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Assessing the Stability of the Oil and Gas Production in Common Fields: Application of Game Theory

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ABSTRACT: One of Iran's oil and gas reservoirs' characteristics is that some of Iran's huge reservoirs are shared with its neighbors. Iran's common oil and gas fields with its neighbors are among the most valuable income and national wealth sources, so production delays cause irreparable damage to the national economy. Therefore, this research attempts to use game theory to investigate the optimal production of common oil and gas fields onshore and offshore. For this purpose, the existing revenues and production costs of oil and gas fields have been identified and extracted by reviewing the research literature. Yadavaran oil field and South Pars gas field were selected as case studies. After developing the model using mathematical optimization, the values of decision variables, optimal production rate, optimal selling price, and optimal profit for each player in each common field were calculated. The results of solving the designed games showed that the best strategy and Nash equilibrium for Iran is the strategy of cooperation.

KEYWORDS: oil and gas common fields, game theory, production of the common field, optimization, Nash equilibrium

1. INTRODUCTION

In the age of globalization, countries large and small worldwide seek to join alliances, multilateral alliances, and economic cooperation. After World War II, it is one of the most successful examples of EU integration to achieve economic cooperation in the European Coal and Steel Community (Fedorenko et al., 2021). After that, and with the passage of time, regionalism and regional convergence began in other parts of the world. After the end of the Cold War and the collapse of the Soviet Union, the pace of convergence increased, and countries sought to forge alliances with their regional and homogeneous allies, thereby increasing their development, security, and prosperity (Lozano et al., 2013).

Given the importance of energy resources, especially oil and gas, the global need for oil and gas resources, and the Persian Gulf's potential in this regard, it can be an opportunity for Iran to produce these resources. Despite the chance for Iran in this regard, Iran also faces a series of obstacles (Toufighi et al., 2020). The first obstacle for Iran is the unequal production of these countries compared to Iran. The second obstacle is the sanctions imposed on Iran, followed by Iran's technological weakness in extracting these resources (Roman & Stanculescu, 2021). The recovery factor in the share of extraction from common fields is one of the main priorities of macro and strategic policies for monitoring oil and gas resources (Moradinasab et al., 2018). The recovery factor is, in short, the percentage of oil-in-place that can be extracted. The average recovery factor from Iran's oil reservoirs is about 24 to 27 percent, which is very low compared to regional competitors due to international sanctions and lack of protection production. According to statistics, with every one percent increase in the recovery factor, it will add 6 billion barrels to Iran's extractable reserves (NIOC, 2012).

The production of common oil and gas fields is essential for Iran (Toufighi et al., 2020). It is carefully considered how the neighbors produce from the common fields and compare it with Iran's production of these fields, which can be regarded as a game approach (Toufighi et al., 2022). Each of the players is trying to increase its payoffs. Game theory is mathematical modeling to study the behavior of players. In situations where each player's behavior affects another situation, one can look for the equilibrium behavior that they choose, which is called Nash equilibrium, and each of them tries to make the most beneficial decision.

The rest of the paper is organized as follows: in section 2, the literature review and research gap were illustrated. Section 3 introduced the data gathering methodology, sample, and mathematical model. The result of optimization and game designing is shown in section 4. Finally, in section 5, the conclusion and suggestion were presented.

2. LITERATURE REVIEW

The common fields are scattered in a diverse range in Iran, but most are located in Iran's western and southern strip to the Oman Sea's warm waters. According to available information, Iran has 28 common oil and gas fields (Fontes & Freires, 2018). Eighteen oil fields, four gas fields, and six oil and gas reserves. The National Iranian Oil Company has started production from more than ten common oil and gas fields, but 18 common reservoirs have not begun. Of the 28 common fields, 15 reservoirs are located in the Persian Gulf, and 13 reservoirs are located onshore. Iraq tops Iran's common hydrocarbon neighbors with 12 common fields. The United Arab Emirates follows it with seven reservoirs, Saudi Arabia and Qatar, with two reservoirs, Oman, Kuwait, and Turkmenistan (Salimian & Shahbazi, 2017).

The Persian Gulf is the common water border between Iran, Iraq, Kuwait, Saudi Arabia, Oman, Qatar, Bahrain, and the United Arab Emirates. Iran's neighboring countries in the Persian Gulf are producing these fields more and more by using international companies' capital and political flexibility and using the world's latest technical knowledge (Hoffman & Wilkinson, 2011). Continuation of these countries' processes and unilateral production will cause the loss of these fields' balance. In Iran's common fields in the Persian Gulf, drilling competition is being carried out by neighbors with full intensity, which will destroy the structure of the reservoirs over time regardless of the economic losses for Iran. Proper management of joint fields requires mutual trust between the parties. According to the stakeholders' political will, temporary and permanent measures are taken to gain mutual trust, and the parties' fundamental interests are guaranteed (Ghaffari & Taklif, 2015).

