sustainability*, vol. 13, no. 1, pp. 153–220, 2020.

[6] E. Malini, "Build operate transfer municipal bridge projects in India," *Journal of Management in Engineering*, vol. 15, no. 4, pp. 51–58, 1999.

[7] L. Y. Shen and Y. Z. Wu, "Risk concession model for Build-operate-transfer contract projects," *Journal of Construction Engineering and Management*, vol. 131, no. 2, pp. 211–220, February, 2005.

[8] T. Zhao, S. K. Sundararajan, and C. Tseng, "Highway development decision-making under uncertainty : a real options approach," *Journal of Infrastructure Systems*, vol. 10, pp. 23–32, 2004.

[9] N. Carbonara, N. Costantino, and R. Pellegrino, "Revenue Guarantee in public-private partnerships:A Fair risk allocation model," *Construction Management & Economics*, vol. 32, no. 4, pp. 403–415, 2014.

[10] W. B. Group, *Global Economic Prospects*, W. B. Group, Ozarow Mazowiecki, Poland, 2020.

[11] E. Moschouli, R. Murwantara, and T. Vanelslander, "Research in Transportation Economics Cost performance of transport infrastructure projects before and after the global financial crisis (GFC): are differences observed in the conditions of project performance," *Res. Transp. Econ.*vol. 75, pp. 21–35, 2019.

[12] P. Burger, J. Tyson, I. Karpowicz, and M. D. Coelho, "The effects of the financial crisis on public-private partnerships," *SSRN Electronic Journal*, 2009.

[13] H. Zhao, S. Ma, and Z. Bu, "Constructing a risk-Sharing framework for Sponge city PPP projects from the perspective of the Individual participant," *Advances in Civil Engineering*, vol. 2020, Article ID 8832664, 16 pages, 2020.

[14] A. Shalaby and A. Hassanein, "A decision support system (DSS) for facilitating the scenario selection process of the renegotiation of PPP contracts," *Engineering Construction and Architectural Management*, vol. 26, no. 6, pp. 1004–1023, 2019.

[15] F. L. Avio and M. Ryan, *Default and renegotiation in public private partnership auctions*, vol. 17, no. 1, pp. 49–77, 2015.

[16] C. Fernandes, C. Oliveira Cruz, and F. Moura, "Ex post evaluation of PPP government-led renegotiations : impacts on the financing of road infrastructure," *The Engineering Economist*, vol. 64, no. 2, pp. 116–141, 2019.

[17] B. Li, A. Akintoye, P. J. Edwards, and C. Hardcastle, "Critical success factors for PPP/PFI projects in the UK construction industry," *Construction Management & Economics*, vol. 23, no. 5, pp. 459–471, 2015.

[18] F. R. Medda, G. Carbonaro, and S. L. Davis, "Public private partnerships in transportation: some insights from the European experience," *IATSS Research*, vol. 36, no. 2, pp. 83–87, 2013.

[19] Y. Xu, A. P. C. Chan, and J. F. Y. Yeung, "Developing a fuzzy risk allocation model for PPP projects in China," *Journal of Construction Engineering and Management*, vol. 136, no. 8, pp. 894–903, 2010.

[20] R. O. Asamoah, B. K. Baiden, G. Nani, and E. Kissi, "Review of exogenous economic indicators influencing construction industry," *Advances in Civil Engineering*, vol. 2019, Article ID 6073289, 8 pages, 2019.

[21] Y. Ke, S. Q. Wang, A. P. C. Chan, and P. T. I. Lam, "Preferred risk allocation in China's public-private partnership (PPP) projects," *International Journal of Project Management*, vol. 28, no. 5, pp. 482–492, 2010.

[22] E. E. Ameyaw and A. P. C. Chan, "Evaluation and ranking of risk factors in public-private partnership water supply projects in developing countries using fuzzy synthetic evaluation approach," *Expert Systems with Applications*, vol. 42, no. 12, pp. 5102–5116, 2015.

[23] K. H. Yoon and R. A. Ratti, "Energy price uncertainty, energy intensity and firm investment," *Energy Economics*, vol. 33, no. 1, pp. 67–78, 2011.

[24] N. Bloom, "The impact of uncertainty Shocks," *Econometrica*, vol. 77, no. 3, pp. 623–685, 2009.

[25] H. Mumtaz, L. Sunder-Plassmann, and A. Theophilopoulou, "The state-level impact of uncertainty Shocks," *Journal of Money, Credit, and Banking*, vol. 50, no. 8, pp. 1879–1899, 2018.

