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MINIMUM REVENUE GUARANTEE AND TOLL REVENUE CAP OPTIMIZATION FOR PPP HIGHWAYS: PARETO OPTIMAL STATE APPROACH

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Abstract. In the Public-Private Partnership highway projects the Minimum Revenue Guarantee and Toll Revenue Cap policies are effective measures for risk and benefit sharing between the government and the private sector. However, if the Minimum Revenue Guarantee and Toll Revenue Cap values are unreasonable, it may lead one part of the investors to take too much risk and financial burden. This paper mainly establishes six objectives from the return and risk perspectives of the government, the concessionaire and the overall situation respectively. Because the traditional Discount Cash Flow method does not consider the risk factors, this paper proposes to use Monte Carlo simulation and scatter search algorithm to calculate the optimal values of the Minimum Revenue Guarantee and Toll Revenue Cap under different objectives. Compared with the statistics of the Net Present Value under different cases, it was summarized that when the objective is minimizing the variance of the total Net Present Value, the investors will realize the Pareto optimal state between the return and risk. In addition, it was found that the government is more sensitive to the Minimum Revenue Guarantee and Toll Revenue Cap marginal values according to the sensitive analysis. Therefore, the model has an effect on improving the fairness of the risk sharing measures, reducing the financial burden of the investors especially the government, and increasing the investment attraction of the private sectors.

Keywords: Minimum Revenue Guarantee, Monte Carlo, Net Present Value, risk, scatter search algorithm, Toll Revenue Cap.

1. Introduction

At present, the highway investment modes are divided into three types, the first type is the completely government's investment. In this mode, the main capital sources are the government financial investment and government debt financing. This mode can raise construction fund quickly by using the good credit of the government and the operation process is simple. However, with the increase of the number of the construction projects, the excessive investment and debt bring huge financial pressure to the government. The second type is the completely private investment. In this mode, the funds are mainly from the private sectors. The private sectors raise funds independently and take the corresponding responsibility. This mode can improve the efficiency of management, but the ability of financing is weak, the operation is complex and the resistance ability of risk is poor. The third type is the combination of the two modes above. In this mode, the government still plays an important role and the marketization is introduced into the infrastructure investment. This mode is widely used among the international. Such as Public–Private Partnership (PPP), Transfer–Operation–Transfer (TOT), Asset–Backed–Securitization (ABS), etc. On the one hand, this mode can increase the ability of financing and resistance of risk through the government's good credit and high reliability. On the other hand, this mode can utilize the private enterprise's abundant capital, advanced technology and efficient management experience to ease the government's financial pressure and improve the management efficiency. However, this mode also has two major disadvantages. First, the risk factors are relatively more complex than other modes. Especially in recent years, the actual cost is always more than the budget and the traffic forecasts are usually higher than the actual traffic demands. Therefore, it's important to find an effective method to analyse the risk factors. Second, the participants are more diversified than other modes. Therefore, how to establish an effective risk and benefit sharing mechanism is critical to the investors. If the private sector takes too much risk, it will reduce the interest of the private enterprise to invest.

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If the government takes too much risk, it will increase the government's financial burden.

Traditionally, the investors used the Discount Cash Flow (DCF) analysis approach to make project valuation and decision making. If the calculated Net Present Value (NPV) is less than zero, they would give up. Otherwise, they would invest. However, this method assumes that the future cash flows are certain, which goes against the analysis of the risk sharing mechanism. Some scholars proposed to use Monte Carlo simulation method. Compared with the other risk analysis methods, the greatest advantage of Monte Carlo simulation method is that its convergence speed will not be affected by the dimensions of the risk factors. Because PPP highways have many uncertain factors, Monte Carlo method will be more suitable. In recent years, some scholars use Monte Carlo method and real options combined for developing the risk sharing mechanism and decision making in the public-private projects. Park *et al.* (2012) used Monte Carlo method to analyse risk sharing measures and presented a real option-based contract model to make agreement on the value of the project. Zhao *et al.* (2004) proposed a real options model to achieve decision-making optimality, which used the Monte Carlo simulation method to analysis the uncertainty. Garvin (2005) proposed that the real options analysis can help both the public leaders and private participants in designing more effective project execution and risk management strategies for various participants. Kim *et al.* (2010) proposed an analytics framework based on real option and Monte Carlo simulation for deciding on a new construction market entry. Almassi *et al.* (2012) proposed to use FDM (Finite Difference Method) to examine contractual configurations and assists governments to design a guarantee in the PPP projects, however, the performance of FDM will be diminished when the risk factors exceed 4.

