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Iran's Strategy in Utilizing Common Resources of Oil and Gas: Game Theory Approach

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Abstract

Utilization management of Persian Gulf oil and gas reserves is important, because of the importance of this area owing to the fact that it comprised 60% of the proven oil reserves and 40% of the proven gas reserves of the world and it determines the world's oil and gas strategies. By using game theory, this paper seeks to achieve the best strategy that Iran could use in confronting other partners of common fields. Moreover, it seems to find the best approach for Iran and other countries in cooperation and non-cooperation conditions in extraction. The results showed that the higher the number of countries for a common resource, the less the attempt of each country would be; however, the more the total attempt of countries will be, which means more waste of attempt. Overall, partner countries in a resource are recommended to take actions to extract common resource via agreement and mutual cooperation; so that they could extract the same amount of common resources exercising less effort.

1. Introduction

With reference to the important and strategic role of Persian Gulf in global energy supply and the inclusion of considerable common resources with other countries, it is necessary to carry out some researches and studies on how to extract from these common resources and how to interact with countries sharing these resources. On the other hand, among the OPEC members, Saudi Arabia, Iran, Iraq, Kuwait, United Arab Emirates, and Qatar will own in total 60% of the proven oil reserves of the world in long term with reduction of OPEC members and will determine the global oil strategies (Forneth, 2004). Trans-boundary natural resources is any type of natural resources that normally without interference of human is able to pass through political borders of country. Common oil and gas fields could be the obvious case of these resources owing to their geographical expansion and belonging to more than one country (Beyene and Wadley, 2004). The issue of common oil and gas resources for countries such as Iran whose economy depends considerably on oil revenues is

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critical (Ilias, 2008). On the other hand, the management of these resources in consumption and utilization after oil shocks of 1970s is one of the priorities of energy policy making at international, regional, and national levels. By oil price increase shock and manner of optimum extraction, a new motivation was created in oil producers which doubled the importance of optimum utilization of oil resources (Gorbani Pashakolaei et al., 2014). Undoubtedly, the most important paper proposing theoretical principles of the behavior of corporates extracting nonrenewable resources regarding the efficient use of the existing resources is that of Hotelling in 1931 (Haji Mirzaaei et al., 2016).

Today, in most areas of the world, such as America continent and North Sea, common oil fields among various countries of companies are use through coordinated extraction or united management. Agreement on legal and technical issues in this area is a common trend and the coastal countries of Persian Gulf area should take action on the extraction and use of these common resources by looking at the future and by considering this main issue, will lead to cost reduction. Since in terms of oil and gas reserves, Persian Gulf has the richest oil and gas reserves of the world (Navazni and Nojoumi, 2008). Thus, the disputes in Persian Gulf should be managed and actions should be taken for common and coordinated use of oil and gas resources for improvement of economic condition and maintenance and elevation of these reserves. On the other hand, the benefits that these countries obtained by cooperating in this area is more sustainable and long term than negligible profit of unscientific and uncontrolled use of these common reserves (Darvishi and Nojoumi, 2007).

Since there is conflict of interest in mutual relation of countries in extraction and use of common resources and some consequences were obtained concerning their selected strategies and other common countries, it is possible to study this issue in form of a static game with perfect information. The essential and main assumption in these games is that any party to the game does not have any information on the selection of opponent and in fact it seems as if both of them simultaneously do their selection. It might be the case that players perform their selections in various times during the game, but keep their selections unknown to each other. The other main assumption in these games is that all outcomes and consequences of game are known to all players, that is, each player knows what he would get in respect to his selection and his opponent's selection.

This paper is organized into 7 parts. After introduction, the literature review will be presented in the second part and then research background in the third part. The fourth part includes complementary explanations about common reserves and agreements. Modeling of game is presented in the fifth part and the results of the model in the sixth part. The final part includes conclusion and recommendations.

2. Research Background

The analyses and forecasts of credited economic centers of the world in investigation and analysis of production and consumption indices show that the world will demand non-renewable natural energies in future years like in the past and only the demand will gradually change from oil to natural gas in this process. Iran is one of the seven leading countries in in-site oil reserves and the second country having natural gas resources and its current geographical situation has special and unique place that could make Iran one of the best actors of the world economic future. When Iran geographical situation is considered in oil and gas, the first main issue apart from energy transit issue is the presence of joint oil and gas fields between Iran and its neighbors. The presence of common land and water borders in some oil and gas areas of Iran with neighboring countries has made this issue very important in major planning of oil industry such that the experts and specialists of political and economic issues consider it as the frontline of oil industry. The presence of this amount of common oil, gas, offshore, and onshore fields is a considerable issue with its special necessities and requirements. By using the capital of international companies and political flexibility in negotiations, the neighboring countries are harvesting oil fields and the continuation of this trend will bring irreparable losses to Iran.

