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RESEARCH PAPER

Evolutionary Game Theory Approach to Technology Development of Oil and Gas Equipment Manufacturing Industry: The Case of the Ten Major Commodity Groups' Project of the Petroleum Industry

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Abstract
Technology development, especially in petroleum industries, is one of the most important ways of economic development in oil-rich countries. However, despite such challenges as structural economic problems, the issue of moral hazards, and the conflict of interests, government policies are crucial. This study analyzed the long-term behavior of the government and the private sector as two main actors using the evolutionary game theory and solved their strategies by replicator dynamic equations. Finally, based on a real-world case in Iran, a numerical study was performed to better understand the characteristics of the game model under realistic conditions. The outputs indicate that the main approach of the government, with minimal incentive mechanisms, should be legal monitoring. Sensitivity analyses on some key parameters show that the important factor in project implementation is attention to the private sector's revenues and expenditures, and the government's revenues and expenditures have little effect on the outputs and behavior change.

Keywords: technology and economic development, policymaking, oil and gas manufacturing industries, cooperation, moral hazards.

1. Introduction

Scientists are interested in determining how government-centered technology-oriented policies create different tangible values in different societies (Freeman & Soete, 1997). Some papers examine how the external regulatory environment can influence corporate strategic capabilities of innovativeness and learning (Tajeddini & Trueman, 2016).Accordingly, many scholars have focused, in their systematic study of government policies, on technology and entrepreneurial activities in a sustained manner (Furman & Hayes, 2004). and some scientist have studied the government policies and programs that provide advice and support for new businesses (Tajeddini & Trueman, 2016). To be effective in the innovation process, innovative economies need an interconnected set of institutions, and this is why governments in both developing countries and developed countries need innovation policy (Sachs & McArthur, 2002).

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Moreover, some oil-rich countries like Iran are struggling with issues such as economic stagnation and turmoil, sanctions, the inefficiency of legal and infrastructure systems, the lack of productivity in the production process, inflation, exchange rate instability, and overhead costs.

On the other hand, the large-scale development projects of technology development in these countries, especially in Iran, typically face many challenges. In addition to macroeconomic problems, these projects – in particular – usually involve various institutions with different executives that have different views and interests. Given the need for the cooperation of the beneficiary institutions, it is imperative to settle the conflicts of the institutions involved. This is also evident in the Project of Ten Commodity Groups (PTCG), which can be regarded as the largest industrial technology development project in Iran.

The development of the oilfield equipment technology will have very positive effects on both the oil industry and the economy of Iran. However, there are differences in the perception of the interests of the state-run and private companies. Private companies do not fully understand the external, environmental, national, and long-term effects of the development of TPCG because they are concerned more about their interests. Although technology development can be considered an appropriate solution for the development of the oil industry and a consequence of the development of the Iranian economy, disadvantages can also be imposed on private companies. Since the oil industry is national in Iran and the government plays a major role in it, the government acts as a contractor and the companies act as operators in the context of equipment development for this industry. Failure to provide the benefits of private companies, which will reduce their welfare, will raise ethical dilemmas for them, such as the use of low-quality raw materials and non-compliance with the required standards. It may cause irreparable damages to the industry and its upstream equipment. For example, failure to observe safety issues in production can lead to fire and the destruction of the entire facility. Companies are required to fully comply with all safety and quality standards in production, which will increase their costs, reduce their usefulness and welfare, inevitably force them to reduce support for this notion, and cause them to resist technology development. Another example of ethical dilemmas and the use of low-quality components is related to the low quality of such pieces as drill pipes and pumps. The former may lead to the closure of wells, imposing high costs, and the latter may lead to the explosion of wells with heavy costs for the industry.

In a three-year investigation to identify possible problems while reviewing other megaprojects in Iran and their institutional problems, more than 480 companies were evaluated. Interviews were performed with over 60 executives and experts from winning companies, over 50 senior executives from the Ministry of Petroleum of Iran, and 70 faculty members and academic researchers. The interviews aimed to identify the parameters and important factors of the contradictions, the contributing factors, the demands of the companies, the demands of the government, the environmental factors, etc., which were effective in developing a cooperation model for the policymakers of the project. Inputs were used for game-based modeling.

Because of the importance of innovation and differentiation in the market, companies should outperform their competitors through innovation, provided that this will grow their profitability (Edwards et al., 2002; Hult et al., 2004; Nieto & Quevedo, 2005; Tajeddini, 2016; Tajeddini & Trueman, 2008, 2012, 2014).

Extensive research has addressed the collaboration and cooperation of various partners and players, such as universities, suppliers and customers, service intermediaries, government agencies, and competitors (e.g., Belderbos et al., 2004; Wu, 2011). However, few studies, especially in developing countries, have focused on the cooperation of policymakers and

companies on technology development. An important point in the literature review is the collaboration between different partners and players, with few studies focusing on technology development, especially in oil-rich countries. Ethical issues in the study of science and technology in the oil industry, including the non-use of quality raw materials, compliance with the necessary standards, and so on, have been studied to a lesser extent. Moral hazards can cause a lot of damage to the oil industry. Another contribution of this research is the study of effective cooperation policy in technology development projects in the oil industry. This research tries to discover the cooperation policies, motivational mechanisms, or legal supervision that are more effective in the oil and gas industry. Another advantage is that it deals with the government's impact on technological innovation in the oil and gas industry, which has not been explored yet.

