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Optimizing Concession Agreement Terms and Conditions: Stakeholder Interest Alignment in the Petrochemical Sector

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Abstract: This article is devoted to the examination of models and the selection of optimal parameters for concession agreements pertaining to construction and operation projects within the pipeline infrastructure of the petrochemical sector. Pipelines are underscored as capital-intensive assets crucial for the organization of complex petrochemical production processes. These processes play a vital role in generating added value, tax revenue, employment opportunities, and fostering territorial development while upholding environmental quality standards. This study aims to ascertain the economic parameters of concession agreements, with a focus on achieving a balance of economic interests between the government and businesses. Through a comparative analysis of fundamental economic and mathematical models of concession agreements, the authors model economic parameters to determine the government's share in investments and concession fees concerning pipeline projects. Subsequently, an oil product pipeline project is discussed as a case study. The results gleaned from this analysis can be harnessed to optimize the parameters of concession agreements and enhance the economic efficiency of project implementation. Economically viable parameters not only facilitate the execution of concession agreements but also foster the generation of added value, social benefits, and environmental oversight, thus aligning with the principles of sustainable development.

Keywords: public–private partnership; concession agreement; petrochemical sector; procedural-transport infrastructure; government incentive

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1. Introduction

Infrastructure projects across the economy should prioritize achieving socially significant goals and public benefits, while simultaneously striving for optimal economic outcomes within environmental constraints. Such objectives align with the conceptual principles of sustainable development.

The execution of capital-intensive infrastructure projects involves a variety of collaborative frameworks between the government and private enterprises. Within the spectrum of public–private partnerships (PPPs), concession agreements (CAs) have emerged as a highly developed mechanism. However, the intricacies of different sectors and projects necessitate adaptations to the conditions of national economies. Notably, CAs pertaining to transport and social infrastructure projects, oriented towards satisfying consumer (retail) demand for services, have received more comprehensive attention (Lv et al. 2020). The primary aim of such projects is to operate infrastructure facilities to provide public goods, concurrently fostering job creation, territorial development, and enhancing tax revenue. Despite entailing significant risks, such agreements are used in the construction of highways, airports, and medical centers. Conversely, there is a dearth of research on CAs for projects catering to industrial consumers, including ports, railways, and pipelines (Ashuri et al. 2012; Swanson and Sakhrani 2020).

The objectives of such projects also encompass providing production services, which may yield additional economic benefits such as multiplier and agglomeration effects, alongside generating societal benefits such as new employment opportunities, territorial development, and increased tax revenue. It is noteworthy that contemporary technical design standards mandate an evaluation of the environmental and social implications of the project (Helmrich et al. 2023; Jones et al. 2022). Consequently, effective CAs ensure adherence to sustainable development requirements across three key dimensions: economic, environmental, and social.

CAs need to strike a balance between national interests and those of private businesses when determining economic parameters. These parameters encompass the state and business participation percentages in project investments, the lifecycle of the concession agreement, the timeline for specific benefits, applied interest rates, concession payments to the state (in the form of concession fees), and government compensation to the concessionaire (either capital or an operating grant, or a minimum guaranteed return). Evaluation of these economic indicators (Lebedev and Cherepovitsyn 2024; Matrokhina et al. 2023; Solovyova and Cherepovitsyn 2021; Tsiglianu et al. 2023) can be performed through modeling, which enhances the precision of investment assessments, contributing to the more effective implementation of the project (Cherepovitsyn et al. 2019, 2023; Choi et al. 2020). Insufficient substantiation of the specified parameters may result in concession agreements being less effective in their implementation compared to the investment justification. This shortfall can lead to refusals that result in losses for the state, businesses, and consumers of public goods.

Halting or terminating an infrastructure project not only means failing to achieve the expected economic effects but also results in the non-receipt of public benefits and the inability to produce social effects.

The primary goal is to determine the parameters of concession agreements, taking into account the achievement of a balance of interests between the state and business in the construction and operation of pipeline infrastructure facilities in the petrochemical industry, and to test the results of the application of the author's methodology using the example of a concession agreement in Russia.

Our research objectives are outlined below:

1. Conduct a comparative analysis of the principal models of concession agreements;
2. Develop mathematical economic model and identify the weightiest economic features in order to balance concession agreements' interests;
3. Perform a comparative analysis of the results obtained for the CA and the results of the alternative approach, expressed in terms of government incentives for the private sector.

This article is organized into six sections. The introduction establishes the study's relevance, outlines goals and objectives, and presents the research methodology. Section 2 explores academic research on concession agreement models, encompassing various CA areas and objects. This includes a comparative analysis of the model types and considered concession agreement parameters. In Section 5, the authors present a methodology for determining concession agreement parameters for pipeline infrastructure, build a mathematical model, and present calculations for a specific pipeline facility in the Russian petrochemical sector. The conclusion summarizes the main findings, addresses limitations, and outlines future research prospects.

The scientific novelty of this article arises from the development of an economic and mathematical model for concession agreements in production and transport infrastructure. This model considers various input parameters and potential forms of government support, including direct and indirect regulation.