Given these realities and the fact that Iran will be involved in a game with the countries with whom it shares these fields, a decision must be made such that violation of it will not be to the interest of any country and the game theory with Nash equilibrium will be the instrument for this game and its solution. Thus, in this study, regarding to the existing conditions, the game model will be designed and the model will be solved in cooperative and non-cooperatives status with reference to the laws governing the game theory.

In game theory, the interactions (mutual relations) where there is mutual dependency and relation between parties are called game. The main feature of decision making in game terms and conditions is that any player should analyze the reaction of others to his selection and decision before making any decision and selection and then makes the best decision. In other words, any player that wants to earn the highest benefit needs to consider the reaction of the other party (Abduli, 2007).

Game theory is useful especially when the number of players is limited. Since in this condition, the action of any player has meaningful effect on the payoff of other players. The aim of game theory model is to predict the outcomes (the list of taken actions by any participant) while the motivation of all participants are clearly known. Thus, game theory is very useful in analyzing industries including a limited number of competitors since the action of any corporate (price determination, production rate, research and development or marketing strategies) has severe effect on the profit of competitive corporates (Shy, 2014).

Game theory has various uses and various model makers make use of it since when the price theory cannot respond to them, makes them think the same as economists (Gibbons, 1997). For example, based on the strategies in a special game similar to chess, Newman was able to model the interactions between United States and Soviet Union during cold war by considering them as two players in a zero-sum game (Rashidi, 2013).

Some years ago, Adam Smith, father of modern economy, claimed that in competition, individual motivations help to achieve common objectives and the best results might be achieved when everybody in the group perform what is the best for him. This thinking was the base of man economic decision makings for some years and is taught as the basics of science of economy and a complete principle.

At the end, John Nash proposed his theory in 1994 as opposed to 150 years of economic theory in this way, "The best results are achieved when everyone performs what is best for him and the group". He expanded the issue of collaboration in game theory and showed that if people cooperate and meanwhile consider the interest of the group, they will achieve the highest interests and benefits for themselves and the group. This issue was explained using the example of prisoners' dilemma and how two people in cooperation make themselves suffer and lose in order to achieve higher profit it was shown (in fact, pursuing personal profit leads to self-harm and lose) while they could achieve better results via cooperation (Siegfried, 2013).

On the other hand, from Plato time to second half of the twentieth century, there were several fundamental believes in human rational thinking and they survived without being challenged such as, "like proposition is either correct or false", "any correct proposition could be proven anyway but it is difficult to prove", "Solving any dispute is possible by defeating one of the parties or both".

The most important achievement of intellectualism of the twentieth century and especially its second half is challenging; these thoughts were done by great thinkers. In the first case, it was proven that there are most propositions that are neither correct nor false. In the second case, it was proven that there are many correct propositions that cannot be proved at all and the dimensions of correct unverifiable propositions are more than the provable propositions. Here, the discussion and debate is about the third category of intellectualism achievement of twenties century, that is the possibility of finding equilibrium and balance in conflicts (Tabibian, 2010).

Thus, this question might propose that conflict is an inevitable part of the history and interaction of human communities, is it possible to find optimum point and balance in conflict? Since it might happen that the effort for overcoming the opponent is not the optimum solution even for the winning party (Tabibian, 2010).

The main principle of game theory is that all players know the structure of game in a common game and they also know that their opponents know it too; moreover, the other competitors also know that they know this issue and so on. This condition of game is called common knowledge (Mas-Colell et al., 1995).

Games are classified in various groups; one of the most common types of games is the static games of complete information where the players select their strategy simultaneously and every player knows the payoffs of other players in the game (Abduli, 2012, Mas-Colell et al., 1995). The obtained equilibrium from this type of games is called Nash equilibrium which is defined as follow:

$u_i(\sigma_i, \sigma_{-i}) \geq u_i(\sigma_i^{'}, \sigma_{-i})$

It means that the strategy of player is to be the best reaction to selected performance of other competitors (Mas-Colell et al., 1995). It should be confirmed that if game theory wants to present a unique answer to game, that should be Nash equilibrium. If any player selects the strategy which makes him get the highest outcomes concerning his belief toward the opponent's choice and the belief of the player is true (that is, in practice, the opponent selects the strategy which is formed in the belief of player), then Nash equilibrium will be achieved. The strategies chosen in this way constitute Nash equilibrium (Abduli, 2007).