This study aimed to investigate the role of government's support policies of technology development in oil-rich countries, especially Iran, taking into account the cooperation between policymakers and private sector companies, ethical issues, and structural problems, which have rarely been studied in the literature.

The remainder of the paper is organized as follows. The next section presents the important assumptions of the game model, followed by the strategy formulation, the dynamics of repetition equations, and stability analysis. A case study is then reviewed and the computational results and policy insights are analyzed and presented. Finally, the paper is closed with some concluding points and policy implications.

2. Literature Review

TPCG

The strategic role of the pioneering industries is of crucial significance as one of the main development strategies. Industries that have high added value in the market have a wide range of technologies in common with other industries and products that can contribute to developing other industries and products. However, the role of strategic industries such as the oil and gas industry, which accounts for an average of 16% of the gross national product of Iran (Statistical Center of Iran, 2011), is indisputable.

This project involved various institutions in Iran, such as the Ministry of Petroleum (as the project employer), the Ministry of Industry, Mining, and Commerce (responsible for industry development), Presidential Vice-President for Science and Technology (responsible for technology development), the Iranian Parliament (as the legislator), and the monetary and banking system, which have their interests. Therefore, the progress of this project and, consequently, the advancement of technology development, require the cooperation of these institutions and the settlement of their conflicts. The ten major commodity groups' project of the petroleum industry was launched as the most important industrial and technological development project in Iran with a budget size of more than $ 2 billion in 2014 after several years of study. In 2015 and 2016, 480 companies participated in the bid and were evaluated based on their market, financial, and technological capabilities. Finally, 75 companies were awarded the necessary privileges and were allowed to secure a guaranteed purchase contract with the Ministry of Petroleum (Ristip, 2015).

The ten groups of commodities required by the oil industry were selected as follows:

- A project for providing source equipment and in-well supplementary field equipment
- A project for building pumps inside and at the wellhead
- A project for building all kinds of drills, rock, and diamond
- A project for making all kinds of control valves, safety, and accessories

- A project for making all kinds of pipes
- A project for making explosion-proof and variable speed electric motors
- A project for making rotary machines (turbines, compressors, and pumps, including centrifugal ones)
- A project for making all kinds of alloy steels, including Cryogenic steels and refrigeration
- A project for making measurement instruments in drilling
- Smart PIGS project.

Cooperation in Game Theories

In recent decades, a range of subjects in economics and international relations on the topic of cooperation theory has been formed within the framework of game theory.

In game theory, the actors in a game compete with each other and choose their strategies and policies without knowing the strategies chosen by the other players (Anderson et al., 2012). This behavior is called rational behavior in which one thinks carefully before taking action, considers the goals, settings, and limitations of one's actions, and does the final actions according to personal criteria for doing the best (Dixit & Skeath, 2004. Game theory has become the provider of analytical concepts and techniques for many disciplines, and it is described (Dixit & Skeath 2004) as the science of rational behavior in interactive situations.

Various methods have been presented in the game theory so far. Simultaneous-move games are situations in which players perform a movement simultaneously. Therefore, players are unaware of the movement of other players. Conversely, sequential-move games involve strategic situations with precise game order (Dixit & Skeath 2004). In sequential-move games, the players take turns making their moves, and they are aware of the movements of the previous players. As a result, the impact of current actions on future actions must be widely considered. However, as in the real world of business, sequential and simultaneous moves can be used in combination, depending on the nature of the situation. A zero-sum game means that the gain or loss for one player is equal to the loss or gain of another player (Anderson et al., 2012). As a result, profit and loss are balanced and the result is zero for the game. What one player wins, the other player loses. Conversely, a game with a non-zero sum means that a loss to one player does not win another player gains. In fact, a zero-sum game is a war, where damage to the opponent is rarely considered a point by the other side.

Cooperation naturally refers to the degree of the cooperation of players in a particular game, where, for example, some players can cooperate against another player. In non-cooperative games, there is no constructive connection between the players. This does not mean that players have no interdependence. There is interdependence where the outcome of a player's choice depends on the choice of other competitors (Johnson et al., 2011). In conditions of dependence, it is very important to be in competitors' minds, be formed from the perspective of competitors, "potential actions, and build personal actions based on them" (Johnson et al., 2011, p.21) The performance of competitors concerning that move in the future should be confirmed. In this case, the game theory can be seen as a very relevant approach to use.

In the game formulation, the basic features of the game include:

- List of players
- Available strategies for each player
- Efficiency of each player about all combinations of strategies of all players
- Assuming logical behavior by each player to achieve the goal of maximum utility

After identifying the players in a game, the next step is to consider the strategies and policies. Strategies are options available to players, but their design must take into account whether the game involves simultaneous moves that are performed only once or in sequential moves (Dixit & Skeath, 2004). If a game has sequential moves, the performance of recent players may depend on the movement of previous players. Therefore, to get a solid strategy, all the different scenarios must be planned. The dimension of payments is determined. Each player is assigned a numerical scale or a simple numerical point with which to compare the results of the game. The number that accompanies any possible outcome is the player's return or usefulness (Watson, 2013). The higher the number is, the better the result for the player will be. Depending on the game, the return may be expressed in monetary terms, or it could be any other instrument that indicates good performance such as time or amount of visitors.