2. Literature Review

Concession agreements (CAs) between the state and businesses serve as a mechanism to ensure project service quality, facilitate co-financing of capital-intensive infrastructure by both the state and businesses, share risks, engage in joint property rights implementation, and achieve long-term operational effectiveness. Given the multifaceted nature of CA parameters in the context of evolving external conditions, the mathematical modeling (MM) of concession agreements, along with a judicious selection of parameters, becomes imperative. Uncertainty and risk in CA projects may emanate from diverse factors, including economic shifts, fluctuations in demand for concession services, legal regulations, and geopolitical factors such as sanctions or changes in key interest rates.

An exploration of literature on the topic reveals predominant approaches, such as game theory (Arkin and Slastnikov 2017; Khutoretskii and Nefedkin 2020; Kokuitseva and Yudin 2015; Mertes et al. 2023; Ouenniche et al. 2016; Shen et al. 2007; Wardhana et al. 2022), mathematical modeling (Ashuri et al. 2012; Ng et al. 2007; Nguyen et al. 2020; Sodikov and Jalilov 2019; Ye and Tiong 2003), incorporating various models, and real-option valuation (ROV) (Arkin and Slastnikov 2017; Arnold et al. 2022; Ashuri et al. 2012; Chu et al. 2017), among others. These approaches have developed methodological tools that can be extensively applied for modeling and addressing diverse economic and investment challenges.

Given that a concession agreement involves multiple entities pursuing individual objectives, game theory tools prove pivotal to facilitating optimal decision-making in interactive and informed-choice scenarios (Choi et al. 2020; Sohrabi and Azgomi 2020). The application of game theory to modeling the behavior of subjects (agents) under varying competitive (Filatova et al. 2021; Litvinenko et al. 2023) and cooperative (Cherepovitsyn et al. 2019) conditions is well-established. Accordingly, optimization parameters may include the distribution of investments among investors, contract implementation period, and concession payment parameters.

The game theory approach finds utility in evaluating the potential of the concession fee as a mechanism for stimulating private business investment in CA projects. In this scenario, the concession fee's value is selected to maximize the benefits over the CA's implementation period. This approach involves two-level optimization in modeling the economic parameters of the concession project (Arkin and Slastnikov 2017). At the lower level, the concessionaire, guided by the state-set concession fee, strives to maximize the net present value (NPV) of the project by optimizing the investment timing, which essentially means solving a time-based optimization problem. At the upper level, the grantor (government) leverages knowledge of the concessionaire's optimal behavior (NPV maximization) to determine the optimal concession agreement terms, either maximizing the benefits or optimizing the agreement terms. Thus, two-level optimization in concession projects includes optimizing the concessionaire's income (lower level) and optimizing government revenue (upper level).

Applying similar approaches is feasible for optimizing other CA parameters, such as CA duration, investment distribution between the state and businesses, and determining capital and operating grant amounts (return of capital or current costs or lost income).

The mathematical modeling of economic parameters in public–private partnership (PPP) projects involves the creation and application of mathematical models to assess and forecast financial flows and economic indicators, such as net present value (NPV) and internal rate of return (IRR), for both the overall project and individual investors. These models enable the quantification of various project implementation scenarios and the determination of optimal economic parameter values that are acceptable for both the concessionaire and the grantor.

The mathematical models employed for calculating economic parameters in CAs can vary in complexity and detail. Simple models focus on basic financial indicators such as revenue, costs, and profit. In contrast, more sophisticated models incorporate additional factors such as inflation, changes in supply and demand, and technological advancements. Simulation modeling and cost–benefit analysis (CBA) methodologies are also integral components of the modeling toolkit (Lovrenčić Butković et al. 2023).

The ROV approach involves estimating the value of an option for the right to use an asset created by the project for a specific duration, considering uncertainties and risks. Utilizing well-established ROV models that account for asset price, asset price volatility (Yusiana et al. 2023), option period, and interest rate (Mixon 2009; Sharma et al. 2024), the option value is determined. Importantly, in concession agreements, this option's cost to use the CA facility for a designated period can be incorporated into the concession fee paid by the concessionaire to the state. This approach not only allows the government to mitigate uncertainty and project risks but also generates additional income (Wang et al. 2019).

Our examination of the academic literature reveals significant variations in CA conditions across diverse economic spheres and types of objects. Many agreements exhibit individual characteristics and economic parameters, necessitating a multifaceted approach to optimizing CA parameters that can combine several tools. Integrated approaches, such as combining the game theory approach with the ROV approach (Arkin and Slastnikov 2017), or integrating the game theory approach with mathematical modeling (Shen et al. 2007), can be developed based on comprehensive assessments.

An integrated approach that combines economic and mathematical modeling with elements of the game theory approach is proposed in Shen's works. For determining the CA period, Shen et al. developed models titled the BOTCcM (Build–Operate–Transfer Contract Concession Model) and BOTBaC (BOT Bargaining Concession Model) (Shen and Wu 2005) based on the widely used Build–Operate–Transfer (BOT) model.

The BOTCcM allows for the calculation of the concession period without taking into account risks (Shen and Wu 2005), ensuring the protection of both private sector and state interests. The interval's starting point is determined by ensuring that the NPV during the concession period aligns with the investor's expected return on investment (ROI). The endpoint of the interval ensures that the NPV from the payback point to the final period is not less than zero, providing a comprehensive framework for project evaluation.