Wu et al. (2017) conducted a study entitled Profit allocation analysis among the distributed energy network participants based on Game-theory. A distributed energy distribution (DEN) based on electricity and heat is proposed to overcome the supply-demand imbalance in a conventional distributed energy system. First, a mixed-integer linear programming (MILP) model is proposed by selecting the optimal technique, power line layout, and execution strategy. A mathematical model for equitable profit distribution among participants based on the primary collaborative game theory method was presented. For example, three buildings in Tokyo have been selected for analysis. According to the simulation results, the total annual cost is reduced by 14.5% to the energy exchange (Wu et al., 2017).

Ruijie Tian et al. (2017) conducted a study entitled promoting natural gas-fired electricity with energy market reform in China using a dynamic game-theoretic model. A dynamic game theory model was developed to analyze the natural gas market correction effects. Real-time pricing was used in both the natural gas and electricity markets. Two results were obtained. (1) liberalizing the natural gas price, imposing a carbon tax, and adopting an environmental subsidy can significantly increase the influence of the natural gas-fired electricity market; And (2) market deregulation can increase NGFE's share to 5.49% (Ruijie Tian, Qi Zheng, Ge Wang, Hailong Li, Siyuan Chen, Yan Li, 2017).

Al-Assad (2017) conducted his master thesis entitled system design against attack: A tri-level network operation model in oil/gas production and distribution. This study discusses resilience strategies against malicious attacks. A three-tier leader-follower-agent game is developed to determine optimal enrichment tactics to protect critical assets with limited defense resources. Also, the concept of shared cognition is mathematically modeled by the advocate. The mixed nonlinear programming problem results are decomposed into a main and auxiliary problem to show the defender-agent and the attacker-agent. The results show that the cost of offensive damage is significantly reduced (Al-Assad, 2017).

Chen et al. (2017) studied China's oil import/export quota allocation mechanism using a dynamic game-theoretic model. As China's oil market has undergone many reforms in recent years, independent refineries (small companies) have demanded a more significant share in the import and export of their oil and oil derivatives, which will affect the market and even Chinese society. Therefore, without considering the positive and negative effects of this action, designing a mechanism to determine each player's share in the Chinese oil market and the price in global and domestic markets. Therefore, this article addresses this issue by considering the playful relationships between the six companies active in the Chinese oil market, including state-owned companies, independent refineries, domestic and foreign consumers of petroleum products, and domestic and foreign petroleum producers' products. In the designed game model, each player's consequence was to maximize the profit of each of the six players involved in the game (S. Chen et al., 2017).

Ansari (2017) conducted a research entitled OPEC, Saudi Arabia, and the shale revolution: Insights from equilibrium modeling and oil politics. OPEC did not reduce production, although the fall in oil prices in 2014 has also been examined. The quantitative evidence was obtained from calculating the equilibrium of a relative market share in the first quarter of 2011. Although shale oil may increase competition forever (as supported by the model results), the December 2016 agreement should not be interpreted as an OPEC failure (Ansari, 2017).

He et al. (2017) conducted a study on A three-level framework for balancing the tradeoffs among the energy, water, and air-emission implications within the life-cycle shale gas supply chains. Two fundamental challenges are considered: the consumption of high-water resources and greenhouse gas growth across the current shale gas supply chains. This research provides a three-level modeling framework for optimizing the economic and environmental life cycle of shale gas supply chains. Leader-Follower-Stackelberg Life Cycle and Game Analysis are integrated into an optimization framework to describe a hierarchical structure. A degree-of-satisfaction-leader-follower-improvement algorithm is presented to meet the computational challenge of the three-tier program. As a result, overall satisfaction in meeting different decision-makers goals is created by compromising the balance between energy, water, and the consequences of air emissions. The drilling program obtains optimal solutions, shale gas production, freshwater supply, wastewater treatment, greenhouse gas emissions, and electricity generation. These analyzes can help decision-makers make informed decisions about supply chains. Also, decision-making is not kept constant but is improved by repeated communication with different models and sensitivity analysis. The model solutions' robustness and objectivity can be further strengthened (He et al., 2018).

Razmi et al. (2017) studied the cost-saving allocation of horizontal cooperation in the restructured natural gas distribution network. To this end, the natural gas distribution network redesign was considered a collaborative game to identify the cost savings for different scenarios for each player. The allocation of cost savings among players was also considered a cooperative game. This research's case study was the natural gas network of Yazd province located in Iran (Razmi et al., 2018).

Rezazadeh et al. (2018) studied applying game theory for securing oil and gas pipelines against terrorism. Risks related to the safety of oil and gas pipelines in this paper are evaluated using the game theory technique combined with the security risk assessment approach. In this study, a socio-political indicator is included in an innovative and comprehensive assessment method, and the effects of social, economic, and political factors on the pipeline and vulnerability are considered. After analyzing security threats, security measures to increase a pipeline system's security level are evaluated using a game theory model. The sections of the pipeline that are most likely to be attacked are identified. Also, after assessing the possible consequences of attacks on each section, the security of different sections of pipeline routes can be further improved. This research approach can effectively allocate limited security resources to reduce the security risk along the pipeline route. It should be noted that although this study focuses on oil and gas pipelines, the proposed method can be easily adapted to other pipeline systems (Rezazadeh et al., 2018).