One of the hypotheses offered by the game theory is that each player in standard game theory analyses behaves according to the "rational human" model (Rubinstein, 1998). Therefore, this theory assumes that players are great calculators and can flawlessly follow their best strategies to get the highest possible return. Von Neumann and Morgenstern (2004, p.7) explain this by assuming that "the consumer wishes to maximize utility or satisfaction and the entrepreneur maximizes profit." Therefore, the person who is looking for getting this or at most one tool is seen to be acting logically. Another method that has received a lot of attention is evolutionary game theory.

Evolutionary Game Theory

Evolutionary game theory (EGT) is suitable for studying strategic interactions that occur repeatedly over time, often in situations where agents do not have complete information and, like traditional economic models, cannot fully seek rational reasons. In particular, EGT can show how they adapt, learn, or imitate and respond to shocks from their environment. Major work on evolutionary game theory was done by Smith in 1982. In 1987, his work was expanded by Brown and Vincent in online games by defining ESS in a multi-strategy alliance. EGT was initially applied in biology. However, it provides insights into economics, too (Rees, 2005). EGT has been one of the most widely used methods in recent years to analyze different behaviors of actors in different industries (Esmaeili & Allameh, 2016). Several economists have theoretically studied the EGT (e.g., Gintis, 2009; Hofbauer & Sigmund, 1998; Samuelson, 1997; Vega-Redondo, 1996; Weibull, 1995).

3. Research Method

In a three-year investigation to identify possible problems while reviewing other megaprojects in Iran and their institutional problems, more than 480 companies were evaluated. Interviews were performed with over 60 executives and experts from winning companies, over 50 senior executives from the Ministry of Petroleum of Iran, and 70 faculty members and academic researchers. The interviews aimed to identify the parameters and important factors of the contradictions, the contributing factors, the demands of the companies, the demands of the government, the environmental factors, etc., that were effective in developing a cooperation model for the policymakers of the project. Inputs were used for game-based modeling.

To achieve a comprehensive equilibrium, a long-term analysis of the actors' policies in the PTCG needs to be undertaken, as it is likely that the equilibrium of game theory is unstable in reality. This study used the evolutionary game theory (EGT) to analyze actors' behavior because EGT seeks to have an optimal long-term strategy, which is called the evolutionary stable strategy (ESS) (Esmaeili et al., 2016).

Assumptions

The assumptions of the game model are as follows:

1. The game model is assumed between two players: governments and the private sector.
2. The policies envisaged by the government in this project included the application of legal regulations and incentive mechanisms. Although in reality, it is not possible to fully regulate without incentive mechanisms, it was the intention of the researchers and the project team of the PTCG to state the main inclination of government in each policy.
3. Private sectors had two strategies of performing technology development and not performing the development process completely.
4. Private sectors that failed to perform technology development were divided into two groups. The first group received the prepayment, but the technology development was performed incompletely and the final products were of low quality. The second group was not capable of performing technology development and thus paid a penalty to the governments.
5. The notations presented were based on two sources of government objectives and parameters of the private sector. The parameters of the private sector were extracted through interviews with experts in the private sector.

Notations

The following notations are considered in the proposed game model:

IG_g	Government income from direct economic growth
IG_{ig}	Government income from indirect economic growth
IG_j	Government income from employment creation
CG_m	Costs imposed on governments for monitoring contract execution
CG_p	Cost of prepayment paid by governments
CG_d	Cost of damage caused by private sectors to government
IG_p	Penalty received by the government from private sectors
IP_{TD}	Private sector income from performing complete technology development
IP_v	Income from increasing companies' value
CP_{HR}	Cost of training human resources
$CP_{R\&D}$	R&D expenditures
CP_p	Cost of production line for technology development
CP_B	Cost of bank guarantee by private sectors
CP_f	Cost of currency fluctuations
CP_m	Cost of moral hazard
x	The proportion of private sectors breaking the ethical rules
$\prod_G$	The profit of governments playing strategies
$\prod_{PS_j}$	The profit of private sectors playing strategy j=T, NT
X_G	The proportion of government that imposes regulation $(0 \le X_G \le 1)$
$1-X_G$	The proportion of government that utilizes incentive

X_P The proportion of the private sector that performs technology development completely $(0 \le X_P \le 1)$

$1 - X_P$ The proportion of the private sector that does not perform technology development

Evolutionary Game Analysis

This section examines the long-term behavior of the government and the private sector, each with two strategies, using the evolutionary game theory.

The players' overall strategy framework was as follows:

- Formulate each player's strategy mix.
- Interpret each player's behavior using a long-term replicator dynamic.
- Obtain an evolutionary stable strategy by solving replicator dynamic equations.