Recently, some scholars put forward using the policies of Minimum Revenue Guarantee (MRG) and Toll Revenue Cap (TRC) for risk management (Ashuri, Kashani 2011), which are similar to the call option and put option respectively. The main rules are as follows: if the project's actual annual revenue is less than the MRG, the government will make up for the loss; if the project's actual annual revenue is more than the TRC, the government will share the surplus revenue. MRG and TRC are effective policies for the risk and benefit sharing. Mandri-Perrott (2006) proved that the measures of MRG and TRC not only reduced the investment risk of the private sector, but also alleviated the government›s financial burden. Ashuri *et al.* (2012) indicated that the private sector can use the model of MRG and TRC to make better entry decisions to BOT highway projects considering the level of support provided by the government. Meanwhile, the government can use the model to identify the appropriate MRG levels to encourage private investments without comprising future budgetary strength. However, the previous research determined the values of the MRG and TRC subjectively and did not consider the rationality. Actually, the rationality of the MRG and TRC marginal coefficients are related to the fairness of risk and benefit sharing among the investors. Eg, if the marginal values of MRG and TRC make too low, it may reduce the benefit and increase the risk of the private enterprise. If the marginal values of the MRG and TRC make too high, it may reduce the benefit and increase the risk of the government.

In order to find the Pareto optimal marginal values of the MRG and TRC, evolutionary algorithms have been widely used to solve this optimization problem. Such as the genetic algorithm, simulated annealing algorithm, ant colony algorithm, etc. In this paper, the scatter search algorithm is proposed which is an effective meta-heuristic algorithm introduced by Glover in 1977. Unlike the other evolutionary algorithms, scatter search algorithm provides the unifying principles for joining solutions based on generalized path construction in Euclidean space where other approaches resort to randomization (Laguna *et al.* 2003). So the solution set of the scatter search is smaller and with high quality. Recently, scatter search algorithm is widely used for solving many optimization problems. Garci-Lopez *et al.* (2003) developed three parallelization algorithms based on the scatter search and tested them on the p-median problem. Chiang and Russell (2006) used scatter search to solve the vehicle routing problem with time windows. Walton (2010) presented a hardware implementation on a Field Programmable Gate Array (FPGA). The main principle is based on the optimization application of scatter search to solve the knapsack problem. Nebro *et al.* (2008) proposed a hybrid metaheuristic algorithm which follows the scatter search structure to solve multi-objective optimization problems. Compared with the optimizers of Non-dominated sorting genetic algorithm II (NSGA-II) and Strength Pareto Evolutionary Algorithm 2 (SPEA2), the proposed algorithm outperforms concerning the diversity of the solutions and the hypervolume metric. Laguna and Marti (2005) tested the merit of several scatter search designs compared with the genetic algorithm for global optimization of multimodal functions. They proposed that the solutions of scatter search algorithm have a good convergence and distribution, and the calculated result shows that the scatter search algorithm is robust.

The main purpose of this article is to propose an approach that will realize Pareto optimal state for different investment partners. The next section describes the traditional DCF method and points out its limitations. Then, put forward the combined method of Monte Carlo simulation method and the scattered search algorithm to solve the optimization problems. The third section applies the approach mentioned to analyse a PPP highway project of Zhejiang province. The fourth part gives conclusion and future work.