Using an agent-based method, Guo and Hawkes (2018) conducted research entitled simulating the game-theoretic market equilibrium and contract-driven investment in global gas trade. Using an agent-based framework, a global gas scale model was developed to understand how US liquefied natural gas export strategies may affect future global gas market dynamics. This model is the first straightforward contract-based capacity development process that allows investors to maintain incomplete forecasts and simulate market power in global gas trading. The gas game can analyze market development with each market player's motivations and views with these features. This model simulates the short-term market equilibrium with the complementary problem approach of mixing. For long-term investment decisions, bilateral contracting processes are modeled, considering import demand and export profitability. A baseline case was presented and validated; then, a case study considered the US export strategy. When the United States remains conservative in its export development, gas shortages occur, leading to Europe's continued dependence on Russian gas and a shift in pipeline-based imports into the Chinese market. In contrast, when the United States invests heavily, both the Middle East and Australia see significant financial losses, and Western Europe builds more power plants to provide alternatives to Russia. The game captures the fundamental dynamics between market power, short-term prices, and long-term contracts to provide a more accurate view of the global gas market (Guo & Hawkes, 2018).

Zhang et al. (2018) conducted a study entitled Integrating API SRA method - The ANSI/API standard 780 on Security Risk Assessment for the petroleum and petrochemical industries - and game theory to improve chemical units' protection. Integrating game theory and the API SRA method to improve chemical units' protection is an exciting study area .The API SRA method bridges the gap between chemical security reality and chemical security theory (i.e., theoretical game models) by providing quantitative inputs for game theory models and the game's theoretical results concerning industrial performance (L. Zhang et al., 2018). Toufighi et al. (2020) optimized production in forouzan common oil field based on game theory. This research developed revenue, cost, and profit functions for each player's desired field and game theory approach(Toufighi et al., 2020). Table 1 describes the essential surveys in terms of game approach, a game mode used, validation of the proposed model, and research achievements.

Table 1. Summary of optimization research in the field of oil and gas fields

No.	Reference	Used Tools	Game Type	Validity	Results
1	(Li et al., 2013)	GT/Nash Eq.	Static/Perfect/Cooperative	Numerical Example	Game analysis and China-Russia oil project cooperation measures
2	(SantosAlves, 2014)	GT/Nash Eq.	Static/Perfect/Cooperative	Numerical Example	Investigating Global Energy Market Cooperation for

					South American Energy Producers
3	(Yang & Cong, 2014)	GT/Nash Eq./Coalition G.	Non-Cooperative/Complete Information/Non -Rep.	Numerical Example	Determining the optimal strategic reserves of the oil company in each country
4	(Barrett B. Schitka, 2014)	GT/Nash Eq.	Static/Cooperative/Prison Dilemma/Nash Eq.	Numerical Example	Review of oil and gas production contracts
5	(Cobanli, 2014)	GT/Bargaining Game/Shapely Value	Static/Perfect/Cooperative	Model Sensitivity Analysis	Assessing the bargaining power of players in the Eurasian gas trade
6	(Wadhawan & Neuman, 2016)	GT/Nash Eq./Stackelberg Eq.	Non-Cooperative	Numerical Example	Defense against cyber-physical attacks in oil pipeline systems
7	(Ajimoko, 2016)	GT/Nash Eq./Shapley Value	Non-Repeatable / Static	Numerical Example	Reduction the cost of drilling oil wells
8	(T. Zhang et al., 2016)	GT/Nash Eq.	Evolutionary game/Non-Rep./Nash Eq.	Model Sensitivity Analysis	Pollution treatment of oil and gas companies' activities
9	(Zhu et al., 2016)	GT/Nash Eq.	Evolutionary symmetric game	Numerical Example	Environmental Sovereignty in International Collaborations for an Oil Leak Article
10	(Kheiravar et al., 2017)	GT/Return Method	Dynamic/Complete Information	Numerical Example	The optimal economic model between oil producers
11	(Leroux & Spiro, 2018)	GT/Nash Eq./Stackelberg Eq.	Dynamic/Perfect/Non-Repeatable	Model Sensitivity Analysis	Review of regenerative strategies to prevent oil production in the Arctic
12	(Guo & Hawkes, 2018)	GT/Nash Eq./Shapley Value	Static/Non-Rep.	Numerical Example	Contractual investment in global gas trade
13	(Moradinasab et al., 2018)	GT/Mathematical Optimization	Stackelberg Eq./Nash Eq./MILP	Numerical Example	Investigating the issue of environmental pollution in the oil supply chain
14	(Samoylenko et al., 2018)	GT/Nash Eq./Math. Optimization	Static/Mixed Eq.	Numerical Example	Mathematical simulation of pipeline reliability
15	(Sharif & Kerachian, 2018)	GT/Nash Eq.	Static/Zero-Sum Game	Numerical Example	Resolve contractual disputes between owners and contractors in a refinery construction project
16	(Skovsgaard & Jensen, 2018)	GT/Stackelberg Eq./Math. Optimization	Static/MIP	Numerical Example	Optimization of biogas value chains
17	(J. Chen & Zhu, 2018)	GT/Stackelberg	Nash Eq./Stackelberg Eq.	Numerical Example	Distributed energy management in smart grids
18	(Ramos et al., 2018)	GT/Stackelberg	Stackelberg Eq./Non-Repeatable	Numerical Example	Power grid optimization in industrial parks
19	(Yin & Xiong, 2018)	GT/Nash Eq./Cooperative Agreement	Static/Perfect/Nash	Numerical Example	Prevent oil spills and control modes in the area of the three George reservoirs