Table 1. The Second Player Evolutionary Game Among Governments and Private Sector

		Private sector	
		T: Performing technology development (X_P)	NT: Not performing technology development $(1-X_P)$
Governments	R: Regulation (X_G)	1: $(\Pi_{G_{R-T}}, \Pi_{P_{R-T}})$	2: $(\Pi_{G_{R-NT}}, \Pi_{P_{R-NT}})$
	I: Incentive $(1-X_G)$	3: $(\Pi_{G_{I-T}}, \Pi_{P_{I-T}})$	4: $(\Pi_{G_{I-NT}}, \Pi_{P_{I-NT}})$

Strategy Formulations

The payoff formulations of strategies 1 to 8 are presented below:

-Strategy R-T

The governments' profit = direct economic growth + indirect economic growth + income of job creation – monitoring cost – prepayment cost

The private sectors' profit = income of complete technology development + income of increasing companies' reputation + prepayment received from the government – HR training cost – R&D cost – production cost – bank guarantee cost – the cost of currency fluctuations

$$\Pi_{G_{R-T}} = IG_g + IG_{ig} + IG_j - CG_m - CG_p \quad (1)$$

$$\Pi_{P_{R-T}} = IP_{TD} + IP_v + CG_p - CP_{HR} - CP_{R\&D} - CP_P - CP_B - CP_F \quad (2)$$

-Strategy R-NT

The governments' profit = (1-x) (penalty received from the private sectors) – x (damage cost) – monitoring cost – prepayment cost

The private sectors' profit= x (income of complete technology development + income of increasing companies' reputation + prepayment received from the government – the cost of moral hazard) – (1-x) (prepayment received from the government – penalty received by governments)

$$\Pi_{G_{R-NT}} = (1-x)IG_P - xCG_d - CG_m - CG_p \quad (3)$$

$$\Pi_{P_{R-NT}} = x(IP_{TD} + IP_v + CG_p - CP_m) + (1-x)(CG_p - IG_p) \quad (4)$$

-Strategy I-T

The governments' profit = direct economic growth + indirect economic growth + income of job creation – subsidies are given to the private sectors – prepayment cost

The private sectors' profit = income of complete technology development + income of increasing companies' reputation + subsidies received from government + prepayment received from the government – HR training cost – R&D cost – production cost – bank guarantee cost – the cost of currency fluctuations

$$\Pi_{G_{I-T}} = IG_g + IG_{ig} + IG_j - CG_s - CG_p \tag{5}$$

$$\Pi_{P_{I-T}} = IP_{TD} + IP_v + CG_S + CG_p - CP_{HR} - CP_{R\&D} - CP_P - CP_b - CP_f \tag{6}$$

-Strategy I-NT

The governments' profit = (1-x) (penalty received from private sectors) – x (damage cost) – subsidies given to the private sectors – prepayment cost

The private sectors' profit = x (income of complete technology development + income of increasing companies' reputation + prepayment received from government + subsidies received from the government – the cost of moral hazard) + (1-x) (prepayment received from government + subsidies received from the government – penalty received by governments)

$$\Pi_{G_{I-NT}} = (1-x)IG_P - xCG_d - CG_s - CG_p \tag{7}$$

$$\Pi_{P_{R-NT}} = x(IP_{TD} + IP_v + CG_p + CG_s - CP_m) + (1-x)(CG_p + CG_s - IG_p) \tag{8}$$

Stability Analysis

Suppose that $EG_R(t)$ and $EG_I(t)$ denote the expected payoff for the governments applying regulations and imposing subsidies at time *t*, respectively. Moreover, $\overline{EG}(t)$ is the average payoff of the governments in the population at time *t*. Similarly, $EP_I(t)$, $EP_R(t)$, and $\overline{EP}(t)$ are the notations used for the private sectors selecting their strategies. The calculations are presented below:

$$EG_R(t) = X_P\Pi_{G_{R-T}} + (1-X_P)\Pi_{G_{R-NT}} \tag{9}$$

$$EG_I(t) = X_P\Pi_{G_{I-T}} + (1-X_P)\Pi_{G_{I-NT}} \tag{10}$$

$$\begin{aligned}\overline{EG}(t) &= X_G EG_R(t) + (1-X_G)EG_I(t) \\ &= X_G X_P\Pi_{G_{R-T}} + X_G(1-X_P)\Pi_{G_{R-NT}} + (1-X_G)X_P\Pi_{G_{I-T}} + (1-X_G)(1-X_P)\Pi_{G_{I-NT}}\end{aligned} \tag{11}$$

$$EP_{TD}(t) = X_G\Pi_{P_{R-T}} + (1-X_G)\Pi_{P_{I-T}} \tag{12}$$

$$EP_{NTD}(t) = X_G\Pi_{P_{R-NT}} + (1-X_G)\Pi_{P_{I-NT}} \tag{13}$$

$$\begin{aligned}\overline{EP}(t) &= X_p EP_{TD}(t) + (1-X_p)EP_{NTD}(t) \\ &= X_P X_G\Pi_{P_{R-T}} + X_P(1-X_G)\Pi_{P_{I-T}} + (1-X_P)X_G\Pi_{P_{R-NT}} + (1-X_P)(1-X_G)\Pi_{P_{I-NT}}\end{aligned} \tag{14}$$

To find the evolutionary stable strategy, the following replicator dynamic equations are applied, which determine the evolution of strategies played by the players. The ESS is derived by equating the replicator dynamic equations to zero and checking the stability of the derived points using the Jacobian matrix.