Advanced models building upon the BOTCcM have been developed to address elements of risk and incorporate the liquidation value of project assets. The BOTBaC considers the negotiation behavior of both the private and public sectors (Shen et al. 2007). Grounded in cooperative bargaining game theory, it operates on the premise that an individual's actions are contingent on the actions of other negotiators. Following the BOTCcM methodology, investors and the government engage in negotiations until a concession period is reached that harmonizes the interests of both sectors. However, criticisms by Wu et al. highlight that the BOTCcM neglects the net asset value (NAV) when the concessionaire transfers the concession item to the grantor (Wu et al. 2012). Wu and others criticized the BOTCcM because it does not consider the net asset value (NAV) at the time the concessionaire transfers the concession object to the concessionaire (Wu et al. 2012), so the concession period is more reasonably determined (Nguyen et al. 2020).

Nguyen et al. contribute an integrated model for determining the concession period of any public–private partnership (PPP) project, accounting for risks and contractual scenarios (Nguyen et al. 2020). Their article considers cost–benefit analysis, incorporating risk considerations and cash flow analysis using the decoupled net present value (DNPV) methodology for risk-adjusted calculations to identify the optimal concession period. The DNPV method introduces the concept of the risk–cost ratio, evaluating the risk associated with lower-than-expected cash flows and representing compensation to investors for undertaking such risks (Espinoza et al. 2020). Nguyen et al. advocate for the separate consideration of interest rates and risk assessments in the value-for-money analysis process to evaluate the optimal concession period. The model integrates risks affecting PPP project life cycles, contract terms, Delphi methods, and mathematical modeling for assessing the optimal concession period. This approach is envisaged as a mechanism for risk assessment and allocation, as well as determining the optimal concession period.

For greenfield ventures, Russian researchers V. I. Arkin and A. D. Slastnikov propose a modified approach rooted in the investment expectations model based on real-option theory and incorporating the game theory approach (Arkin and Slastnikov 2017). This tailored approach is particularly relevant for projects characterized by high uncertainty in cash flows due to random fluctuations in resource prices and service demand.

It is essential to note a limitation in the aforementioned approach, focusing solely on the benefits, or the difference between expected discounted revenue (taxes and concession payments) and government costs. A more holistic evaluation of concession project efficiency involves various economic, financial, social, and environmental indicators, which can be assessed using the cost–benefit analysis (CBA) methodology.

In this model, determining the parameters of the concession agreement can be likened to a Stackelberg equilibrium in the game between the concessionaire and the state (Arkin and Slastnikov 2017). The concessionaire, as the first player, focuses on the project period, while the state, as the second player, focuses on the concession fee. It is assumed that the state, as the second player, is privy to the rules guiding the first player in finding optimal solutions (for any strategies of the second player). However, employing general results from game theory in this model encounters challenges, as the proposed approach to selecting a concession fee can be tentatively labeled as government-oriented, given that the final decision rests with the state.

This game theory model, presented in Stackelberg's version (Kokuitseva and Yudin 2015), is employed in CAs characterized by consistent yet unequal interests. This model extends to PPP scenarios, which traditionally model situations where all interested partners cooperate on mutually beneficial terms. The hierarchical structure of the game positions the government as the first player, setting conditions and formulating circumstances for the project's implementation. Following the state's decision, private partners select their strategy, aiming for a maximum win for each player. After accounting for random factors, optimization problems are solved to find optimal strategic solutions in Stackelberg's sense. Subsequently, a second type of game situation arises, requiring the consideration of private partners competing with each other. Consequently, the optimal solution in this game may differ from the one obtained in the initial mathematical model.

For infrastructure projects like highway construction, Sodikov J. and Jalilov A. describe multiple models for determining the concession period and fee (Sodikov and Jalilov 2019). They introduce a Build–Operate–Transfer (BOT) concession model that factors in risks impacting the concession period (Shen and Wu 2005). Employing the Monte Carlo simulation, the average NPV and risk-adjusted NPV for various concession periods are calculated, assuming a normal distribution of variables (Ye and Tiong 2003). The obtained data inform proposed structures of concession agreement periods, project types, and a simulation model to optimize the concession period in PPP projects (Ng et al. 2007). However, these models rely on financial data developed at the project's initial stage, which poses a risk, as any alterations to such data can result in changes to real cash flows and profits (Liou and Huang 2008).

The highway concession agreement model based on the net present value of future cash flows has its limitations, including a subjective discount rate and inaccurate assessments of future traffic and project life cycles. In response, Ashuri et al. advocate for a real-option model, predicting the annual average daily traffic volume through a binomial lattice in one-month increments (Ashuri et al. 2012). Once all economic parameters are determined, a Monte Carlo simulation is applied to visualize potential cash flows along the binomial lattice.

The uncertainties and risks inherent in CAs prompt investors to seek guarantees from the government. A common example of such an assurance is the minimum revenue guarantee (MRG). This model is also applicable to Build–Operate–Transfer (BOT) projects with a limited maximum revenue (LMR). Being the opposite of maximum revenue (MR), it serves as a countermeasure to protect the state from the risk of a private partner accruing excessive profits. A model incorporating a minimum revenue guarantee (MRG) and LMR options, with revenue split when exceeding the maximum or falling below the minimum, has been proposed (Iyer and Sagheer 2011).

