Simulation model for the coordination of environmental and economic interests

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Abstract. The purpose of the work is to develop a simulation model that could be used as the basis for a practical methodology for forming a 'green' program for the development of mining industry. For this purpose, the Stackelberg model and the apparatus of two-level mathematical programming are used and thus take into account the peculiarities of the hierarchy of interaction between the state and the private investor in the mineral resource sector. The obtained data make it possible to determine the quantitative parameters of expenditures of public financial resources, at which the target function of the state reaches its maximum. It is concluded that the strategy of choosing higher operating costs and, as a result, lower post-project environmental losses is preferable for both the state and the investor.

1. Introduction

The formation of mechanisms to stimulate private investment and the assessment of their effectiveness is still an unresolved task for the Russian state. The well-established practice of making such decisions in subsoil use operates mainly with political arguments and the simplest assessments of the effectiveness of decisions made, based on an analysis of technological projects and current raw material prices. In addition, the variety of situations in which the use of public financial resources is necessary for success is often overlooked. This explains many of the failures in the implementation of public-private partnership (PPP) projects. Additional difficulties arise when it is necessary not only to create the basic infrastructure – without this it is impossible to achieve an acceptable level of return on private investment - but also to solve a number of social and environmental problems that inevitably arise when a new production is created in a sparsely populated and undeveloped territory.

In the regions of Siberia and the Far East, during the implementation of mineral and raw materials projects, new environmental risks arise, associated with a multiple increase in the negative impact on the environment. An increase in the population permanently and temporarily residing in a given territory also leads to additional environmental costs, an increase in the volume of municipal waste and effluents, and a general degradation of local ecosystems. This must be taken into account when forming a program for the development of the mineral resource base. In many cases, it is necessary to create an environmental protection infrastructure practically from scratch. Within the framework of such a program, it is necessary to decide what kind of industrial infrastructure is needed for the development of the territory and attracting investors, and whether it is possible to spend additional
budgetary funds to help the investor in infrastructure and environmental construction [1]. This formulation of the question is used in planning PPPs in some developing countries [3].

In this regard, it is necessary to find answers to a number of questions at the pre-project stage. How can an investor be helped to overcome the barriers of lack of the necessary infrastructure and high level of environmental costs, which are so characteristic of most of the Siberian and Far Eastern regions of Russia? What should be the mechanism for stimulating private investment, combining various measures of the state’s investment policy and forming the basis of the program for the development of the natural resources of the territory? How do the environmental factors influence the formation of this mechanism? These problems are the focus of this work. The purpose of the article is to develop a model that could be used as the basis for a practical methodology for the formation of a ‘green’ program for the development of mining industry.

This article continues the research of the authors on the problems of cooperation between the state and the private investor in the mineral sector [4, 5]. In these works, it was the Russian version of partnership (in which only the state was building the infrastructure) that was investigated. Here we are trying to explore possible ways of transforming the Russian PPP model, using the funds of the Investment Fund of the Russian Federation, in the direction of classical forms of partnership. For this, it is assumed that both partners can participate in both infrastructure and environmental construction.

2. Data and methods
We propose to use the Stackelberg model and the apparatus of two-level mathematical programming and thus take into account the peculiarities of the hierarchy of interaction between the state and the private investor in the mineral resource sector [4, 5]. This approach allows us to find a compromise between the interests of the budget and the private investor and to form a program for the development of the natural resource complex that is effective from the point of view of sustainable development prospects.

The basic version of the proposed model is described in the work [1]. In the model, the quality of the investment climate is determined by the discount rates of the investor and the state. We will assume that favorable investment conditions are described by the pair A={DG=0.01; DI=0.11}, and the current investment climate in resource regions with a high level of transaction costs and unfavorable macroeconomic conditions is described by the pair B={DG=0.05; DI=0.15}. (Here DG is the state discount rate; DI is the investor’s discount rate).