3. Review of Literature

Here, a brief review of the studies done on common resources and also game theory will be presented. Darvishi and Nojomi (2007) in their study on geographical area investigated the common hydrocarbon reserves of Iran in Persian Gulf. The results of the study showed that reconsideration of the current trend of extraction from common reserves and taking actions in unification of management on this type of reserves are necessary and will maximize Iran economic interests. Daneshnia (2011) studied the application of game theory and neoliberal institutionalization in analyzing the behavior of the main players of gas OPEC. In this study, he studied the effective variables in relations between Iran, Russia, and Qatar in terms of structure and made scenario based on strategic choices on functional relations of these countries. The results showed that despite diverging barriers between these three countries, cooperation in energy section and taking collective behavior is a structural and functional necessity for these countries. Emphasizing the significance of financial resources, Ahmadian and Varherami (2013) focused on extraction of optimum route from South Pars offshore reservoir (by applying environmental constraints). They used data related to 2002-2012 and the results of the study showed that the use of environmental constraints as one of the content of contracts indirectly leads to increased extraction from reservoir. In their study, Keramati Moezabad and Ghasem (2014) determined the optimum number of wells in one of the oil fields of Iran using Monte Carlo and genetic algorithm models. They performed two scenarios as horizontal and vertical wells and the results of the study showed that horizontal wells scenario have more appropriate production and higher economic efficiency than vertical wells in the studied field.

Pyndyck (1978) presented a model on optimum rate of exploration and production of exhaustible resources using data related to Texas in 1965-1974.

Then he showed the optimum extraction path in competitive and monopoly markets condition. In their study on the report of oil and gas hiring bid, Haile et al. (2010) investigated this issue that there might be some collusion between participating oil and gas companies and also the partnership manner of foreign companies in exploration, excavation, and extraction. The results of the study showed the geographical and political conditions of the area, the location of offshore reserves and companies' achieving new technology have considerable role on the contractual price and investment rate of foreign companies.

Magirou (1984) analyzed the process of national decisions on energy saving and fuel exchange in a zero-sum game. The results of the study revealed that if there is a commitment mechanism that will remove the possibility of deviating from some preagreed strategy, these countries can all gain by reaching some Pareto strategy. Leighty et al. (2012) studied the dynamic optimization model by explaining the cost and revenue functions of seven oil fields in northern part of Alaska and the effect of financial policies of the government in extraction of optimum path for oil production. The results of the study showed that the structure of tax policy can be designed to affect the economically optimal production path, but at a cost in net social benefit.

Aplak and Sogut (2013) examined the decision making process in energy management using a combined method of fuzzy method and game theory. In their model, players were defined as industry and environment and strategies were analyzed using MCDM[1]. They asserted that this combined method could also be used in complex structures such as production to consumption and energy sensible sectors. The results of the study revealed that while industry tries to maintain the sustainability of production with the strategies of fossil fuel, renewable energies, energy recovery, and nuclear energy usage, environment exhibits reactive approach to ensure its sustainability.

Esmaeili et al. (2015) interpreted the sustainable policy in Iran and Qatar disputes in a 2*2 game using game theory. Their results revealed that countries should use reasonable strategy in utilization of common oil and gas resources. In their study, Popescu and Hurduzeu (2015) studied the energy challenges for Europe via the significance of natural gas price in two conditions of cooperative and non-cooperative game from game theory approach. Their results showed that European Union needs to decrease its gas import from Russia and selects better options for import. Zeng et al. (2018) studied the modeling of interprovincial cooperative energy saving in China: An electricity utilization perspective. The results, based on the data from 2001–2014, showed that cooperation can significantly increase the benefits of electricity utilization for each province in the union.

As earlier shown, due to significance of oil and gas in economic and political issues, various studies have been performed in this regard; however, no study has dealt with the strategies of countries in case of simultaneous presence

[1] Multiple Criteria Decision Making

in a common field based on game theory so far. Most previous studies have focused on the optimum extraction path based on costs, revenues, oil and gas price, etc. Thus, this study focuses on the issue that in case of cooperation and failure to cooperate, how is the optimum results for extraction and utilization of common resources and which condition (cooperation or failure to cooperate) has better payoffs. Moreover, it will show how any player (country) should behave so that its violation is not against him in the case of shared utilization of a resource; in other words, how Nash equilibrium will be.