This model facilitates the development of various future cash flow scenarios by adjusting real-option parameters and determining the share of distributed proceeds above or below established limits. Such an approach empowers public and private partners to evaluate the impact of the MRG and LMR on the overall financial assessment of the project, with effects ranging from positive to negative. Consequently, PPP partners can strategically choose a combination that aligns with the interests of both parties, enhancing the financial attractiveness of the project. This model serves as an exemplary integration of the game theory approach and real-option theory in determining CA parameters.

Risk factors for CA projects can significantly vary across different sectors. In the context of highway construction in China, influential factors impacting costs and income under the CA include the risk of construction failure, market risk, legislative risk, force majeure, the risk of rising operating costs, inflation risk, fluctuation in the base interest rate, and the risk of the disruption of government subsidies (Sodikov and Jalilov 2019). A public partner, equipped with an understanding of these risks and their probabilities, can incorporate them when calculating the concession fee during the early stages of the PPP project. In turn, this model enables the private partner to gauge the financial attractiveness of the project.

For highway construction projects, the authors draw noteworthy conclusions (Sodikov and Jalilov 2019). They highlight that estimating the fair value of the concession fee is a multifactorial problem evolving over time, necessitating the use of probability theory and forecasting methods. The utilization of MRG and LMR options proves instrumental in adjusting and distributing risks between public and private participants. The transparency of remuneration and penalty models emerges as a critical factor in enhancing project attractiveness for both public and private participants. The adequate forecasting of average daily traffic intensity can mitigate risks and maintain project profitability.

Our analysis of the considered approaches to CA assessment leads to the recommendation of using mathematical modeling for substantiating initial economic parameters. Among the tools available, investment valuation based on discounted cash flow (DCF) method stands out, allowing for the incorporation of crucial project input parameters and ensuring equitable income distribution between the investor and the state. However, factors related to the consideration of uncertainties and risks are often overlooked or not adequately modeled.

3. Methodology

The research includes the following stages:

1. Identifying and analyzing three key approaches to modeling concession agreements concerning various objects and economic spheres (game theory, real-option valuation, and mathematical modeling);
2. Justifying the use of a model for calculating the net present value (NPV) of total income for a CA with optimal distribution between the state and businesses in pipeline infrastructure construction within the petrochemical sector, based on investment assessment models;
3. Conducting an analysis of the input and output economic parameters' pack of the CA model, along with the technical and economic parameters essential for building the model;
4. Developing a mathematical model (MM) of the CA based on the DCF method for pipeline infrastructure projects with two optimization parameters, namely the share of state participation in the CA and the amount of the concession fee, and determining the range of optimal parameter values.

Further, these actions are considered in more detail.

3.1. Justification for the Choice of Approach to Calculating a Concession Agreement

The methodology is based on the specific characteristics of concession agreements in production and transport infrastructure, as identified through a literature review. These characteristics are influenced by several factors.

1. The participants in the concession agreement are equal in rights; the principle of the hierarchy of interactions and the order (sequence) of actions when justifying the parameters of the concession agreement is not applied.

2. The grantor can provide effective monitoring and control of the concessionaire's performance, which eliminates opportunism on the part of the concessionaire.
3. The share of state participation is partly determined by the deficit of budget resources. The government strives to implement the project with a minimum share of participation that can be economically justified and will be able to provide income to the state budget while having no effect on the concessionaire. In turn, the concessionaire strives for the maximum share of state participation that will have no budget effect on the state and maximum profitability for the concessionaire.
4. The project must ensure a balance between economic interests, which is determined by the amount of the concession fee.
5. There is no guaranteed public demand for transport services, and the demand is associated with the use of specific assets of two or more entities (Williamson 1985). The key entities are refineries and large-scale petrochemical producers, and the remaining entities are other small-tonnage (often specialized) petrochemical producers. The economic efficiency of the project is determined by the value chain that encompasses oil-refining and petrochemical processes. Extra income can be generated by attracting additional participants.
6. The economic risks of projects for building pipelines between refineries and petrochemical facilities are associated with the number of facilities producing small-tonnage petrochemicals and the need to regularly shut down plants for major repairs.

The process of developing a specific partnership mechanism can be described by a number of economic and mathematical models that make it possible to assess the effectiveness of management decisions. The choice of model is determined by the characteristics identified and the content of the production and transport infrastructure project.

As there is no hierarchy in decision-making regarding the parameters of the concession agreement (decisions are made jointly by both parties) and opportunism is limited, institutional restrictions are not taken into account when choosing a model. Therefore, the use of game theory tools cannot be recommended to solve such a problem. For example, the Stackelberg model is used in sequential decision-making by the participants at various levels in order to shape and select their strategies (Lavlinskii et al. 2019; Lavlinskii and Zyryanov 2023; Shang and Aziz 2020).