In general, articles in oil using game theory can be divided into two general categories. The first category is articles that cover the entire oil market. For example, Wood et al. (2016), in their article on the global oil market as a two-player game of non-zero-sum in a standard way that each player has continuous strategies (Wood et al., 2016). Each of the two players is an oil importer or OPEC and an oil exporter or OPEC. The problem presented in the non-cooperation model is solved using the Nash equilibrium point. The Nash equilibrium solution expresses the optimal oil price per Barrel for OPEC and the optimal oil import level for OPEC, assuming no cooperation between the players. Oil market articles are reviewed only among OPEC members in the second category. For example, in their article, Chang et al. (2014) wrote that a review of OPEC and its game theory models encourages its members to increase production capacity from what they currently produce to increase revenue (Chang et al., 2014). However, each OPEC member's persistence to explore and expand oil fields is far below their capacity.

The uncertainty in oil and gas reservoirs and the phase behavior of fluids over time during harvesting will study how managers decide and some political conditions in the region in creating cooperation or non-cooperation. In other words, various methods have been used to model the behavior of countries in oil. Given that the stable output that game theory predicts is not necessarily Pareto optimal, and knowing that the game's output will be a set of players' decisions, each player will seek to optimize their profit function. As a result, game theory provides a more realistic simulation of stakeholder profit-based behavior. This self-optimized behavior of players and stakeholders will usually lead to non-collaborative behavior, even when collaborative behavior is more beneficial to all players. Therefore, the game theory tool was selected to achieve the research goal in this research. In general, game theory can be constructive for planning, policy-making, and design and provide a perspective not available in traditional systems engineering methods.

3. RESEARCH METHODOLOGY

3.1. Oilfield Modeling

In the production of the product, especially in the energy industry, it is possible that in the production function, energy carriers, such as coal and electricity, are used, each of which with the capital factor is involved in the production of the product. Demand for non-petroleum energy is determined theoretically. The most widely used function of oil demand estimation is the Cooper (2003) study. This study examined the crude oil demand for 23 countries from 1979 to 2000. It used the variables of crude oil price, income, and per capita demand of the previous year as independent variables (Cooper, 2003). To specify the function of Iran's oil revenue from the production of common oil and gas fields, forecasting the price of Iranian crude oil based on the EIA price model was used. However, to specify the cost function, each of the operational stages of exploration, development, and operation is specified. Then the extended form of the cost function is introduced. For this purpose, the model's components (variables and parameters) were first described in Table 2.

Table 2. Variables and Parameters used in oilfield functions

Description	Abbreviation	Dimension	Extracted
Crude oil demand	D	Million Barrel per Day	OPEC database
Gross domestic production	GDP	Million Dollar per Day	EIA
Crude oil price	P_t	Dollar per Barrel	EIA
Component of disruption	ε_t	-	Research Finding
Crude oil daily production	X_t	Barrel per Day	Research Finding
Regression Parameter	δ_0	-	Research Finding
Regression Parameter	δ_1	-	Research Finding
Daily production share of OPEC	y_t	Percentage	OPEC database
Regression Parameter	δ_2	-	Research Finding
Time trend	T	Year	Gao, 2004
Exploration cost fraction	ω	Percentage	Gao, 2004
Cost of Dev. & Main. Of Facilities	β_1	Dollar per Barrel	EIA
Cost of oil well development	β_2	Dollar per Barrel	EIA
Number of wells	N_t	Number	NIOC
Production Cost Update Index	$d(t)$	-	Research Finding
Depreciation Cost Update Index	$d'(t)$	-	Research Finding
Gas injection rate	gi_t	Billion Cubic Meter	EIA
Water injection rate	wi_t	Million Barrel	EIA