4. Shared Resources and Agreement on Their Utilization

Iran has common resources and reservoir with its neighboring countries, that is, Iraq, Kuwait, Saudi Arabia, Qatar, Emirates, and Oman. There are at least 15 reservoirs in this regard; while the possibility that some of the other resources are common is not clear yet. Iran has common resources on land with Iraq. In Iran-Iraq common border, there are 5 oil reserves including Naftshar (previously called Naftshah), Dehloran, Paydar Qarb, Azadegan, and Yadavaran (previously called Hoseinie-Keveshk). The remaining 10 common fields of Iran are in sea with neighboring countries of Persian Gulf. Arash gas field is the only common field of Iran with Kuwait in Persian Gulf. Esfandiar, Frouzan, Farzad (A), and Farzad (B) are common with Saudi Arabia. So far, no common reserve has been explored and reported between Iran and Bahrain in Persian Gulf. Big South Pars gas field that turns to North field at the end is common with Qatar. This field is the biggest and most important common field of Iran and the world. Salman, Farzam and Nosrat are the shared reserves of Iran with UAE. The only shared and common field of Iran and Oman is Hengam gas field. The biggest shared gas field of the world (South Pars-Qatar North) in Qatar side has been explored and used 20 years earlier than Iranian side. Moreover, currently, UAE uses Salman common field and Saudi Arabia uses Forouzan common field more than twice than Iran (assaluyeh.com).

Sea bed in Persian Gulf has two unique features; on one hand it is full of rich resources of oil and gas and on the other hand, the sea width is narrow. Thus, these properties have provided good ground for proposing governance and conflict of benefits. Based on these truths, coastal countries of Persian Gulf have confined the maritime limits in form of mutual agreements on determination of borderline between parties and use of natural resources (common fields of oil and gas) that will be summarized following the following:

Saudi Arabia-Kuwait agreement: AL-Uqair agreement holds in 1922 where it was decided that Kuwait and Arabia benefit from equal right and the UK government will work on the basis of goodwill on how to use it on a mutually agreed basis. In 1967, more than 584 million oil gallons were extracted by two countries from common fields.

Bahrain-Saudi Arabia agreement: This agreement was held in 1958 between these countries and based on article 2 of this agreement, it was decided that the exploration of oil resources should be done under the supervision of

Saudi Arabia kingdom on the condition that Arabia pay half of the benefits earned from oil exploration and excavation to Bahrain government. In 2007, more than 67 million gallons were extracted from this field by Saudi Arabia.

Qatar-Abu Dhabi agreement: This agreement was held in 1969 between Qatar and Abu Dhabi and based on article 6 of this agreement, it was decided that AL–Bunduq field should be equally divided between parties. The parties will consult periodically about all issues related to this field and its exploration in order to exercise their sovereignty based on justice and fairness.

Iran- Saudi Arabia delimitation agreement: This agreement was held in 1968 between two countries and based on article 4, it was decided that each party should agree that no oil exploration activity will be done in person or by authorities of that party inside an area of 500 m width from specified borderline to the extent of the mentioned line in submarine areas of that country. It should be noted that this agreement lacks any obligatory cooperation commitment and no supervising mechanism has been agreed on for the development of oil and gas common fields in maritime border areas.

Iran-Sharjah agreement: This agreement was held in 1971 between two countries and based on article 5, it was decided that extraction of oil resources and underground reserves under Abu Musa waters should be recognized by Iran (within the contract of Sharjah and Biotes company) and half of oil revenues earned from these resources by the mentioned company should be given to Iran and half to Sharjah. The weakness of this agreement is that it has not referred to future explorations and there is no arbitrary in this regard.

Iran-Oman delimitation agreement: This agreement was held in 1971 between these two countries and based on article 2, it was decided that no well should be dug at both sides of the specified borders whose exploitation part is located at 125 m from borderline unless with parties' agreement. Moreover, in case of any accident, both countries will do their best to coordinate the operation.

Iran-Bahrain delimitation agreement: This agreement was held in 1971 between two countries and article 2 of this agreement is the same as article 2 of Iran-Oman delimitation agreement.

Iran-Qatar delimitation agreement: This agreement was held in 1970 between two countries and article 2 of this agreement is the same as article 2 of Iran-Oman delimitation agreement.

It should be noted that despite these agreements, there was no common use implemented between Iran and other neighbors (Mir Abbasi and Jahani, 2011).

5. Game Modeling

Here, the game modeling for various states (two countries and generalization to n-country state) will be presented.