$$A(X_G, X_P) = \frac{dX_G(t)}{dt} = X_G[EG_R - \overline{EG}(t)] = X_G(1-X_G)[X_p\Pi_{G_{R-T}} + (1-X_p)\Pi_{G_{R-NT}} - X_p\Pi_{G_{I-T}} - (1-X_p)\Pi_{G_{I-NT}}] \quad (15)$$

$$B(X_G, X_P) = \frac{dX_P(t)}{dt} = X_P[EP_{TD} - \overline{EP}(t)] = X_P(1-X_P)[X_G\Pi_{P_{R-T}} + (1-X_G)\Pi_{P_{I-T}} - X_G\Pi_{P_{R-NT}} - (1-X_G)\Pi_{P_{I-NT}}] \quad (16)$$

$$J = \begin{bmatrix} \frac{\partial A(X_G, X_P)}{\partial X_G} & \frac{\partial A(X_G, X_P)}{\partial X_P} \\ \frac{\partial B(X_G, X_P)}{\partial X_G} & \frac{\partial B(X_G, X_P)}{\partial X_P} \end{bmatrix} \quad (17)$$

Table 2. All Derived Fixed Points and Stability Conditions

Fixed points	Conditions
(0,0)	$\Pi_{G_{R-NT}} < \Pi_{G_{I-NT}}, \Pi_{P_{I-T}} < \Pi_{P_{I-NT}}$
(0,1)	$\Pi_{G_{R-T}} < \Pi_{G_{I-T}}, \Pi_{P_{I-NT}} < \Pi_{P_{I-T}}$
(1,0)	$\Pi_{G_{R-NT}} < \Pi_{G_{I-NT}}, \Pi_{P_{R-T}} < \Pi_{P_{R-NT}}$
(1,1)	$\Pi_{G_{I-T}} < \Pi_{G_{R-T}}, \Pi_{P_{R-NT}} < \Pi_{P_{R-T}}$
$(\frac{\Pi_{P_{I-NT}} - \Pi_{P_{I-T}}}{\Pi_{P_{R-T}} - \Pi_{P_{I-T}} + \Pi_{P_{I-NT}} - \Pi_{P_{R-NT}}}, 0)$	$if, 0 < X_G < 0.5 \rightarrow \Pi_{G_{R-NT}} < \Pi_{G_{I-NT}}$ $if, X_G > 0.5 \rightarrow \Pi_{G_{R-NT}} > \Pi_{G_{I-NT}}$
$(\frac{\Pi_{P_{I-NT}} - \Pi_{P_{I-T}}}{\Pi_{P_{R-T}} - \Pi_{P_{I-T}} + \Pi_{P_{I-NT}} - \Pi_{P_{R-NT}}}, 1)$	$if, 0 < X_G < 0.5 \rightarrow \Pi_{G_{R-T}} < \Pi_{G_{I-T}}$ $if, X_G > 0.5 \rightarrow \Pi_{G_{R-T}} > \Pi_{G_{I-T}}$
$(0, \frac{\Pi_{G_{I-NT}} - \Pi_{G_{R-NT}}}{\Pi_{G_{I-NT}} - \Pi_{G_{R-NT}} + \Pi_{G_{R-T}} - \Pi_{G_{I-NT}}})$	$if, 0 < X_P < 0.5 \rightarrow \Pi_{P_{I-T}} < \Pi_{P_{I-NT}}$ $if, X_P > 0.5 \rightarrow \Pi_{P_{I-T}} > \Pi_{P_{I-NT}}$
$(1, \frac{\Pi_{G_{I-NT}} - \Pi_{G_{R-NT}}}{\Pi_{G_{I-NT}} - \Pi_{G_{R-NT}} + \Pi_{G_{R-T}} - \Pi_{G_{I-NT}}})$	$if, 0 < X_P < 0.5 \rightarrow \Pi_{P_{R-T}} < \Pi_{P_{R-NT}}$ $if, X_P > 0.5 \rightarrow \Pi_{P_{R-T}} > \Pi_{P_{R-NT}}$
$(\frac{\Pi_{P_{I-NT}} - \Pi_{P_{I-T}}}{\Pi_{P_{R-T}} - \Pi_{P_{I-T}} + \Pi_{P_{I-NT}} - \Pi_{P_{R-NT}}}, \frac{\Pi_{G_{I-NT}} - \Pi_{G_{R-NT}}}{\Pi_{G_{I-NT}} - \Pi_{G_{R-NT}} + \Pi_{G_{R-T}} - \Pi_{G_{I-NT}}})$	Unstable

Computational Results

This section provides calculations of the profits of each player in the case study of each strategy, solutions of the dynamic replication equations, and tests of the stability of all derived fixed points.

In the proposed case in Iran, the profit of each player is calculated and the stability of the fixed points is checked. The results are listed in Table 4, according to which $\Pi_{G_{I-T}} < \Pi_{G_{R-T}}, \Pi_{P_{R-NT}} < \Pi_{P_{R-T}}$ is satisfied, so the ESS is (1,1), showing that the stable strategy for governments is regulation. Moreover, performing technology development is a stable strategy for private sectors. To have a more precise look into the long-term behavior of

governments and private sectors, the trajectories of the replicator dynamics are plotted. Converging trajectories to point (1,1) is evident in Figure 1.