[26] O. Talavera, A. Tsapin, and O. Zholud, "Macroeconomic uncertainty and bank lending: the case of Ukraine," *Economic Systems*, vol. 36, no. 2, pp. 279–293, 2012.

[27] W. Semmler and W. Zhang, "Asset price volatility and monetary policy rules: a dynamic model and empirical evidence," *Economic Modelling*, vol. 24, no. 3, pp. 411–430, 2007.

[28] S. Mane and S. S. Pimplikar, "Risk Assessment of Bot projects," *ELK Asia Pacific J. Financ. Risk Manag.*vol. 66, no. 4, pp. 37–39, 2013.

[29] Y. Li, W. Xing, and C. Wei, "Introspection and reconstruction of capital financing for PPP projects in the background of standardized operations," *Econ. Probl.*vol. 8, no. 12, pp. 32–39, 2018.

[30] E. Gaiotti and A. Generale, "Does monetary poliy have asymmetric effects?" *A look at the investment decisions of Italian firms*, vol. 39, 2001.

[31] T. Yang, R. Long, and W. Li, "Suggestion on tax policy for promoting the PPP projects of charging infrastructure in China," *Journal of Cleaner Production*, vol. 174, pp. 133–138, 2018.

[32] A. S. Berk and D. Podhraski, "Superiority of Monte Carlo simulation in valuing real options within public-private partnerships," *Risk Management*, vol. 20, no. 1, pp. 1–28, 2018.

[33] F. Buyukyoran and S. Gundes, "Optimized real options-based approach for government guarantees in PPP toll road projects," *Construction Management & Economics*, vol. 36, no. 4, pp. 203–216, 2018.

[34] S. Alonso-Bonis, V. Azofra-Palenzuela, and G. de la Fuente-Herrero, "Real option value and random jumps: application of a simulation model," *Applied Economics*, vol. 41, no. 23, pp. 2977–2989, 2009.

[35] X. Fan, F. Wang, and G. Zhong, "A dynamic fuzzy evaluation method of project financing risk on Large Scale infrastructure," *Journal of Shanghai Jiao Tong University*, vol. 38, no. 3, pp. 450–454, 2004.

[36] J. W. Forrester, *Industrial Dynamics. Cambridge, Mass*, The M.I.T. Press, Cambridge, MA, USA, 1961.

[37] J. W. Forrester, "Counterintuitive behavior of social systems," *Theory and Decision*, vol. 2, pp. 109–140, 1971.

[38] L. Ming xiao and Y. Wan, "PPP concession period is to determine the method research," *J. Eng. Manag.*vol. 30, no. 5, pp. 66–70, 2016.