It is advisable to divide the costs of the state and the investor in connection with the negative impact on the environment into current costs, for which the ZE designation is used in the model, and the costs necessary to neutralize environmental losses after the project implementation – EPP. In the case of SME development projects, the latter can include land reclamation, subsequent care of restored plots, etc. In some cases, it is important to take into account the neutralization of dangerous and especially dangerous substances, the emission of which may be insignificant in some cases each year, but as a result of accumulation can lead to damage of catastrophic proportions. Therefore, it is necessary to provide large intervals for the EPP parameter in the model. The ZE parameter depends mainly on the degree of environmental friendliness of the technologies used by the investor – both industrial and environmental. The best technologies require, as a rule, high costs. Therefore, it is important that the investor is placed in a regulatory (on the part of the state) framework that does not allow him to succumb to the temptations of saving on environmental measures. For exporters to the European Union, one of these tools will probably be the Carbon Border Adjustment Mechanism [6].

Let us denote by \(NP, NI\) and \(NE\) – the number of production, infrastructure and environmental projects, \(T\) – the planning horizon; \(ZI_{jt}, ZE_{kt}\) – the budget cost schedule for infrastructure and environmental projects, respectively, \(DBP_{jt}\) – budget revenues, \(VDI_{jt}\) – non-project (related to the general development of the territory’s economy) budget revenues from the implementation of the project \(i\) in the year \(t\) from; \(W_{i}\) – the schedule of compensation by the state for the investor’s infrastructure costs. When we talk about compensation by the state for costs, we mean financial
resources that can be allocated for these purposes from state budgets and funds, i.e. the use of public finance. Considering the state as an economic agent at the disposal of these finances, and designed to ensure the interests of society, we will continue to use the term ‘objective function of the state’ Integer variables \( x_j, y_k, z_i, u_j, v_j \) are equal to 1 or 0, depending on whether the corresponding project is being implemented or not.

The interrelation of projects is described by the following Boolean variables:

- \( \mu_{ij} \) – the indicator of technological connectivity of production and infrastructure projects, equal to 1, if the implementation of the production project \( i \) requires the implementation of the infrastructure project \( j \), and equal to 0 in the opposite case;
- \( \nu_{ik} \) – an indicator of the connectivity of production and environmental projects, equal to 1 if the implementation of the production project \( i \) entails the need to implement the environmental project \( k \), and equal to 0 in the opposite case.

The task of the state as an economic agent can be represented by a formula that provides for maximizing all the benefits of the state (in value terms) from the implemented projects, including multiplicative effects, taking into account all the costs of public finance:

\[
\begin{align*}
T \sum_{t=1}^{T} \left( \sum_{i=1}^{NP} (DBP_{it} - EPP_{it})z_i + \sum_{j=1}^{NI} (VDI_{\mu_j} - EPI_{\mu_j})(x_j + v_j) - \right. \\
- \sum_{j=1}^{NI} ZI_{\mu_j}x_j - \sum_{k=1}^{NE} ZE_{kl}y_k - W_t \left( 1 + DG \right) \Rightarrow \max 
\end{align*}
\]

under the conditions that:

\[
\sum_{t=1}^{T} \left( \sum_{i=1}^{NP} CFP_{\mu_i} z_i - \sum_{l=1}^{NE} ZE_{il} u_l - \sum_{j=1}^{NI} ZI_{\mu_j} v_j + W_t \right) / (1 + DI) \Rightarrow \max 
\]

(1)

under the conditions that:

\[
\sum_{t=1}^{T} \left( - \sum_{j=1}^{NI} ZI_{\mu_j} x_j + W_t \right) / (1 + DI) \geq 0
\]

(5)

\[
\sum_{t=1}^{T} \left( - \sum_{i=1}^{NP} CFP_{\mu_i} z_i + \sum_{l=1}^{NE} ZE_{il} u_l + \sum_{j=1}^{NI} ZI_{\mu_j} v_j - W_t \right) \leq \sum_{t=1}^{T} \sum_{l=1}^{NE} Budl_t, \quad \omega = 1, \ldots, T,
\]

(6)

Here, conditions (5) and (6) guarantee compensation for the costs of infrastructure and environmental projects implemented with the support of the state.