Table 3. All Data in the Proposed Case Study

IG_g	4000 (MIRR)	IP_{TD}	2400 (MIRR)
IG_{ig}	1200 (MIRR)	IP_v	4800 (MIRR)
IG_j	4000 (MIRR)	CP_{HR}	80 (MIRR)
CG_m	7.5 (MIRR)	$CP_{R\&D}$	400 (MIRR)
CG_p	1600 (MIRR)	CP_p	1200 (MIRR)
CG_d	40000 (MIRR)	CP_B	590 (MIRR)
CG_s	576 (MIRR)	CP_m	2000 (MIRR)
IG_p	3280 (MIRR)	x	0.5

Table 4. The Pairs of Fixed Points and the Stability Conditions

$\Pi_{G_{R-T}}$	7592.5	$\Pi_{P_{R-T}}$	3330
$\Pi_{G_{R-NT}}$	-19967.5	$\Pi_{P_{R-NT}}$	2560.0
$\Pi_{G_{I-T}}$	7024	$\Pi_{P_{I-T}}$	3906
$\Pi_{G_{I-NT}}$	-20536.0	$\Pi_{P_{I-NT}}$	3136.0

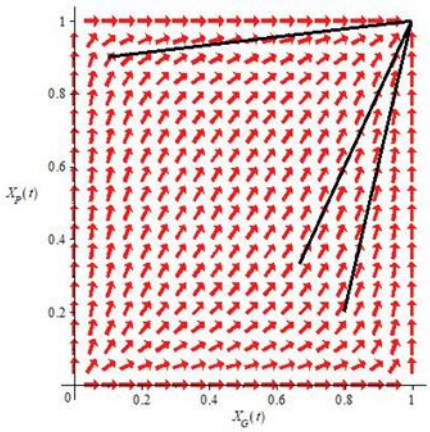


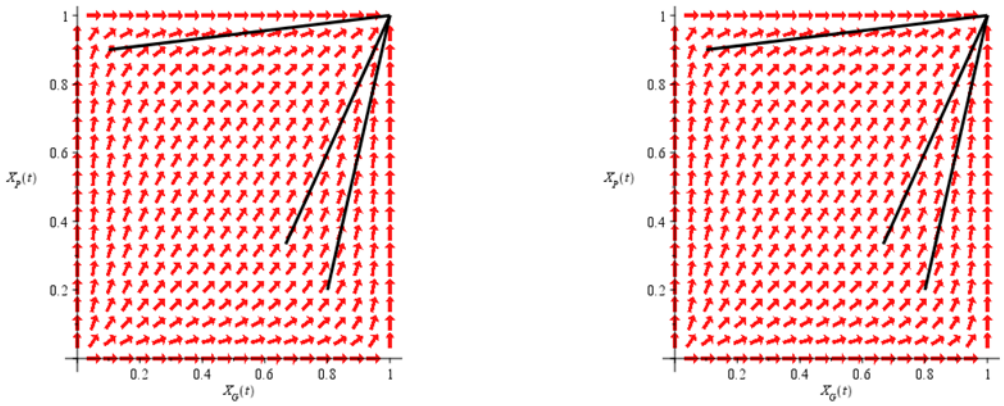
Figure 1. The Trajectories Convergence to the ESS in the Long-Term

4. Discussion and Policy Insights

The Effects of Government Income From Direct Economic Growth on the Long-Term Behavior

The effects of government income from direct economic growth on policy selection were explored by a sensitivity analysis as shown in Figure 2. It is observed that the government income from direct economic growth does not have a considerable effect on game results.

Indeed, an increase or decrease in the government's income does not affect the behavior and decision of the government and private sector.

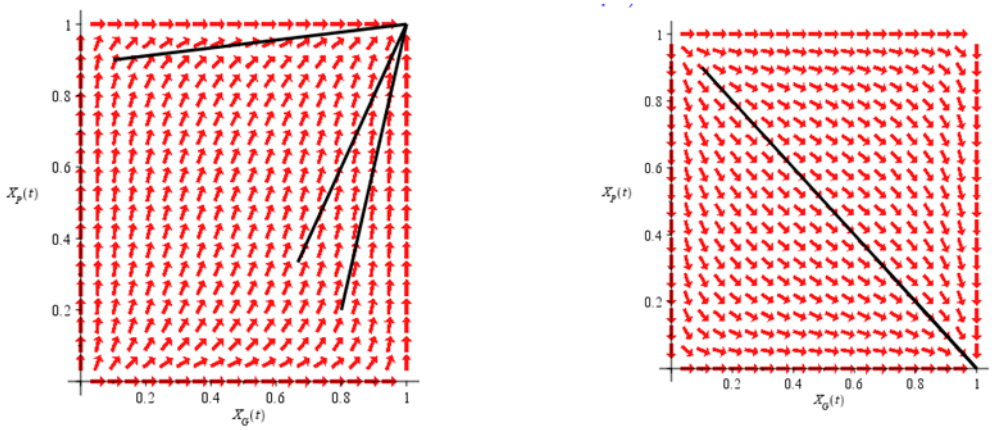


IG_g =2000(MIRR) IG_g =8000(MIRR)

Figure 2. The Effect of Government's Income (IG_g) on the Long-Term Strategies

The Effect of Private Sector Income From Performing Complete Technology Development on the Long-Term Behavior

A sensitivity analysis was employed to investigate the effects of the private sector income from performing complete technology development on long-term behavior and policy selection. It is revealed that the private sector income has a significant influence on game results as shown in Figure 3. With a 50% decline in the private sector revenue, this sector becomes reluctant to engage in technology development and the government's strategy is still the regulation. The convergence of the trajectories from (1, 1) to (0, 1) clearly shows that by a 2-fold increase in the private sector revenue, the long-term behavior of the government tends towards an incentive strategy. Therefore, the government's incentive policies such as income have a significant effect on changing the behavior of the private sector towards engaging in technology development.