Cost of maintenance	chs	Dollar per Barrel	EIA
Exploration Cost Function	TC_E	Dollar per Day	Research Finding
Development Cost Function	TC_D	Dollar per Day	Research Finding
Production Cost Function	TC_P	Dollar per Day	Research Finding
Maintenance Cost Function	TC_H	Dollar per Day	Research Finding
Water injection cost function	TC_{WI}	Dollar per Day	Research Finding
Gas injection cost function	TC_{GI}	Dollar per Day	Research Finding
Total Cost Function	TC	Dollar per Day	Research Finding
Total revenue function	TR	Dollar per Day	Research Finding
Players Pay-off	π_i	Dollar per Day	Research Finding
Production Variable Cost	TC_{VP}	Dollar per Day	Research Finding
Cost of Repair and Depreciation	TC_{PFM}	Dollar per Day	Research Finding

$$\pi i = TR - TC$$

$$\pi_i = \left[(X_t) \times e^{\delta_0+\delta_1 y_t+\delta_2 t}\right] - \Big[(1+\omega) \times \Big\{ (\beta_1 X_t + \beta_2 N_t) + \Big(\big(1+d(t)\big)(0.7714 \times (X_t)^{-0.2423}) + \big(1+d(\acute{t})\big)(0.44 \times X_t)\Big) + \big(0.5 \times chs \times e^{\delta_0+\delta_1 y_t+\delta_2 t}\big) + \frac{0.176}{365}\, gi_t + \frac{0.78}{365}\, wi_t \Big\}\Big]$$

3.2. Gas field Modelling

In this section, mathematical models related to gas fields were described.

Table 3 describes the variables and parameters used.

Table 3. Variables and Parameters used in gas field functions

Description	Abbreviation	Dimension	Extracted
Natural Gas Price	P_{tg}	Dollar per Cubic Meter	EIA
Produced Gas Rate	q_t	Cubic Meter	NIOC
Residual Gas	R_t	Cubic Meter	NIOC
Month of Production	pm	Month	Standard
Gas Production Period	t	Day	Standard
Demand Function Intercept	α	-	Research Finding
Regression Parameter	β_q	-	EIA
Regression Parameter	β_R	-	EIA
Regression Parameter	β_t	-	EIA
Regression Parameter	β_{pm}	-	EIA
Component of Disruption	e_{ij}	-	Research Finding
Cost of Dev. & Main. Of Facilities	μ_1	Dollar per Day	EIA
Cost of Gas Well Development	μ_2	Dollar per Day	EIA
No of Gas Well	N_t	Quantity	NIOC
Daily Gas Production	G_t	Cubic Meter Per Day	NIOC
Production Variable Cost	TC_{VP}	Dollar per Day	Research Finding
Cost of Repair and Depreciation	TC_{PFM}	Dollar per Day	Research Finding
Gas Demand Function	Z_t	Million Barrel Per day	Research Finding
Actual Revenue	I_t	Dollar per Day	Research Finding
Regression Parameter	α_0	-	Research Finding
Regression Parameter	α_1	-	Research Finding
Regression Parameter	α_2	-	Research Finding
Regression Parameter	α_3	-	Research Finding

Production Cost Update Index	$d(t)$	-	Research Finding
Depreciation Cost Update Index	$d'(t)$	-	Research Finding
Exploration Cost Function	TC_E	Dollar per Day	Research Finding
Development Cost Function	TC_D	Dollar per Day	Research Finding
Production Cost Function	TC_P	Dollar per Day	Research Finding
Total Cost Function	TC	Dollar per Day	Research Finding
Players Pay-off	πi	Dollar per Day	Research Finding

$$\pi i = TR - TC$$
$$\pi_i = \left[G_t \times \alpha_0 (exp(\alpha_1 t)) I_t^{\alpha_2} P_{tg}^{\alpha_3}\right] - \left[e^{\alpha+\beta_q lnq_t+\beta_R lnR_t+\beta_t lnt+\beta_{pm} lnpm+e_{ij}} + \mu_1 G_t + \mu_2 N_t + \left((1+d(t))(0.7714 \times (G_t)^{-0.2423}) + (1+d(\acute{t}))(0.44 \times G_t)\right)\right]$$

4. FINDINGS AND RESULTS

Yadavaran field is one of Iran's oil fields, located in Khuzestan province, 70 km southwest of Ahvaz city and north of Khorramshahr. The dimensions of the square are 15 by 45 km. The volume of oil at the site is estimated at 17 billion barrels. Yadavaran field is located next to Sinbad field, one of the oil fields in Iraq. This field's reserves in place are estimated at more than 17 billion barrels (2.7 cubic kilometers), and the number of recyclable reserves is estimated at 3 billion barrels (0.5 cubic kilometers). It is estimated that between 300,000 and 400,000 barrels of oil can be extracted daily from this field.

South Pars gas field (in Qatar: North Dome) is the largest gas field globally, located in the Persian Gulf and jointly in the territorial waters of Iran and Qatar. From the beginning of the harvest from this joint field, Iran and Qatar have always competed to excel in exploiting the hydrocarbon resources of this field. The field was discovered in 1971, and its exploitation began in 1989. The volume of natural gas reserves in the South Pars field is estimated at 51 trillion cubic meters, and its recoverable reserves are estimated at 36 trillion cubic meters. Currently, an average of 1 billion and 210 million cubic meters of natural gas is extracted daily from this field, of which 610 million cubic meters per day is produced by the National Iranian Oil Company and 600 million cubic meters per day by Qatar Petroleum. Tables 4 & 5 present the demand function parameters for each player's oil and gas fields.