5.1 Two-country state

Assuming that y is the remaining amount of oil reserves, X_T is the identified oil amount from existing oil reserves (since some oil resources might be identified but currently impossible to be extracted or temporally not being extracted for any reason) and x is the extracted oil from X_T. Thus, $X_T = x + x_0$, where x_0 is the extractable oil from oil reserves that is yet to be extracted. One can consider the following Equation 1 for the remaining amount of oil reserves and extracted oil from oil reserves' resources:

$$y = 1 - x \quad (1)$$

For simplicity, it is assumed that total amount of the existing oil reserves in underground resources is equal to 1. This equation shows that the same amount of oil that is extracted will be reduced from the remaining reserves. On the other hand, oil extraction from underground resources (E) requires the use of some factors (such as workforce, tools, etc.) that is shown by W and is called level of effort/work. Moreover, oil extraction from underground resources depends on the amount of identified oil from the underground resources (X_T). Thus, we can define these items using Equation 2:

$$E = WX_T \quad (2)$$

This equation shows that using more workforces, tools, etc., led to higher extraction of oil from underground resources. Moreover, the more oil is identified from available reserves; the more oil will be extracted from underground resources. By drawing Equations 1 and 2 in a graph, the following equation will be achieved:

$$1 - x = WX_T \Rightarrow 1 - x = W(x + x_0)$$

Simply, we can obtain x^*as follow:

$$x^* = \frac{1 - x_0 W}{1 + W} \quad (3)$$

By substituting $(x^*)x$ optimum value in function E:

$$E = W(x + x_0) \Rightarrow E = W\left(\frac{1 - x_0 W}{1 + W} + x_0\right) \Rightarrow E = \frac{W(1 + x_0)}{1 + W} \quad (4)$$

This equation shows the relationship between oil extraction from underground resources, level of effort, and the amount of not-extracted oil that could be extracted from oil reserves. Assuming that there are two countries that are individually using these common oil resources and they play a static game with full information in allocating the level of effort for extraction. The level of effort of I country (Iran) is represented by W_I and the level of effort of other country, -I (other than Iran) is represented by W_{-I}. Having these general conditions, the effort spent for extraction from underground oil resources is equal to:

$$E_T = \frac{W_T(1 + x_0)}{1 + W_T} \quad (5)$$

Since, $W_T = W_I + W_{-I}$,

Equation 5 could be written as follows:

$$E_T = \frac{(W_I + W_{-I})(1 + x_0)}{1 + W_I + W_{-I}} \quad (6)$$

Assuming that the share of any country from oil extraction is equal to the share of the country from total effort (this assumption is logical since the oil resources are common and any country that exercises more effort could extract more from common oil resources), thus:

$$E_I = \frac{W_I}{W_T} E_T \Rightarrow E_I = \frac{W_I}{W_I + W_{-I}} \frac{(W_I + W_{-I})(1 + x_0)}{1 + W_I + W_{-I}} \Rightarrow E_I = \frac{W_I(1 + x_0)}{1 + W_I + W_{-I}} \quad (7)$$

In the same way

$$E_{-I} = \frac{W_{-I}(1 + x_0)}{1 + W_I + W_{-I}} \quad (8)$$

where $E_T = E_I + E_{-I}$.

Assume the sale price of any unit of extracted oil (in terms of gallon) to be p and cost function is $C = e^{-by}$. In this function, C is the production cost, y is the remaining oil reserve, and b is the reserve effect parameter. This parameter shows how much oil extraction cost depends on the remaining oil reserves. In relation to the fact that oil extraction cost increases by decreasing the existing reserves, it is expected that this value has negative sign. In addition, the bigger number, means that the oil extraction cost is more dependent on the remaining reserves (Lin, 2009). Now, we can consider the outcomes of the two countries as follow:

$$\pi_I = pE_I - cW_I \Rightarrow \pi_I = p \frac{W_I(1 + x_0)}{1 + W_I + W_{-I}} - e^{-by} W_I \quad (9)$$

$$\pi_{-I} = pE_{-I} - cW_{-I} \Rightarrow \pi_{-I} = p \frac{W_{-I}(1 + x_0)}{1 + W_I + W_{-I}} - e^{-by} W_{-I} \quad (10)$$

For simplicity, if we assume $b = 0.0002$ and due to small value of (by) and for simplicity[1], we can consider $e^{by} = 1$. Thus:

$$\pi_I = pE_I - cW_I \Rightarrow \pi_I = p \frac{W_I(1 + x_0)}{1 + W_I + W_{-I}} - W_I \quad (11)$$

$$\pi_{-I} = pE_{-I} - cW_{-I} \Rightarrow \pi_{-I} = p \frac{W_{-I}(1 + x_0)}{1 + W_I + W_{-I}} - W_{-I} \quad (12)$$

Strategic form of game will be as follow:

Players set: $N = \{I, -I\}$

Players' strategy: $i = I, -I, W_i \in S_i, S_i = [0, \infty]$

Player I outcome is shown by $\pi_I(W_I, W_{-I})$ and player $-I$ outcome by $\pi_{-I}(W_I, W_{-I})$.