2. The proposed methodology

2.1. The discount cash flow method

Traditionally, the investors evaluated a highway project using the Discount Cash Flow (DCF) method. The first step of this method is predicting the future cash flows during the period of the project. The second step is selecting an appropriate discount rate and then converting the future cash flows into the present values. The discount rate is calculated by using the Weighted Average Cost of Capital (WACC) model. For highway construction project, the cash outflows are mainly the construction cost and operation cost, the cash inflows are mainly the toll revenue and other revenues. The formula of the NPV is as follows:

$$NPV = -\sum_{i=1}^{n} \frac{CC_i}{\left(1+r\right)^i} + \sum_{j=n+1}^{N} \frac{\left(OR_j - OC_j\right)}{\left(1+r\right)^j}, \quad (1)$$

where n – length of construction period, in years; N – the evaluation period, in years; CC_i – the annual construction cost in year i, EUR; i – 1, 2 …n, in years; OR_j – the annual revenue during the operation period in year i, EUR; j – n+1, n+2…N, in years; OC_j – the annual costs of operation, maintenance and rehabilitation, EUR; r – the discount rate.

The financing structure of the PPP highway projects is complicated and there are many risks. The traditional DCF method assumes that the future cash flow is sure, which is not conducive to the risk management. Therefore, this paper uses the Monte Carlo simulation method to analyse the risk factors on the basis of the NPV model.

2.2. Monte Carlo simulation

The main risk factors of the highway projects are construction cost and traffic volume. The distribution form of the construction cost is fitted by the history data. If the sample is not insufficient, the Delphi method and expert advice method is used. The construction cost usually obeys the triangular distribution and beta distribution. The revenue is mainly subjected by the toll rate and the traffic volume. However, the traffic volume is influenced by the economic and social development, which has a certain regularity and stability. Thus, the normal distribution to fit the distribution form of the revenue was used. Assuming the annual revenue is expressed by $P(t)$.

$$P(t) \sim \left(P(t)\, f_p(t), \left[\sigma_p P(t)\, f_p(t) \right]^2 \right), \quad (2)$$

where $P(t)f_p(t)$ – the predicted revenue in year t, EUR; σ_p – the volatility of the revenue. According to the studies by Baek *et al.* (2005), GDP fluctuation rate is an important indicator which can reflect the risk of investment. Assuming that G_1, G_2, ..., G_n are the national income level per capita in the last n years. Then, the fluctuation coefficient can be calculated by the formula as follows:

$$\sigma = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}\left(x_i - \bar{x}\right)^2},\ x_i = \ln\frac{G_i}{G_{i-1}},\ \bar{x} = \sum_{i=1}^{n} x_i. \quad (3)$$

2.3. Scatter search algorithm

Scatter search is an evolutionary method and has been widely used by solving the optimal problems. The main principle of scatter search is as follows:

1. Generate the diverse solutions as an input.

2. Transform the trial solution into one or more enhanced trial solutions through some optimization methods.

3. Choose solutions according to the quality and diversity and then put them in the reference set (the size of the reference set is no more than 20).

4. The reference set is used to generate new solutions through combining and updating operations until the reference set is no longer changed or satisfied the criteria (Marti *et al.* 2006).

In this paper the scatter search algorithm to calculate the optimal marginal values of the MRG and TRC under different objective functions is used. Where the ratio of the MRG and the predict revenue represents the marginal coefficient of the MRG, so as the TRC. Generally, the mean and the median of the NPV represent the return; the standard deviation and variance represent the risk are used. These are helpful to find Pareto optimal state by comparing the parameters of NPV under different cases.

In this paper the main steps are as follows:

1. Establish the objective functions.

$$\min(\text{or}\ \ \max) f_l(\vec{x}), \quad (4)$$

where $f_l(\vec{x})$ – l_{th} objective; $\vec{x}$ – vector of decision variables (x_1, x_2), which represent the marginal coefficients of the MRG and TRC respectively.

In this paper, six objective functions, which are mainly from the standpoint of different investment partners and overall situation were established. Objectives 1 and 2 represent when the return and risk parameters of the concessionaire's NPV reach the optimal state respectively. Objectives 3 and 4 represent when the return and risk parameters of the government's NPV reach the optimal state respectively. Objectives 5 and 6 represent when the return and risk parameters of the total NPV reach the optimal state respectively.

2. Define the input variables.

Generally, the input variables represent the risk factors of the highways, which include the construction cost, the traffic volume etc.

3. Define the output variables.

The output variables include the government's NPV, the concessionaire's NPV and the total NPV.