Table 4. Estimation of oilfield player's parameters

Country	Parameter	δ_0	δ_1	δ_2
Iran	Estimated values	3.56895	-0.0417	3.9239
	Standard Error	0.0471	0.0014	0.1478
	R^2	0.7476	-	-
Iraq	Estimated values	4.1246	-0.0987	4.3265
	Standard Error	0.07456	0.01236	0.2416
	R^2	0.60236	-	-

Table 5. Estimation of gas field player's parameters

Country	Parameter	α_0	α_1	α_2	α_3
Iran	Estimated values	33.96	-1.98	-1.195	2.54
	Standard Error	0.0548	0.0369	0.1014	0.0365
	R^2	0.4695	-	-	-
Qatar	Estimated values	23.47	-1.02	-1.011	1.39
	Standard Error	0.0065	0.01984	0.1496	0.0269
	R^2	0.7498	-	-	-

Then, mathematical models were solved, and the optimal answer was found for each player's decision values in each model, which are given separately for the calculation results. Initially, Iran and Iraq's consequences in the Yadavaran field, an onshore oil field, are optimized. After solving the above model, each player's optimal values were extracted as described in Table 6.

Table 6. Estimation of oil field player's parameters

Description	Iran	Iraq
X_t^* Optimum Value, Cubic Barrel per Day	139841	224873
Actual Production, Barrel Per Day	85000	71000
π_t^*- Dollar per Day	12,425,782	23,221,387

The results show that Iraq's share of the current total production is close to 45%, and Iran's share is close to 55%. Also, Iran's share in the optimal production will be close to 40%, and Iraq's share will be close to 60%.
Next, Iran and Qatar's South Pars gas field consequences are optimized. After solving the above model, each player's optimal values were extracted as described in Table 7.

Table 7. Estimation of gas field player's parameters

Description	Iran	Qatar
G_t^* Optimum Value, Cubic Meter per Day	587,624,951	1,034,650,074
Actual Production, Cubic Meter Per Day	610,000,000	600,000,000
π_t^*- Dollar per Day	176,287,485	310,368,022

As can be seen, Iran's share of the current production is 51%, and Qatar's share is 49%. Also, the current share of Iran's optimal production is equal to a 3% surplus. Qatar's share of the optimal production is equal to 58%. According to the information available in 2025, Qatar will achieve 91% of its optimal production. Then, based on the previous part's results and determining each player's strategies, the game was designed, and a balance was found in each game. Their cumulative profit was calculated using the field development plan's information and the results of the previous step's optimal values.
Iran's recovery factor in the Yadavaran field was assumed to be 13%, considering the primary and secondary enhanced oil recovery methods, while Iraq's recovery factor is 60%. On the other hand, Iraq is more up-to-date in the field of extraction from the Yadavaran field, and its recovery factor is close to 4 times that of Iran. The volume of extractable oil in this field is equivalent to 2.233 billion barrels for 25 years. Given that the life of oil fields is considered 25 years and considering the amount of pressure drop in the tanks, the following assumptions are defined to design the game between the two countries:
Assumptions of non-cooperation: Given the political situation and international and confidential sanctions, the information of common fields for each of the competitors is the basis for the non-cooperation of the Master Development Plan (MDP). Considering that the results of the proposed model of this research are consistent with the information contained in the MDP, to find the production values and consequently the outcome of each player, the answers obtained from the mathematical model of the Yadavaran field based on the logic of reservoir engineering and processing was calculated.
Assumptions of cooperation: If an agreement is reached and the countries cooperate, it is assumed that based on the information of the field development plan, each of the actors will produce, and the calculations related to the reservoir pressure drop are also included in the development plan. It should also be noted that if one of the parties cooperates, the non-cooperating party produces in the same way as before. In this case, it is assumed that the two countries will sign a cooperation agreement to extract 50% of the field. At the same time, Iran will have the opportunity to use the other side's technologies in the cooperation strategy. The results of each country's profit calculations in billion dollars over 25 years are presented in strategic form.

Table 8. Results of each country's payoff

No.	Pay off Function	Payoff (Billion USD)	Membership set of Strategies
1	$U_{Iran}(C,C)$	99.212	$C \in S_{Iran}, C \in S_{Iraq}$
2	$U_{Iraq}(C,C)$	115.301	$C \in S_{Iran}, C \in S_{Iraq}$
3	$U_{Iran}(C,NC)$	89.482	$C \in S_{Iran}, NC \in S_{Iraq}$
4	$U_{Iraq}(C,NC)$	126.609	$C \in S_{Iran}, NC \in S_{Iraq}$
5	$U_{Iran}(NC,C)$	85.661	$NC \in S_{Iran}, C \in S_{Iraq}$
6	$U_{Iraq}(NC,C)$	131.050	$NC \in S_{Iran}, C \in S_{Iraq}$
7	$U_{Iran}(NC,NC)$	76.064	$NC \in S_{Iran}, NC \in S_{Iraq}$
8	$U_{Iraq}(NC,NC)$	142.203	$NC \in S_{Iran}, NC \in S_{Iraq}$

The matrix form of the outcomes of the two countries in this field is as follows.