5.2 General Condition of n-Countries

Let assume there are n-countries that individually uses common oil resources and perform a static game with full information in allocating the effort for extraction. The level of effort of the first country is represented by W_1, the second country is represented by W_2, the third country is represented by W_3, … ,

[1] Gorbani Pashakolaei et al. (2014) have estimated this number in their study. Thus, for simplicity, this value has been used for average effect of oil reserves.

and the n^{th} country is represented by W_n. With this condition, the total effort for extraction from underground oil resources, regarding to what was previously explained (Equation 5) is equal to:

$$E_T = \frac{W_T(1+x_0)}{1+W_T}$$

Since, $W_T = W_1 + W_2 + W_3 + \cdots + W_n$, we can write Equation 5 as follows:

$$E_T = \frac{(W_1+W_2+W_3+\cdots+W_n)(1+x_0)}{1+W_1+W_2+W_3+\cdots+W_n} \tag{13}$$

Assuming that the share of any country from oil extraction is equal to the share of that country from total effort (this assumption is logical since the oil resources are common and any country that exercises more effort could extract more from common oil resources), thus:

$$E_1 = \frac{W_1}{W_T} E_T \Rightarrow E_1 = \frac{W_1}{W_1+W_2+W_3+\cdots+W_n} \frac{(W_1+W_2+W_3+\cdots+W_n)(1+x_0)}{1+W_1+W_2+W_3+\cdots+W_n} \Rightarrow$$

$$E_1 = \frac{W_1(1+x_0)}{1+W_1+W_2+W_3+\cdots+W_n} \tag{14}$$

In the same way:

$$E_2 = \frac{W_2(1+x_0)}{1+W_1+W_2+W_3+\cdots+W_n} \tag{15}$$

Moreover, for n^{th} country:

$$E_n = \frac{W_n(1+x_0)}{1+W_1+W_2+W_3+\cdots+W_n} \tag{16}$$

where in these equations $E_T = E_1 + E_2 + \cdots + E_n$.

Considering the previous assumptions, the outcome of *n*-countries is obtained as follows:

$$\pi_1 = pE_1 - cW_1 \Rightarrow \pi_1 = p\frac{W_1(1+x_0)}{1+W_1+W_2+W_3+\cdots+W_n} - W_1 \tag{17}$$

$$\pi_2 = pE_2 - cW_2 \Rightarrow \pi_2 = p\frac{W_2(1+x_0)}{1+W_1+W_2+W_3+\cdots+W_n} - W_2 \tag{18}$$

6. Results

Here, the results of game model for two, three and *n* countries states will be presented:

6.1 Two-Country State

The best response of any player was obtained in order to obtain Nash equilibrium. Concerning Equation 11, we have:

$$\frac{\partial \pi_I}{\partial W_I} = 0 \Rightarrow \frac{p(1+W_{-I})(1+x_0)}{(1+W_I+W_{-I})^2} - 1 = 0$$

Simplifying and solving this equation, we have:

$$B_I(W_{-I}) = W_I^* = \sqrt{p}\sqrt{1+W_{-I}}\sqrt{1+x_0} - W_{-I} - 1 \tag{19}$$

On the other hand, concerning Equation 12, we have:

$\frac{\partial \pi_{-I}}{\partial W_{-I}} = 0 \Rightarrow \frac{p(1+w_I)(1+x_0)}{(1+w_I+w_{-I})^2} - 1 = 0$

By simplifying and having previous assumptions and solving this equation:

$$B_{-I}(W_I) = W_{-I}^* = \sqrt{p}\sqrt{1+W_I}\sqrt{1+x_0} - W_I - 1 \quad (20)$$

Since $p = 46, x_0 = 0.58$ [1], we have:

By substituting Equations 11 and 12, we have:

$$W_I^* = 8.52\sqrt{1+W_{-I}} - W_{-I} - 1 \quad (21)$$

$$W_{-I}^* = 8.52\sqrt{1+W_I} - W_I - 1 \quad (22)$$

By substituting Equations 21 and 22 inside each other, we have:

$$W_I^* = 18.13 \quad (23)$$

$$W_{-I}^* = 18.13 \quad (24)$$

Thus, Nash equilibrium is equal to:

$$N(G) = \{(W_I^*, W_{-I}^*) = (18.13, 18.13)\}$$

Considering the above terms, the following results could be obtained:

- Total effort of the two countries in Nash equilibrium is equal to:

$$W_T^* = W_I^* + W_{-I}^* = 18.13 + 18.13 = 36.26 \quad (25)$$

- Total extracted oil by two countries (according to Equations 7 and 8) in Nash equilibrium is equal to:

$$E_T^* = E_I^* + E_{-I}^*$$

$$\begin{cases} E_I^* = \frac{W_I^*(1+x_0)}{1+W_I^*+W_{-I}^*} = \frac{28.64}{1+18.13+18.13} = 0.76 \\ E_{-I}^* = \frac{W_{-I}^*(1+x_0)}{1+W_I^*+W_{-I}^*} = \frac{28.64}{1+18.13+18.13} = 0.76 \end{cases} \quad (26)$$

$$\Rightarrow E_T^* = 0.76 + 0.76 = 1.52 \quad (27)$$

Now, according to Equation 6:

$$E_T = \frac{(W_I + W_{-I})(1+x_0)}{1 + W_I + W_{-I}}$$

Moreover, according to Equation 27:

$$E_T^* = 1.52$$

Thus (by equating Equations 5 and 27), we have:

$$1.52 = \frac{W_T(1+x_0)}{1+W_T} \quad (28)$$

By solving this equation, W_T root will be 25.33.

This important equation shows that in case of cooperation between countries, it is possible to extract 1.52 by less effort (25.33); while, previously, an effort of 36.26 was required. In the first equilibrium, by playing a static game, two countries lead to wasting of some effort (ineffective effort) since the available resources are to be ended and more effort is required to reach those oil

[1] The recoverable crude oil reserves of the country is 711.5 billion gallons out of which 175.39 billion gallons are considered as recoverable reserves out of which 102 billion gallons remained (Iran Oil Company, June 2017)

resources in lower levels. In addition, with increase in the number of countries using common resources, the waste of effort will increase. It is necessary to note that these points are Nash equilibrium points and in other words, deviation from them is in the interest of no country.

6.2 Three Countries Status

Considering countries 1, 2 and 3; since $p = 46$, $x_0 = 0.58$, by model expansion and concerning Equations 21 and 22, we have:

$$W_1^* = 8.52\sqrt{1 + W_2 + W_3} - W_2 - W_3 - 1 \quad (29)$$

$$W_2^* = 8.52\sqrt{1 + W_1 + W_3} - W_1 - W_3 - 1 \quad (30)$$

$$W_3^* = 8.52\sqrt{1 + W_1 + W_2} - W_1 - W_2 - 1 \quad (31)$$

By substituting Equations 29, 30, and 31 in each other, we have:

$$W_1^* = 16, \quad W_2^* = 16, \quad W_3^* = 16 \quad (32)$$

Thus, Nash equilibrium is equal to:

$$N(G) = \{(W_1^*, W_2^*, W_3^*) = (16,16,16)\}$$

Considering the above terms and conditions, the following results will be obtained:

- The total effort of two countries in Nash equilibrium is:

$$W_T^* = W_1^* + W_2^* + W_3^* = 16 + 16 + 16 = 48 \quad (33)$$

- Total extracted oil by two countries in Nash equilibrium is:

$$E_T^* = E_1^* + E_2^* + E_3^*$$

$$\begin{cases} E_1^* = \frac{W_1^*(1+x_0)}{1+W_1^*+W_2^*+W_3^*} = \frac{25.28}{1+16+16+16} = 0.51 \\ E_2^* = \frac{W_2^*(1+x_0)}{1+W_1^*+W_2^*+W_3^*} = \frac{25.28}{1+16+16+16} = 0.51 \\ E_3^* = \frac{W_3^*(1+x_0)}{1+W_1^*+W_2^*+W_3^*} = \frac{25.28}{1+16+16+16} = 0.51 \end{cases} \quad (34)$$

$$\Rightarrow E_T^* = 0.51 + 0.51 + 0.51 = 1.53 \quad (35)$$

Now, since:

$$E_T = \frac{(W_1 + W_2 + W_3)(1 + x_0)}{1 + W_1 + W_2 + W_3}$$

and according to Equation 35:

$$E_T^* = 1.53$$

Thus, we have:

$$1.53 = \frac{W_T(1+x_0)}{1+W_T} \quad (36)$$

By solving this equation, W_T root will be 30.6.

This important equation shows that in case of cooperation between countries, it is possible to extract the same 1.53 by less effort (30.6); while, previously an effort of 48 was required. In the first equilibrium, by playing a static game, three countries lead to the waste of some efforts (ineffective effort), since the available resources were to be ended and more effort is required to reach those oil resources in lower levels. In addition, by increasing the number of countries using common resources, the waste of effort will also increase.