Models that take into account the real-option approach can be recommended at the next stage of modeling, since they involve a larger number of participants, the formation of a larger number of strategies factoring in new opportunities, taking into account additional risks, etc. The real-option valuation complements economic valuation and improves them by taking into account additional factors when the project is insufficiently effective (Swanson and Sakhrani 2020). The mathematical tools of the real-option approach are mainly based on the Black–Scholes model and the binomial approach, which have methodological problems both in application and in the interpretation of results (Arnold et al. 2022; Guo et al. 2023).

For a concession agreement aimed at developing production and transport infrastructure, the main goal is to find a compromise between the state and business based on optimization. Therefore, we believe that the use of optimization models, particularly those based on linear optimization, is advisable for production and transport infrastructure facilities as these models maximize the income of each of the parties (grantor and concessionaire).

3.2. Analysis of Input and Output Economic Parameters' List for the Model

The model of concession agreements proposed by the authors is intended for projects for the construction and operation of pipeline infrastructure facilities in the petrochemical sector in Russia (Dvoynikov and Leusheva 2022).

Estimation and modeling of economic parameters of the CA includes the following input parameters:

1. Operating costs of the concessionaire;

2. Tariff set by the concessionaire for other consumers;
3. Discount rates in DCF calculations;
4. Tax rates (for income tax and property tax in accordance with Russian tax legislation).

The output economic parameters in the CA model are:

1. NPV for the project;
2. Optimal CA period;
3. The amount of the concession fee and its distribution during the term of the contract;
4. The amount and moment of payment of the capital grant;
5. The state's and the concessionaire's participation shares in investments;
6. The amount and distribution of compensation from the state (operating grant).

In the developed methodology, two economic parameters are modeled: the participation shares and the amount of the concession fee.

3.3. Generation of a Mathematical Model (MM) of the CA Based on NPV for Pipeline Infrastructure Projects with Two Optimization Parameters

1. Determination of the economic feasibility of the concession agreement.

To do this, two conditions must be met:

$NPV_k < 0$ (if the opposite is true, then the project is commercially feasible, so a CA is not needed), where NPV_k is the net present value for the concessionaire from the implementation of the project.

$NPV_S = NPV_k + NPV_g \geq 0$ (if the opposite is true, then the project is not economically feasible even with a concession agreement), where NPV_S is the total net present value for the concessionaire and the state from the implementation of the project; NPV_g is the net present value for the state from the implementation of the project.

2. Determination of the boundary conditions of the concession agreement based on maximizing the state's income (1st condition) and maximizing the concessionaire's income (2nd condition).

2.1. Solving the linear optimization problem:

$$\begin{cases} NPV_g \to \max; \\ NPV_k \geq 0. \end{cases}$$

From the concessionaire's point of view, the maximum is always achieved at g = 1; solving this problem, we find the maximum size of the concession fee A_{max}.

2.2. Solving the linear optimization problem:

$$\begin{cases} NPV_g \geq 0; \\ NPV_k \to \max. \end{cases}$$

From the government's point of view, the maximum is always achieved at A = 0; solving this problem, we find the minimum amount of state participation g_{min} in project investments.

3. Determination of the exact parameters of the concession agreement based on any principle underlying it. For example, if the total NPV of a project is distributed in proportion to the share of each participant in the initial investment, then equality must be observed:

$$g = NPV_g/(NPV_g + NPV_k) \quad (1)$$

Next, NPV indicators are transformed as follows.

Any amount of discounted cash flows can be converted using the annuity gradient theory (Blank and Tarquin 2017).

For example, let us consider the quantity X_t that takes a different value each period, i.e., $X_{t-1} \neq X_t \neq X_{t+1} \neq \ldots \neq X_{t+n}$. However, if all quantities $X_{t-1} \ldots X_{t+n}$ are known (or given), then it is also possible to determine the sum $X_{t-1} + \ldots + X_{t+n}$.

Let the quantities $X_t \ldots X_{t+n}$ be the values of cash flows in each time period t. Then, $T_{ppp} = t + n,\ t = 1$.

Thus, the amounts of these cash flows will amount to the total cost of payments for the period T_{ppp}. That is, by attributing the sum of these flows ($\sum_{t}^{Tppp} X_t$) to the duration of the concession agreement (T_{ppp}), there is a certain analog of the postnumerando annuity ($\sum_{t}^{Tppp} X_t/T_{ppp}$) = X_A = const.

In this regard, the expression $\sum_{t=1}^{Tppp} X_t \ /(1+r)^t$ for discounted cash flows takes the form (Blank and Tarquin 2017):

$$PV_X = X_A \cdot \left(\left(1 - 1/(1+r)^{T_{ppp}} \right) / r \right) \quad (2)$$

Then, for the model proposed by the authors, it is possible to transform the expression for NPV_k и NPV_g in the following way:

$$NPV_g = \sum_{t=1}^{Tppp} Tk_t/(1+r)^t + T_{pch}/r \ - g \cdot I + \sum_{t=1}^{Tppp} A_t/(1+r)^t \quad (3)$$

where NPV_g is the net present value for the state from the implementation of the project; Tk is the amount of property and profit taxes that the concessionaire will pay to the state as a result of the implementation of the project; T_{pch} is the income from a company in the petrochemical sector, which receives additional income through the diversification of activities as a result of the implementation of the project; g is the state's share in investments; I is the amount of investment; A_t is the amount of the concession payment; r is the discount rate; t is the project implementation period.