4. Optimization.

When the solution set reach the optimization criteria or the number of iterations is sufficient, the algorithm is terminated.

3. The case study

In this paper, a highway in Zhejiang province as an example was taken. The highway is financed by the private sector according to a BOT contract. In order to predict the future cash flows of the new highway project and apply the proposed approach, the eleven-year data of the existing highway system in Zhejiang province during

2000–2010 are collected. The data items mainly covered the unit rates of construction, rehabilitation and maintenance; annual average daily traffic and growth rates; discount rate, loan rate, the government subsidies etc. According to the forecast results, the investment of a highway

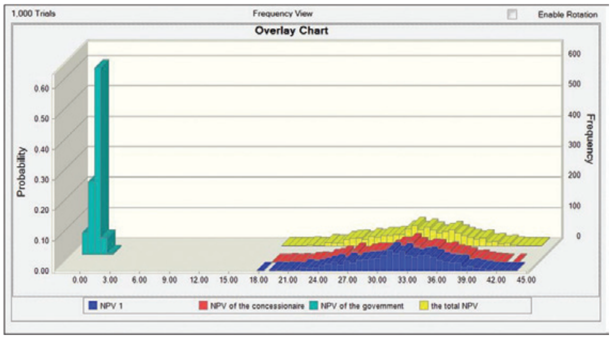

Fig. 1. The probability distribution of the NPV with and without MRG and TRC (in million EUR)

Table 1. The statistical parameters of the NPV with and without MRG and TRC (in million Eur)

Statistic	NPV1	NPV2		
		concessionaire	government	total
Base Case	31.47	31.47	0.00	31.47
Mean	29.51	29.55	–0.16	29.39
Median	29.91	29.88	–0.04	29.69
Standard Deviation	4.21	4.15	0.44	4.25
Variance	17.77	17.19	0.19	18.09
Coefficient of Variability	0.14	0.14	–2.79	0.14
Minimum	17.16	16.81	–2.35	16.88
Maximum	40.52	41.30	1.44	42.16
Mean Standard Error	0.13	0.13	0.01	0.13

Table 2. Comparison with the optimal values of the MRG and TRC under different objectives

Objectives		Optimal solution	
		x_1	x_2
Objective 1	maximize the mean of the concessionaire's NPV	1.00	1.50
Objective 2	minimize the variance of the concessionaire's NPV	1.00	1.00
Objective 3	maximize the mean of the government's NPV	0.50	1.00
Objective 4	minimize the variance of the government's NPV	0.75	1.25
Objective 5	maximize the mean of the total NPV	0.50	1.00
Objective 6	minimize the variance of the total NPV	0.68	1.33

project is 152.6 million EUR, the construction period is three years and the operation period is twenty years. The sales tax rate is 3.3% and the income tax rate is 25%. The discount rate is 5.6%. The annual growth rate of maintenance and management cost is 5%. Assuming that the construction cost meet the triangular distribution form, the minimum is 144.91 million EUR and the maximum is 167.8 million EUR. The annual revenue meet the normal distribution form, the mean μ is the predicted toll revenue; the volatility σ is 6.2%, which is calculated according to the historical Gross Domestic Product data from 1978 to 2009. In the contract the compensation policy of the government is as follows:

$$\text{Case1}\ \ \text{APR} < \text{MRG}\ \ \textit{Payoff} = \text{MRG} - \text{APR}; \qquad (5)$$

$$\text{Case2}\ \ \text{MRG} \le \text{APR} \le \text{TRC}\ \ \textit{Payoff} = 0; \qquad (6)$$

$$\text{Case3}\ \ \text{APR} \ge \text{TRC}\ \ \textit{Payoff} = (\text{APR} - \text{TRC})k, \qquad (7)$$

where APR – actual predicted revenue; *Payoff* – the subsidies from the government to the private sectors; k – the proportion coefficient of the surplus revenue given to the government.