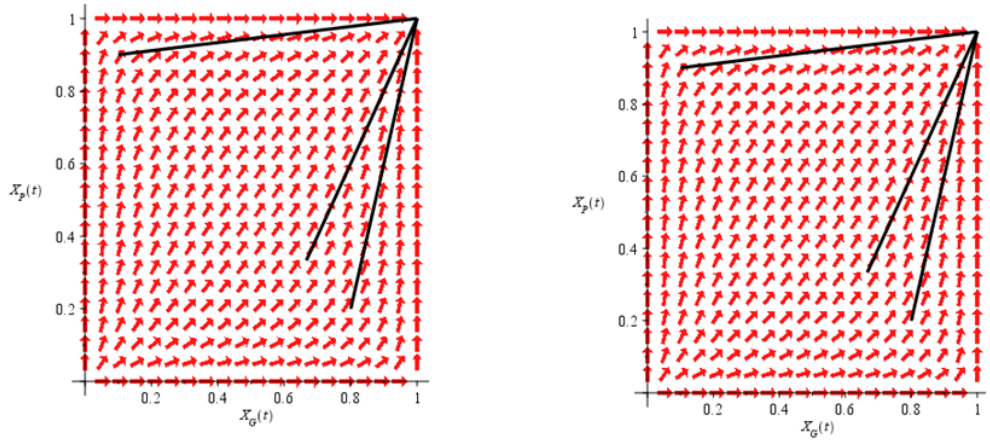


IP_{TD} =4800(MIRR) IP_{TD} =1200(MIRR)

Figure 3. The Effect of Private Sector Income From Performing Complete Technology Development (IP_{TD}) on the Long-Term Strategies

The Effect of Prepayment Cost Paid by the Government on the Long-Term Behavior

To know the effects of prepayment cost paid by the government on policy selection, a sensitivity analysis was performed, the results of which are depicted in Figure 4. As it is seen, the prepayment cost paid by the government does not influence the game results significantly. With a 50% decline or 100% increase in the cost of the private sector, it will still tend to perform technology development and the government's strategy will tend towards the regulation policies. Indeed, an increase or decrease in prepayments does not affect the behaviors and decisions of the government and private sector.

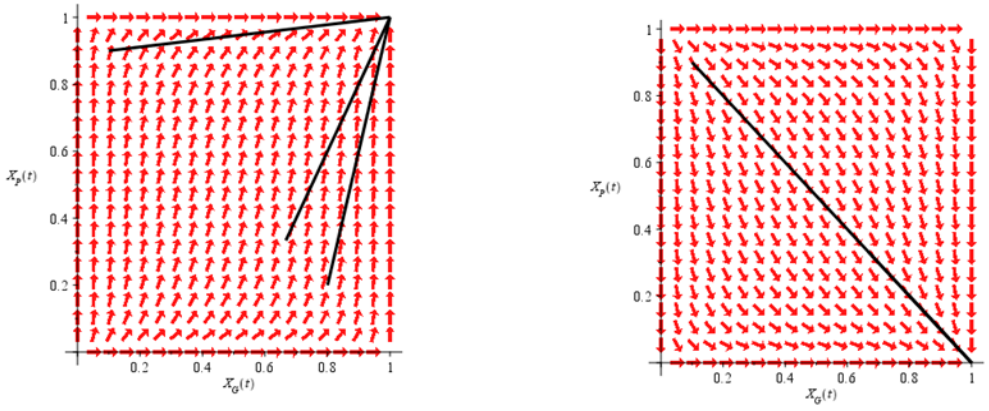


CG_p =3200(MIRR) CG_p =800(MIRR)

Figure 4. The Effect of Prepayment Cost Paid by Governments (CG_p) on the Long-Term Strategies

The Effect of the Cost of CHR, R&D, and Production on the Long-Term Behavior

Figure 5 displays the results of a sensitivity analysis on the effects of the cost of CHR, R&D, and production on policy selection. The cost of CHR, R&D, and production has a significant effect on the game results. With a 50% decline in the cost of the private sector, this sector still tends to perform technology development, but the government's strategy tends to adopt incentive policies. By a 2-fold increase in the cost, the long-term behavior of the private sector shifts to not performing technology development. The convergence of the trajectories from (1, 1) to (0, 1) clearly shows this. Therefore, increasing costs can prevent performing contract and technology development.