$$NPV_k = \sum_{t=1}^{Tppp} ((1 \ - T) \cdot (\Delta CF_t - DA_t - A_t - WT_t) + DA_t)/(1+r)^t - k \cdot I \quad (4)$$

where NPV_k is the net present value for the concessionaire from the implementation of the project; T is the income tax, 20%; ΔCF_t is the benefit from the implementation of the project for the concessionaire; DA_t is the depreciation as a result of project implementation; WT_t is the amount of property tax in period t; k is the concessionaire's share in investments, which can be expressed as $(1 - g)$.

$$Tk_t = T \cdot (\Delta CF_t - DA_t - A_t - WT_t) + WT_t \quad (5)$$

$$DA_t = I/T_{ppp} = \text{const}, \quad (6)$$

where T_{ppp} is the term of the public–private partnership.

$$WT_t = wt \cdot (I - DA_t \cdot t), \quad (7)$$

where wt is the property tax rate, 2.2%.

It follows from Equation (6) that

$$WT_t = 2.2\% \cdot I \cdot (1 - t/\ T_{ppp}), \quad (8)$$

Thus, g and A_t are the required quantities; T_{ppp}, I, and ΔCF_t are the input parameters.

4. Methods and Data

Let us consider the proposed model using a concrete example—the construction of a gas pipeline for external transport, with d = 530 mm, and the place of laying being a dry, not swampy area. The initial data for modeling are presented in Table 1.

Table 1. Input data for the model of concession agreements for the construction and operation of a pipeline.

Technical and Economic Parameters	Units of Measurement	Value
Length of the product pipeline	km	500
Product transportation volume	thousand t/year	6500
Investments in construction and installation works	thousand rubles	14,465,613.81
Investments in agreements	thousand rubles	962,016.11
Other	thousand rubles	3,527,205.76
Total investment	thousand rubles	18,954,835.68
Useful life (depreciation)	years	20
Depreciation rate	%	5
Transportation tariff	RUB/t	750
Annual tariff increase	%	2
Discount rate	%	16
Income tax rate	%	20
Property tax rate	%	2.2
The amount of taxes of petrochemical companies	thousand rubles	300,000

The project operates under the following assumptions. Investments are made during the initial year of implementation. Annual operating expenditure (OPEX) values are considered to be equivalent to 10% of the capital expenditure (CAPEX) amount. Depreciation is excluded from the OPEX calculation and is treated as a separate entity. Annual revenue is computed based on the tariffs established by the concessionaire for third-party consumers utilizing the gas pipeline, coupled with transportation volumes. The income tax is calculated on an annual basis, driven by the premise that the concessionaire is concurrently executing multiple investment projects. Property tax is assessed annually, proportional to the initial CAPEX amount. The initial parameters are formed on the basis of analog objects and modeling (Ministry of Construction of Russia n.d.).

This study focuses on a representative pipeline project characterized by conventional technical and economic parameters, such as diameter, type, length of the product pipeline, and volume of product transportation. These parameters were selected based on analogs utilized in the oil and gas transportation industry. Investments, encompassing the estimated cost of constructing the product pipeline, are calculated by drawing inspiration from existing analogs. The regulatory document (Decree of the Government of the Russian Federation 2022) defines the service life of the product pipeline, and the depreciation rate is computed using the linear method. The transportation tariff is determined in accordance with regulatory documents and analogs used in the oil and gas transportation industry. The discount rate is set at the level of the key rate of the Central Bank of the Russian Federation (Bank of Russia 2024). Profit and property tax rates adhere to the current regulations of the Russian Federation (Federal Tax Service n.d.a, n.d.b).

5. Results and Discussion

At the given parameters of the pipeline project and by financing of the project without the participation of the state, there is a negative economic efficiency for businesses ($NPV_k = -4.18$ billion rubles). At the same time, the total budgetary effect for the state from the implementation of this project, formed by tax deductions, is 7.025 billion rubles. Obviously, despite the negative efficiency of the project for businesses, the state benefits from the implementation of the pipeline construction project and its subsequent operation. Therefore, it would be justified for the state to apply support and incentive tools for the project's implementation; for example, a reduction in profit tax and property tax rates for a particular project. In addition, macroeconomic parameters such as the key rate of the Bank of Russia and the tariff for product transportation services may change.

Next, a sensitivity analysis of the project was performed considering a reduction in the income tax rate (T, Equation (4)) from the current 20% to 0% and the property tax rate (WT, Equation (4)) from the current 2.2% to 0% (Figure 1). Each point represents a combination of the income and property tax rates. The red dots show the combination that keeps the investor's net present value negative, while the blue dots characterize the positive value of the investor's net present value.