Supposing that the marginal coefficient of MRG is 0.9, the TRC is 1.1 and the k is 0.5, NPV1 represents the concessionaire's NPV without MRG and TRC. NPV 2 includes the government's NPV, the concessionaire's NPV and the total NPV, which are calculated with MRG and TRC simultaneously. The total NPV is the sum of the concessionaire's NPV and the government's NPV. Then the Monte Carlo risk simulation was run, the simulation times were 1000 and the results are shown in Fig. 1 and Table 1.

According to the statistics in Table 1, from the point of return, the mean and the median of NPV1 is less than the concessionaire's NPV and greater than the total NPV. From the point of risk, the Standard Deviation, Variance, Coefficient of Variation and Average Standard Error of NPV1 is greater than concessionaire's NPV and less than the total NPV. Therefore, the MRG and TRC policy helps the concessionaire share a proportion of risk and improve its investment value. However, the return of the total NPV decrease and the risk increase compared with NPV1, which is not satisfied with the Pareto requirements.

4. Results analysis

In order to achieve Pareto optimum, this paper adopts the method combined with the Monte Carlo risk simulation and scatter search algorithm. Then uses the OptQuest tool of the Crystal ball software to analyse the optimal values of the MRG and TRC under different objectives, which is a general-purpose optimizer that based on the scatter search methodology. Assuming that the decision variables x_1 and x_2 are satisfied $0.5 \le x_1 \le 1.0$; $1.0 \le x_2 \le 1.5$. The results under different objectives are shown in Table 2 and Fig. 2.

This part mainly analyses the statistics of the six objectives and the influence on the investment partners is presented. The statistics in Tables 3–5 are the summary of the statistics, which depict the influence on the

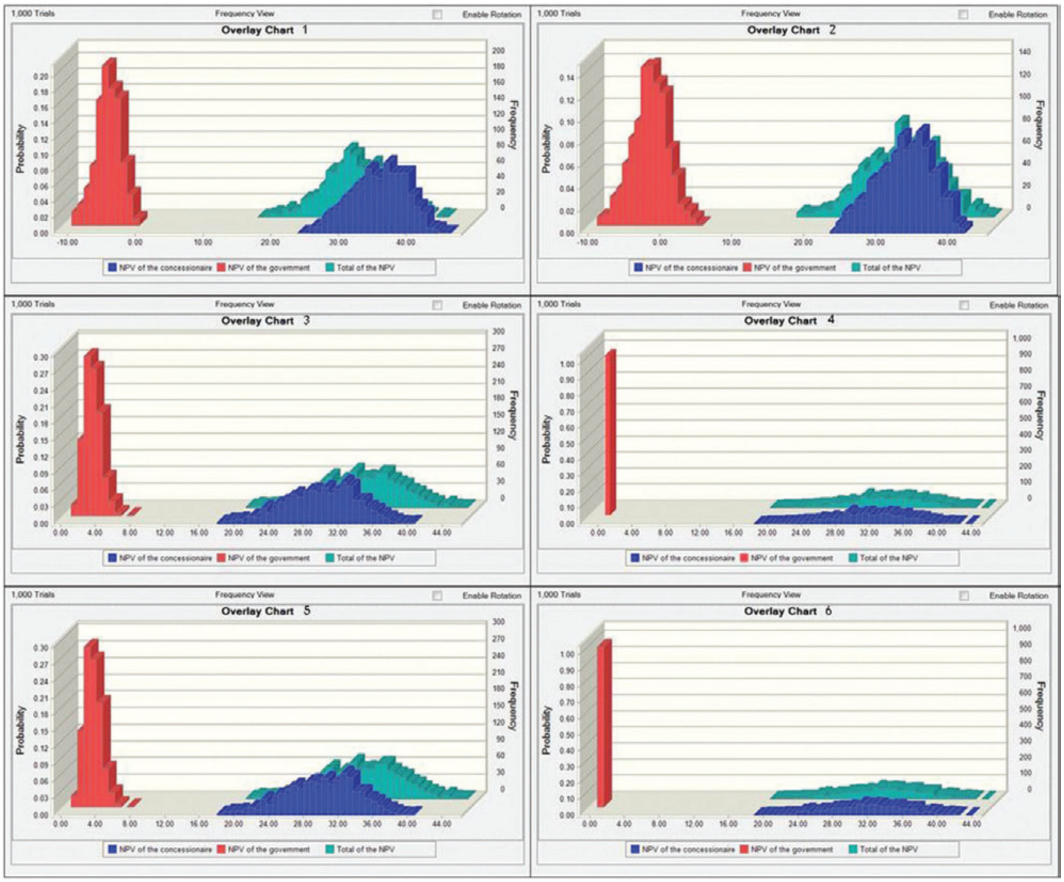

Fig. 2. The probability distribution of the NPV under different Objectives (in million EUR)