3. Results and discussion

In the course of numerical experiments, two variants were recorded that characterize the quality of the investment climate (A or B). The model also provides for the possibility of multiplying the scale of
costs and losses, simulating the increase in the level of costs for nature protection and the consequences of using increasingly ‘dirty’ mining technologies.

Figures 1 and 2 show the dependence of the target function of the state and private investor on the environmental parameters of the model. The state reacts mainly to the increase in the scale of pollution – this is how its functional is arranged (1). The speed of such a reaction depends on the investment climate – in conditions A, the upper half of the range of functional values corresponds to the entire range of cost scale values that used relatively ‘clean’ mining technologies. In both variants, the calculations demonstrate a high sensitivity of the target function of the state to the quality of technologies. The benefits of the society may differ by 2-3 times, depending on whether they require high or low environmental costs. Therefore, it is important that state environmental institutions use not only economic, but also administrative regulatory tools that do not allow the use of deliberately dirty and outdated, but cheap technologies.

![Figure 1](image1.png)

**Figure 1.** The objective function of the state. A is a favorable investment conditions, described by the pair \(A = \{DG=0.01; DI=0.11\}\), B is the current investment climate in resource regions, described by the pair \(B = \{DG=0.05; DI=0.15\}\).

The investor’s sensitivity to environmental costs is also high. In conditions A, with an increase in environmental costs, the investor loses in efficiency (determined by the value of the objective function (4)) at an almost constant rate. With the increase in the scale of environmental losses of the EPR, the value of the investor’s functional forms a step (Figure 2). In this case, it can also be argued that the strategy of choosing higher current ZE costs and, consequently, lower environmental losses of the EPP is preferable [2]. For the worst investment conditions of option B, the investor’s target function is mainly affected by the level of ZE costs, and the dependence on EPP becomes more complex. At the same time, calculations show that the investor’s benefits are dramatically reduced when the investment climate worsens, rather than from an increase in environmental costs. This circumstance may cause the project to be abandoned, especially under the conditions of strict environmental regulation by the state.

![Figure 2](image2.png)

**Figure 2.** The investor’s objective function. A is a favorable investment conditions, described by the pair \(A = \{DG=0.01; DI=0.11\}\), B is the current investment climate in resource regions, described by the pair \(B = \{DG=0.05; DI=0.15\}\).
4. Conclusion
Calculations have shown that the main task of the state in the poorly developed resource territory in the process of forming an investment policy is to select agreed strategic plans for the creation of infrastructure and the implementation of environmental protection measures. The obtained data make it possible to determine the quantitative parameters of the expenditure of public financial resources, at which the target function of the state reaches the optimal level, that is, when its participation can bring the best results. The investment climate that has developed in the territory determines the institutional features of such a choice. It is based on interrelated procedures for cost allocation and mutual settlements, the effectiveness of which is determined by the level of mutual trust between the state and the investor. If such a level of trust is achieved, then the proposed mathematical tools allow us to form an investment policy that is effective in the long term. The simulation results made it possible to identify the hidden risks of income reduction, quantify the differences in the effectiveness of projects for both the investor and the state under different investment conditions and a wide range of necessary environmental costs. It is concluded that the strategy of choosing higher current costs and, consequently, lower post-project environmental losses is preferable for both the state and the investor.

A high degree of uncertainty and the presence of a large number of factors affecting the results of the project implementation require a sufficiently detailed forecast, which is practically impossible without the use of simulation mathematical models and a scenario approach.

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References
[1] Glazyrina I P and Lavliskii S M 2018 J. New Econ. Assoc. 2 121–43
[2] Glazyrina I and Chavkin A 2021 E3S Web of Conf 08003. 258
[3] Lall S V 1999 Economic and Political Weekly 34 717–25
[4] Lavinskii S M, Panin A A and Plyasunov A V 2015 Automation and remote control 76 1976–87
[5] Lavinskii S M, Panin A A and Plyasunov A V 2016 J. Appl. Ind. Math. 10 356–69
[6] Marcu A, Mehtling M and Cosbey A 2020 Border carbon adjustments in the EU: issues and options ERCST 68 p Retrieved from: https://ercst.org(border–carbon–adjustments–in–the–eu–issues–and–options