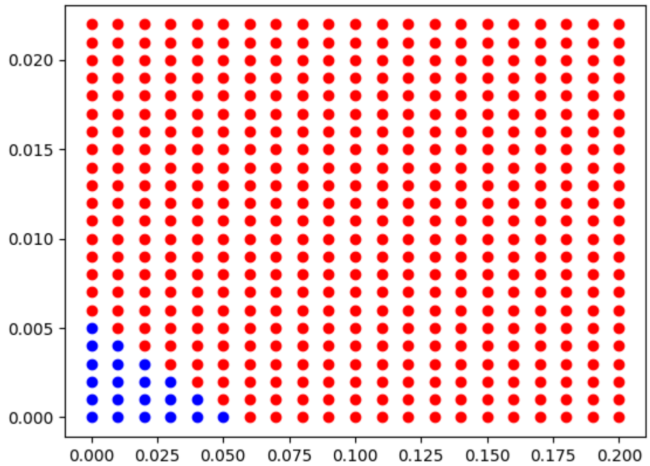

Figure 1. Dependence of NPV_k on tax rates for income tax (X-axis) and property tax (Y-axis).

As can be seen from Figure 1, in order to ensure the commercial efficiency of the project, it is necessary to practically exempt the investor from paying property taxes and income tax during the entire life of the facility (NPV_k = 0.702 billion rubles), which is unlikely in the current macroeconomic circumstances (high budget expenditures of the Russian Federation, the tendency to increase the tax burden, etc.).

Figure 2 shows the sensitivity analysis of macroeconomic indicators, namely the key rate of the Bank of Russia and the tariff for product transportation. As in the previous figure, the red dots show a combination in which the net present value of the investor remains negative, while the blue dots characterize a positive value of the investor's net present value.

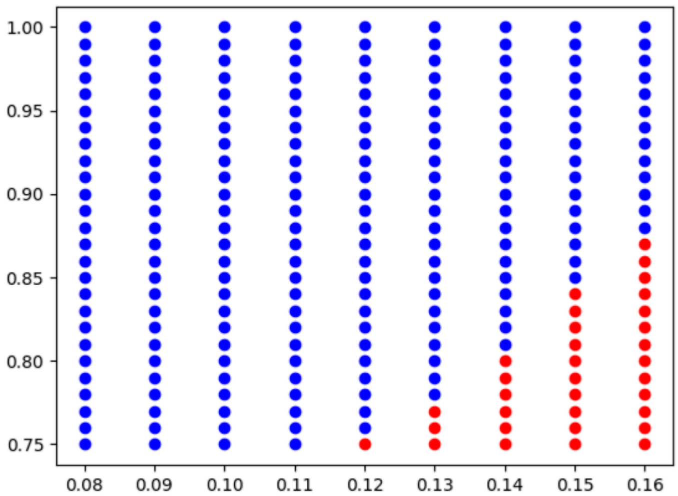

Figure 2. Dependence of NPV_k on key rate/discount rate (X-axis) and tariff in RUB thousand (Y-axis).

As can be seen from Figure 2, in order to achieve non-negative values of the net present value of the project, it is necessary either to reduce the key rate to 11% (almost by one third of the current value), or to increase the transportation tariff by 17.3%, or a favorable combination of the two factors, if the key rate of the Bank of Russia remains unchanged. This situation seems unlikely in the near future.

Accordingly, a concession agreement may be an alternative to the above-mentioned methods of stimulation by the state. Therefore, the conditions of the concession agreement are modeled below.

It is posited that the initial investment is jointly contributed by two investors—the government and the concessionaire. In typical concession projects, government investment ranges from 10% to 30%, while the concessionaire's investment hovers between 70% and 90%.

The concession agreement period aligns with the useful life of the product pipeline (T_{ul}), culminating in the company transferring the facility to the state at zero residual value after the pipeline's useful life concludes—set at 20 years in this specific case.

In general, the minimum limit is the discounted payback period of the product pipeline construction project. Thus, the concession period is determined by the formula:

$$DPP < T < T_{ul}, \tag{9}$$

where DPP is the discounted payback period of the product pipeline construction project.

When a project relies solely on commercial forces, even with government support in the form of reduced taxes and discount rates, the investor, particularly in the petroleum and gas chemical sector, struggles to attain the desired profitability. This predicament necessitates exploring alternative methods of government support, with concession agreements emerging as a viable solution.

Assuming the conclusion of an agreement between the state (concessor) and the concessionaire, the concessionaire utilizes the pipeline for internal needs and generates additional revenue by allowing third-party consumers to use the pipeline. The concessionaire's profit within the agreement then arises from savings on pumping tariffs and additional revenue from third-party consumers. The value of the concessionaire's profit depends on total investments, the state's share, and the concession agreement's duration. In some cases, provisions for repurchasing the object at an agreed value (residual value) before the established transfer deadline may be considered.

At the established initial parameters, the authors, in accordance with the developed methodology, determined the parameters of the gas pipeline construction CA and obtained the following results:

The share of state participation in the initial investment in the construction of the product pipeline should be at least 0.221 ($g = 0.221$). At such a share of the state (and in the absence of concession fees), the net present value of this project for the concessionaire equals zero, i.e., participation in the project becomes expedient. At the same time, the government's benefit from the project is maximized. On the other hand, if the maximization of the concessionaire's benefit is considered as a target function, then it is preferable for the concessionaire to have the state finance the project in full ($g = 1$), while the concessionaire partially compensates for the state investments at the expense of the annual concession fee during the project implementation. Thus, if the initial investment is financed solely by the state, then the annual concession fee should amount to 2.26 billion rubles per year.