		Iraq	
	Strategy	C	NC
Iran	C	115.301 ، 99.212	126.609 ، 89.482
	NC	131.050 ، 85.661	142.203 ، 76.064

Now it is possible to solve the above game using conventional solving methods, which are as follows.

A) Solve by the method of successive elimination of defeated strategies: In this game, the strategy of non-cooperation is defeated for Iran. If Iraq chooses the strategy of cooperation, Iran's consequence by selecting the strategy of cooperation is $ 99.212 billion and by choosing the strategy of non-cooperation is equal to $ 85.661 billion. In this case, cooperation is better than non-cooperation. Also, suppose Iraq chooses the strategy of non-cooperation. In that case, the profit of Iran is equal to 89.482 billion dollars by choosing the strategy of cooperation and 76.06 billion dollars by choosing the strategy of non-cooperation. In these circumstances, the strategy of cooperation is better than non-cooperation. Thus, in any case, the cooperation strategy is better than non-cooperation, cooperation is called the strongly dominant strategy, or non-cooperation is the strictly defeated strategy for Iran. Therefore, Iran never chooses not to cooperate.

The same argument can be applied to Iraq in that if Iran chooses the strategy of cooperation, the profit of Iraq will be equal to 115.301 billion dollars by choosing cooperation and 126.609 billion dollars by choosing non-cooperation. These conditions of non-cooperation will be better than cooperation for Iraq. Also, suppose Iran chooses the strategy of non-cooperation. In that case, the profit of Iraq will be equal to 131.050 billion dollars by choosing cooperation and 142.203 billion dollars by choosing the strategy of non-cooperation. In these circumstances, non-cooperation will be better than cooperation for Iraq. Moreover, it shows that Iraq's cooperation strategy is defeated, and it does not choose it. The calculations of this method are as follows:

$$U_I(s'_I = C, s_{-I} = C) = 99.212 > U_I(s_I = C, s_{-I} = NC) = 89.482$$
$$U_I(s'_I = NC, s_{-I} = C) = 85.661 > U_I(s_I = NC, s_{-I} = NC) = 76.064$$

In the above relationship, s_I is the strategy of Iran ($s_I \epsilon S_{Iran}$), s_{-I} is the strategy of the opponent player ($s_{-I} \epsilon S_{Iraq}$). So:

$$U_I(s'_I, s_{-I}) > U_I(s_I, s_{-I}) \qquad \forall s'_I = NC \epsilon S_I, \forall s_{-I} \epsilon \{NC, C\} = S_{Iraq}$$

So, the s_I Strategy cooperation is an entirely dominant strategy for Iran. We will have the same for Iraq:

$$U_I(s_{-I} = NC, s'_I = C) = 126.609 > U_I(s_{-I} = C, s_I = C) = 115.301$$
$$U_I(s_{-I} = NC, s'_I = NC) = 142.203 > U_I(s_{-I} = C, s_I = NC) = 131.050$$

Therefore, the strategy of non-cooperation is the dominant strategy for Iraq. Therefore, the entirely dominant strategy of this game can be written as follows:

$$D^s = (s_{iran}, s_{iraq}) = (C, NC)$$

B) Solve by Nash equilibrium method: Calculations related to finding the Nash equilibrium of this game are given.

$$B_1(C) = C$$
$$B_1(NC) = C$$
$$B_2(C) = NC$$
$$B_2(NC) = NC$$

			Iraq
	Strategy	C	NC
Iran	C	***99.212*** ، *115.301*	***89.482*** ، ***126.609***
	NC	*85.661* ، *131.050*	*76.064* ، ***142.203***

Nash equilibrium is where both players react to each other simultaneously. Here Nash equilibrium is where both elements are marked at the same time. Based on the best answers above, the game's balance is as follows.

$$\begin{cases} B_1(NC) = C \\ B_2(NC) = NC \end{cases} \rightarrow N(G) = C, NC$$

In other words, the game's equilibrium includes Iran's cooperation and the non-cooperation of Iraq in capturing this field. Figure 1. shows the state of Iran-Iraq's game equilibrium and payoff equilibrium in different scenarios.

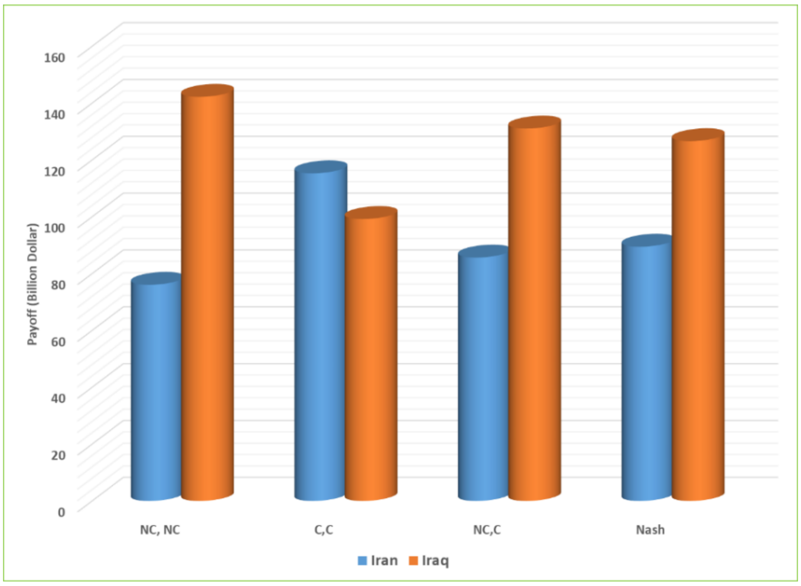

Figure 1. Profit status of players in different strategies and equilibrium

The South Pars gas field's game design results were calculated based on the above.