[39] J. Song, D. Song, and D. Zhang, "Modeling the concession period and subsidy for BOT waste-to-energy incineration projects," *Journal of Construction Engineering and Management*, vol. 141, no. 10, pp. 11-12, 2015.
[40] R. F. Naill, "A system dynamics model for national energy policy planning," *Syst. Dyn. Rev.*vol. 8, no. 1, pp. 1–19, 1992.
[41] J. D. Sterman, *Business Dynamics:Systems Thinking and Modeling for a Complex World*, McGraw Hill Companies, USA, 2000.
[42] Y. Xu, C. Sun, M. J. Skibniewski, A. P. C. Chan, J. F. Y. Yeung, and H. Cheng, "System dynamics(SD)-Based concession pricing model for PPP highway projects," *International Journal of Project Management*, vol. 30, no. 2, pp. 240–251, 2012.
[43] P. E. D. Love, P. Mandal, J. I. M. Smith, and H. Li, "Modelling the dynamics of design error induced rework in construction," *Construction Management & Economics*, vol. 18, no. 5, pp. 567–574, 2000.
[44] L. E. T. Brandao and E. Saraiva, "The option value of government guarantees in infrastructure projects," *Construction Management & Economics*, vol. 26, no. 11, pp. 1171–1180, 2008.
[45] A. Wibowo, "Valuing guarantees in a BOT infrastructure project," *Engineering Construction and Architectural Management*, vol. 11, no. 6, pp. 395–403, 2004.
[46] J. w. Xu and S. Moon, "Stochastic revenue and cost model for determining a BOT concession period under multiple project constraints," *Journal of Management in Engineering*, vol. 30, no. 3, pp. 1–32, 2014.
[47] S. Thomas Ng, J. Xie, M. Skitmore, and Y. K. Cheung, "A fuzzy simulation model for evaluating the concession items of public-private partnership schemes," *Automation in Construction*, vol. 17, no. 1, pp. 22–29, 2007.
[48] X. Zhang and S. M. Abourizk, "Determining a reasonable concession period for private sector provision of public works and services," *Canadian Journal of Civil Engineering*, vol. 33, 2006.
[49] A. Dixit and R. Pindyck, *Investment under Uncertainty*, Princeton University, Princeton, NJ, USA, 1994.
[50] Q. Liu, Z. Liao, Q. Guo, D. M. Degefu, S. Wang, and F. Jian, "Effects of short-term Uncertainties on the revenue Estimation of PPP sewage treatment projects," *Water*, vol. 11, no. 6, pp. 1203–1214, 2019.
[51] C. National, *Notice of the State council on Adjusting and Improving the Capital System for Fixed Assets Investment Projects*, C. National, New Haven, Connecticut, USA, 2015.
[52] Stac, "Finance and taxation," State Taxation Administration of China, Beijing, China, 2015, http://www.chinatax.gov.cn/chinatax/n359/c5138795/content.html.
[53] Ndrc, "National development and reform commission," NDRC, Beijing, China, 2015, http://wjj.jl.gov.cn/hjdczl/zcgz/201708/t20170821_3425858.html.
[54] Y. Zhang, Y. Zhao, and G. Xiong, "Study on the cost and pricing of domestic sewage treatment from the perspective of Scale economy," *PriceTheory Pract*, vol. 10, pp. 96–99, 2017.
[55] K. Ward, *The Word in 2050.Quantifying the Shift in the Global Economy*, HSBC, Research Division, London, UK, 2011.
[56] W. Laicheng and W. Tao, "A research of the tax policy on supporting the Franchies projects," *Public Financ. Tax. Forum*, vol. 9, pp. 10–15, 2016.
[57] W. D. M. Gang, "The policy simulation of coal Resource-based city Copes with energy prices Shock—based on system dynamic model," *Journal of Beijing Institute of Technology (Social Sciences Edition)*, vol. 18, pp. 10–22, 2016.
[58] J. Liu, R. Gao, and R. Xie, "Real option evaluation in PPP projects under uncertainty of interest rate," *Oper. Res. Manag. Sci*, vol. 27, no. 7, pp. 170–176, 2018.
[59] X. Chen and R. Luo, "Debt cost and capital allocation efficiency in the process of interest rate marketization," *Business Management J*, vol. 39, pp. 162–174, 2017.
[60] H. Wang, Z. Yang, G. Ruan, and Y. Cao, "Deregulation of interest rates, Excessive debt and debt Maturity structure," *Journal of Financial Research*, vol. 2, pp. 100–117, 2018.
[61] Y. Barlas, "Formal aspects of model validity and validation in system dynamics," *System Dynamics Review*, vol. 12, no. 3, pp. 183–210, 1996.
[62] C. X. Hu, "Leverage, monetary policy, and firm investment," *Econ. Review*, vol. 2, no. 2, pp. 32–39, 1999.
[63] M. E. Bontempi, R. Golinelli, and G. Parigi, "Why demand uncertainty curbs investment: evidence from a panel of Italian manufacturing firms," *Journal of Macroeconomics*, vol. 32, no. 1, pp. 218–238, 2010.
[64] Y. Ban and Z. Yang, "An analysis of China's real estate market in the era of post capital ratio reduction," *Res. Financ. Econ. Issues*, vol. 8, no. 309, pp. 101–104, 2009.
[65] N. Bloom, S. Bond, J. Van Reenen, and N. Bloom, "Uncertainty and investment dynamics," *The Review of Economic Studies*, vol. 74, no. 2, pp. 391–415, 2007.
[66] J. B. Taylor, "The monetary Transmission mechanism: an empirical framework," *The Journal of Economic Perspectives*, vol. 9, no. 4, pp. 11–26, 1995.
[67] S. Ahmed and J. H. Rogers, "Inflation and the Great ratios: long-term evidence from the U.S," *SSRN Electronic Journal*, vol. 628, 2005.
[68] E. F. Fama and G. W. Schwert, "Asset returns and inflation," *Journal of Financial Economics*, vol. 5, no. 2, pp. 115–146, 1977.
[69] G. Zis and A. P. Papadopoulos, "A monetary analysis of the Drachma/ECU exchange rate determination, 1980-1991," *Empirical Economics*, vol. 25, no. 4, pp. 653–663, 2000.
[70] J. Darby, A. H. Hallett, J. Ireland, and L. Piscitelli, "The impact of exchange rate uncertainty on the level of investment," *The Economic Journal*, vol. 109, no. 454, pp. 55–67, 1999.