Table 3. Comparisons of the concessionaire's NPV under different cases (in million EUR)

NPV of the concessionaire	Base Case	Mean	Median	Standard Deviation	Variance	Coefficient of Variability	Minimum	Maximum	Mean Standard Error
NPV1	31.47	29.51	29.91	4.22	17.77	0.14	17.16	40.52	0.13
NPV2	31.47	29.55	29.88	4.14	17.19	0.14	16.81	41.30	0.13
Objective 1	31.47	33.20	33.41	3.71	13.77	0.11	23.03	43.39	0.12
Objective 2	31.47	31.42	31.63	3.56	12.67	0.11	22.23	38.90	0.11
Objective 3	31.47	27.79	28.07	3.81	14.52	0.14	17.12	37.72	0.12
Objective 4	31.47	29.64	29.77	4.06	16.49	0.14	17.22	41.99	0.13
Objective 5	31.47	27.79	28.07	3.81	14.52	0.14	17.12	37.72	0.12
Objective 6	31.47	29.70	30.07	3.98	15.89	0.13	18.24	40.81	0.13

Table 4. Comparisons of the government's NPV under different cases (in million EUR)

NPV of the government	Base Case	Mean	Median	Standard Deviation	Variance	Coefficient of Variability	Minimum	Maximum	Mean Standard Error
NPV1	0.00	0.00	0.00	0.00	0.00	–	0.00	0.00	0.00
NPV2	0.00	–0.16	–0.04	0.44	0.19	–2.79	–2.35	1.44	0.01
Objective 1	0.00	–5.01	–4.94	1.74	3.03	–0.35	–12.62	–1.03	0.06
Objective 2	0.00	–2.58	–2.50	2.33	5.41	–0.90	–11.10	4.37	0.07
Objective 3	0.00	2.49	2.46	0.87	0.77	0.35	0.32	6.86	0.03
Objective 4	0.00	0.00	0.00	0.00	0.00	–	0.00	0.00	0.00
Objective 5	0.00	2.49	2.46	0.87	0.77	0.35	0.32	6.86	0.03
Objective 6	0.00	0.00	0.00	0.00	0.00	–	0.00	0.00	0.00

Table 5. Comparisons of the total NPV under different cases (in million Eur)

NPV of the concessionaire	Base Case	Mean	Median	Standard Deviation	Variance	Coefficient of Variability	Minimum	Maximum	Mean Standard Error
NPV1	31.47	29.51	29.91	4.22	17.78	0.14	17.16	40.52	0.13
NPV2	31.47	29.39	29.69	4.25	18.09	0.14	16.88	45.30	0.13
Objective 1	31.47	28.18	28.01	4.28	18.33	0.15	14.82	43.17	0.14
Objective 2	31.47	28.84	29.00	4.48	20.04	0.16	15.70	44.14	0.14
Objective 3	31.47	30.29	30.42	4.16	17.31	0.14	18.27	45.86	0.13
Objective 4	31.47	29.64	29.77	4.06	16.47	0.14	17.22	45.12	0.13
Objective 5	31.47	30.29	30.42	4.16	17.31	0.14	18.27	45.86	0.13
Objective 6	31.47	29.70	30.07	3.98	15.87	0.13	18.24	43.85	0.13

government, the concessionaire and the total NPV under different cases.

According to the statistics in Table 3, the concessionaire's NPV under Objectives 1 and 2 are superior to other cases. The mean and the variance of the concessionaire's NPV reaches their optimal state respectively. However, the statistics in Tables 4 and 5 presents that the government's NPV and the total NPV under Objectives 1 and 2 are worse than other cases. The government takes too much risk and financial burden, which cause the mean of the total NPV to decrease and the variance to increase.