In this way, the application of the proposed model allowed us to establish boundary values for such important parameters of a concession agreement as the share of state participation (from 0.221 to 1) and the amount of the annual concession fee (from 0 to 2.26 billion rubles per year). It is within these limits that the parameters of the agreement between the concessionaire and the state should be discussed, but the exact value of the share of state participation and the concession fee can be determined only with an accurate understanding of how the concessionaire and the state consider it fair to share the benefits of the project between them.

This paper proposes to distribute benefits in proportion to the share of each participant in the initial investment in accordance with Equation (1). This allows for each potential value of the share of state participation to set the appropriate concession fee, and vice versa. Thus, if the participants in the agreement prefer to do without concession fees at all, then a fair distribution of the project benefits (in proportion to the share of each participant) is achieved at a public financing share of 0.297 (NPV_g = 1.422 billion rubles). If, for example, the participants agreed that the share of public participation would be exactly 50%, then a concession fee of 1.1 billion rubles per year would have to correspond to this parameter for a fair distribution of benefits.

It is essential to acknowledge that the concession agreement benefits not only the concessionaire, who relies on it to ensure the commercial feasibility of the project, but also the government, given the significant potential of the project in terms of budgetary efficiency. The company constructing the product pipeline will not only contribute taxes to various levels of government (with this study factoring in income tax and property tax effects) but will also enable the supply of raw materials and, consequently, the organization of petrochemical production. Our calculations suggest that tax revenue from this production could amount to approximately 0.3 billion rubles per year. The value added from petrochemical production and cluster projects typically increases by a factor of 4 to 7 compared to the cost of petroleum products. For instance, the production of fertilizers could see a 190% increase in added value, while certain types of small-scale petrochemical products could experience a boost of up to 1500%.

Consequently, the net discounted benefit to the state from increased tax revenue is projected to reach 2.845 billion rubles over the entire project implementation period, leading to a substantial rise in revenue for both federal and regional budgets. Furthermore, the model proposed only considers the direct effect of tax payments, while the overall impact on the social sphere and sustainable development of the region is anticipated to be significantly higher due to job creation, infrastructure development, and other factors. For instance, constructing a 500 km pipeline requires engaging 126 workers, while the estimated workforce at the new petrochemical plants could reach 2500 individuals. Thus, a concession agreement can serve not only to address the economic interests of its participants (concessionaire and grantor) but also as an effective tool for ensuring the sustainable development of regions.

In terms of environmental impact, it is noteworthy that pipeline transportation is the most environmentally friendly mode for petrochemical raw materials, with minimal effects on air and water quality, causing damage primarily to land resources within acceptable limits. Therefore, pipeline construction projects under concession agreements align with the principles of sustainable development, enhancing economic and social aspects while maintaining environmentally acceptable levels of impact.

6. Conclusions

Upon reviewing various approaches to evaluating concession agreements, it is evident that models rooted in game theory, mathematical modeling, and the real-option approach, among others, offer effective tools for factoring in uncertainty and forecasting risks.

In this study, the authors employed an approach based on mathematical modeling to propose a method for assessing the economic efficiency of using CAs in pipeline construction projects. This methodology proves instrumental in determining the viability of a concession agreement, outlining its boundary conditions, and specifying the key parameters.

The article shows that pipeline construction projects meet the requirements of sustainable development because they contribute to domains such as economy (in terms of value added, commercial efficiency, tax revenue, growth in related industries, etc.), society (in terms of public good creation, new jobs, wages, etc.), and the environment (in terms of environmental quality).

The practical application of the proposed methodology in a pipeline infrastructure construction project revealed a negative result for the project's commercial implementation under the accepted assumptions. Despite government support through tax reductions, zeroing rates, discount rate adjustments, and tariff increases, the anticipated profitability failed to materialize.

Conversely, state participation in the concession agreement proved pivotal to project success. The authors identified boundary parameters for the concession agreement, showcasing a maximum concession fee (A_{tmax}) of 2.26 billion rubles with a minimum state participation (g min) at 0.221. Finding the exact parameters, which were determined based on the distribution of the total net present value (NPV) among project participants, highlighted the maximum state share (g) of 0.323 (at $A_t = 0$).

Despite these insights, certain limitations must be acknowledged:

1. The model, while adept at determining boundary and optimal contract parameters, does not leverage game theory tools for modeling decision-making by agreement parties;
2. The model does not take into account changes in discount rates (Marin et al. 2022);
3. The term of the concession agreement is set equal to the useful life of the object;
4. The model does not take into account the possibility of reducing the term of the concession agreement or early purchase of the facility by the state;
5. The model does not take into account the impact of risks on the output economic parameters of interaction;
6. This model was tested using a case study of pipeline infrastructure construction; however, it can be used for projects of various types and for assessing the economic efficiency of a project at various stages of its implementation.

To address these limitations, future studies should advance models for optimal CA parameter determination. Incorporating broader variations and utilizing game theory tools could offer additional insights. Furthermore, the risk assessment of concession agreements could benefit from simulation modeling or the real-option approach. Social effects related to the number of jobs and wages, as well as additional multiplier and agglomeration effects, can also be included in the modeled parameters.

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