		Qatar	
	Strategy	C	NC
Iran	C	**2630**, 2309	**2267**, **2627**
	NC	2195, 2691	1905, **2945**

Nash equilibrium is where both players react to each other simultaneously. Here Nash equilibrium is where both elements are marked at the same time. Based on the best answers above, the game's equilibrium is as follows.

$$\begin{cases} B_1(NC) = C \\ B_2(NC) = NC \end{cases} \rightarrow N(G) = C, NC$$

In other words, the game's equilibrium includes Iran's cooperation and the non-cooperation of Qatar in producing from this field. Figure 2. shows the equilibrium of Iran-Qatar's game and payoff in different scenarios.

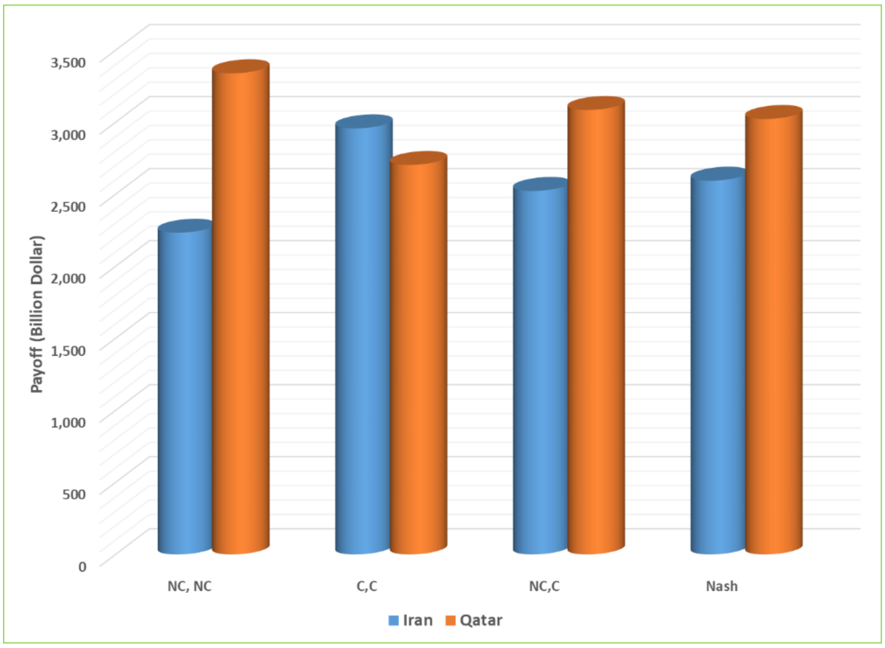

Figure 2. Profit status of players in different strategies and equilibrium

5. CONCLUSIONS AND SUGGESTIONS

Based on the mathematical model of the Yadavaran field, the optimal amount of Iran's harvest from this field was calculated as 139841 barrels per day. This oil field has three development phases, describing reaching the production ceiling of 85,000 barrels of oil per day in the first phase and reaching the production ceiling of 135,000 barrels of oil per day in the second phase, which is currently the first phase and has reached the production stage. According to the documents, negotiations for starting the second phase of the Yadavaran Square development project with an Iranian company in 2020 have begun in earnest. According to the estimated price for a barrel of crude oil in the budget of 2020, equivalent to $ 50, Iran's non-profit will be equal to $ 2.7 million for each day of delay in completing the second phase of Iran's development. Also, due to delays in the start of extraction from the South Pars gas field during the last three decades and relations with countries in the region, and the opportunity created for Qatar to cooperate with international companies and use modern technologies, from next year we will see a decrease in extraction from South Pars phases. According to Qatar's development plans, the changes in the common reservoirs' process conditions are that Iran will suffer many losses if it does not use the production methods and increase production. According to the convergence theory in today's world, convergence and regionalism are economic development, security, resolving regional crises, and advancing political goals. Convergence theory can be applied in all parts of the world, including the Persian Gulf. The games designed in this study showed that Iran's optimal strategy in extracting common oil and gas fields is cooperation, which is in line with convergence theory. Common oil and gas fields can be a way to converge countries; however, this convergence will not be possible shortly due to the many challenges in the convergence between these countries. Suppose preservation production from common fields is on the agenda. In that case, this theory's application will be helpful because conservation production is a production process that harmonizes the fields' economic value and respects the interests of the current and future generations.

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