Similarly, according to the statistics in Table 4, the statistics of the government's NPV under Objectives 3 and 5 are the same and higher than other cases. Compared with the NPV1, the variance of the concessionaire's NPV and the total NPV are reduced, but the mean of the concessionaire's NPV is also decreased. This is because on the one hand, the government gives the concessionaire minimum income guarantee, which reduces the risk of the concessionaire. On the other hand, the marginal coefficients of the MRG and TRC are low, which result in lower revenue to the concessionaire.

In Objectives 3 and 5 the mean and the variance of the total NPV are superior to NPV1 and NPV2, and the variance of the concessionaire's NPV is lower than NPV1 and NPV2. But the mean of the concessionaire's NPV is the lowest among all of the circumstances. This is because on the one hand, the government gives the concessionaire minimum income guarantee, which reduces the risk of the concessionaire. On the other hand, the marginal coefficients of the MRG and TRC are low, which result in lower revenue to the concessionaire.

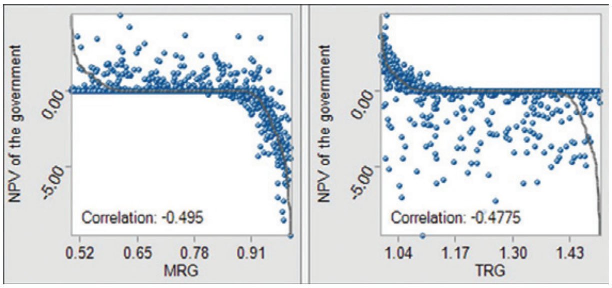

Fig. 3. The correlation scatter diagram (in million EUR)

Therefore, Objective 1, 2, 3, and 5 are not desirable. That is because Objective 1, 2, 3, and 5 only consider the unilateral interests. However, a balancing of all factors is not attainable at the same time, a giving up of one thing always in return for another.

Then, compare the statistics of the NPV under Objective 4 with Objective 6, Table 3 shows the mean of the concessionaire's NPV under Objective 6 is higher than Objective 4 and the variance is lower than Objective 4. In Table 4 all of the parameters of the government's NPV under Objective 4 and Objective 6 are zero. Therefore, the statistics of the total NPV under Objective 4 and Objective 6 in Table 5 are the same with the statistics in Table 3. In conclusion, the statistics of the NPV under Objective 6 are superior to Objective 4 from the standpoint of the investors.

Finally, compare the statistics of NPV under Objective 6 with NPV1 and NPV2, Tables 3–5 show that the mean under Objective 6 is higher than NPV1 and NPV2 and the variance is lower than NPV1 and NPV2. Therefore, it was summarized that the parameters of the NPV under Objective 6 conform to Pareto optimality conditions, which provide a win-win situation for all related parties.

In addition, it has been discovered that the parameters of the NPV under Objectives 3 and 5 are the same, which indicates that the government's NPV is sensitive to the marginal coefficients of MRG and TRC. So the sensitivity analysis to the government's NPV was made too. According to the results, the marginal coefficients of the MRG and TRC have great relevance with the government's NPV (Fig. 3).

5. Conclusion and future work

Public-Private Partnership projects have many special features, such as: the financing structure is complex, the involved parties are diversified, etc. Therefore, it is important to distribute the financial risk reasonably through the contractual agreements. The Minimum Revenue Guarantee and Toll Revenue Cap policies are effective measures to share the risk and benefit, which can help reduce the risk of private sector and alleviate the government's financial burden. However, the government's Net Present Value is sensitive to the marginal coefficients of the Minimum Revenue Guarantee and Toll Revenue Cap. If the marginal coefficients are not reasonable, it may cause the investors especially the government to take too much risk and financial burden unilaterally. Therefore, this paper compares the results under different objectives and concludes that when the objective is minimizing the variance of the total Net Present Value, the investors will realize the Pareto optimal state between the return and risk. This model has a certain effect onr improving the benefit sharing mechanism and risk management. Future work should consider the risk factors more comprehensively, improve the traffic volume forecasting accuracy and do more research of the other risk sharing mechanism.

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