By comparing two and three countries states, it becomes clear that if two countries simultaneously extract from one resource, each country will have an effort of 18.13 and the total effort of both countries will be 36.26. Each country will extract 0.76 and in sum, two countries extract 1.52; however, if three countries simultaneously extract from one resource, the effort of each country will be 16 and overall the total effort of the three countries will be 48. In this condition, every country extracts 0.51 individually and overall, two countries extract 1.53. This comparison shows that the more the number of partner countries in a common source, the lesser the effort each country will need for extraction; however, the total effort is more than the condition where less countries are sharing one resource. In other words, the more the countries sharing a common resource, the individual effort level of any country will decrease but the total effort (total effort of countries) will increase which means that part of the effort is wasted.

6.3 n-Country Status

Considering Equation 17, we have:

$$\frac{\partial \pi_1}{\partial W_1} = 0 \Rightarrow \frac{p(1 + W_2 + W_3 + \cdots + W_n)(1 + x_0)}{(1 + W_1 + W_2 + W_3 + \cdots + W_n)^2} - 1 = 0$$

By simplifying and solving this equation:

$$B_1(W_2) = W_1^* = \sqrt{p}\sqrt{1 + W_2 + W_3 + \cdots + W_n}\sqrt{1 + x_0} - W_2 - W_3 - \cdots - W_n - 1$$

On the other hand, considering Equation 18, we have:

$$B_2(W_1) = W_2^* = \sqrt{p}\sqrt{1 + W_1 + W_3 + \cdots + W_n}\sqrt{1 + x_0} - W_1 - W_3 - \cdots - W_n - 1$$

And so on.

If, as before, $p = 46$ and $x_0 = 0.58$, then:

$$W_1^* = 8.52\sqrt{1 + W_2 + W_3 + \cdots + W_n} - W_2 - W_3 - \cdots - W_n - 1$$
$$W_2^* = 8.52\sqrt{1 + W_1 + W_3 + \cdots + W_n} - W_1 - W_3 - \cdots - W_n - 1$$
$$\vdots$$
$$W_n^* = 8.52\sqrt{1 + W_1 + W_2 + \cdots + W_{n-1}} - W_1 - W_2 - \cdots - W_{n-1} - 1$$
$$\Rightarrow W_1^* = W_2^* = \cdots = W_n^* = 7.52$$

Thus, Nash equilibrium is equal to:

$$N(G) = \{(W_1^*, W_2^*, \ldots, W_n^*) = (7.52, 7.52, \ldots, 7.52)\}$$

Considering the above terms and conditions, the following results are obtained:

- Total effort of two countries in Nash equilibrium is equal to:

$$W_T^* = W_1^* + W_2^* + \cdots + W_n^* = 7.52 + 7.52 + \cdots + 7.52 = n(7.52)$$

- Total extracted oil by two countries in Nash equilibrium is equal to:

$E_T^* = E_1^* + E_2^* + \cdots + E_n^*$

Generally, the obtained values for extraction will approach zero with increased number of countries extracting common source and with this condition, the level of efforts of countries will also approach zero. The reason is that since the common resource is distributed between many countries, no country will pay the cost of use from the source whose extraction approaches zero. Moreover, the obtained results show that the more the number of countries in the extraction of a common source, the required effort for any country for extraction will decrease.

7. Conclusion and Recommendations

After oil shocks in 1970s, economic researchers focused their attention on optimum use of oil and gas resources. Concerning the fact that Iran's share of extraction from common resources of oil and gas is much lower than other partners of these resources, the significance of this study becomes highlighted for giving some insights to managers and politicians. In this study, using game theory (static game of complete information), the optimum strategy for Iran in using common resources of oil and gas was studied. First, this game was modeled for a condition where two countries are sharing one resource and then it was extended to a condition where n countries are sharing a resource. Since the previous studies on common resources of oil and gas were mostly based on extraction optimum path (based on cost reduction, revenues, etc.), the strategy for optimum extraction of resources was considered in the present study. To this end, this game was modeled for two states of cooperation and non-cooperation.

The results of this study showed that the more the countries sharing a common resource, then the effort level of any individual country will decrease, but the total effort level (sum of efforts of countries) will increase and this means that part of the efforts is wasted. Moreover, the values of Nash equilibrium (effort level and extraction rate) were obtained which show that their violation will not be to the benefit of any country.

Considering the trend taken by other countries for cooperation, Iran is recommended to take more economic actions by cooperating with other coastal countries of Persian Gulf, holding new agreement and modifying previous agreement on extraction and utilization of common sources of oil and gas.

Utilizing the capital of international companies and political flexibility in negotiations, the neighboring countries are harvesting these fields and its continuation will bring irrecoverable losses to Iran. In relation to the procedures adopted by other countries in cooperation, it is recommended that Iran should take actions on extraction and utilization of common oil and gas resources for better economic performance with cooperation with other coastal countries of Persian Gulf, holding new contracts and modifying previous contracts and agreements.

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