50% decline 2-fold increasing

Figure 5. The Effect of the Cost of CHR, R&D, and Production (Cp, r&d, hr) on the Long-Term Strategies

The Effect of the Cost of Bank Guarantee by the Private Sector on the Long-Term Behavior

To illustrate the effect of the cost of bank guarantee by the private sector on the long-term strategy selection, a sensitivity analysis was used (Figure 6). As expected, an increase in bank guarantee costs will make the private sector less inclined to engage in technology development and sign a contract.

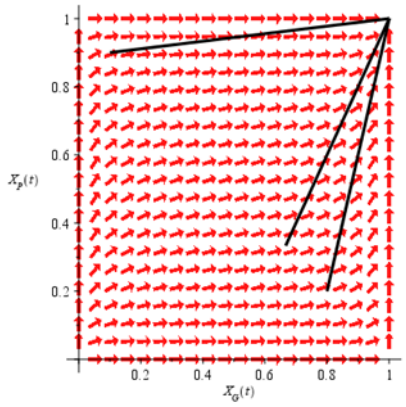
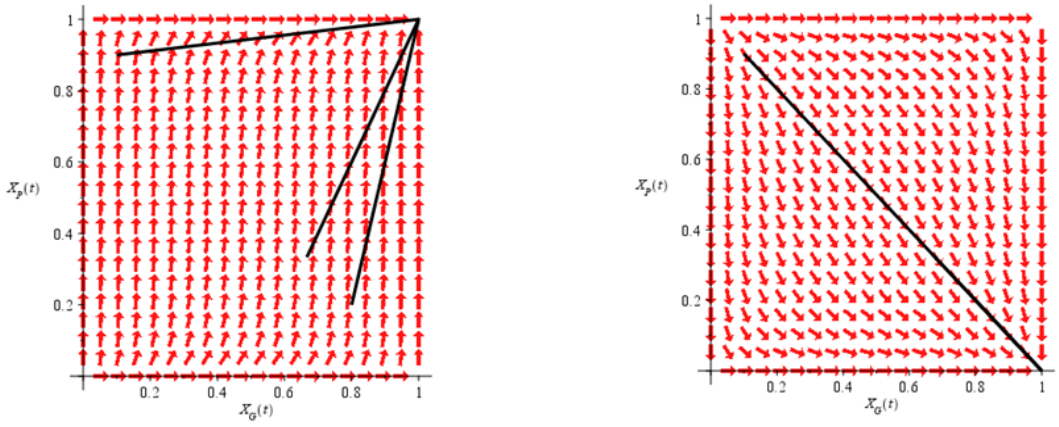


Figure 6. The Effect of the Cost of Bank Guarantee by Private Sectors (CP_B) on the Long-Term Strategies

Increase & decrease

The Effect of the Cost of Currency Fluctuations on the Long-Term Behavior

To illustrate the effect of the cost of currency fluctuations on policy selection, a sensitivity analysis was performed as shown in Figure 7. It is observed that the cost of currency fluctuations has a significant effect on the game results. With a 50% increase in the cost of currency fluctuations, the private sector will not tend to engage in technology development. The convergence of the trajectories from (1, 1) to (0, 1) clearly shows this. By decreasing the cost of fluctuations from 3200M$ to 0$, the long-term behavior of the government tends towards adopting incentive policies. Thus, increasing the cost of currency fluctuations can prevent making contracts and engaging in technology development.

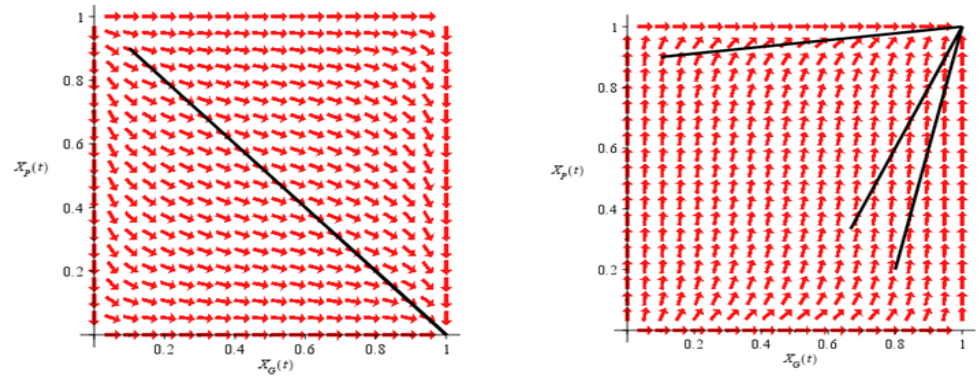


CP_f =0(MIRR) CP_f =4800(MIRR)

Figure 7. The Effect of Cost of Currency Fluctuations (CP_f) on the Long-Term Strategies

The Effect of the Cost of Moral Hazards on the Long-Term Behavior

The effect of the cost of moral hazards on policy selection was examined with a sensitivity analysis whose results are shown in Figure 8. As it is seen, the cost of moral hazards affects the game results significantly. A 100% increase in the cost of moral hazards results in the tendency of the government towards the adoption of incentive policies, while decreasing the cost of fluctuations from 2000M$ to 0$ makes the long-term behavior of the private sector shift towards not engaging in technology development. This is evidently illustrated by converging the trajectories from (1,1) to (0,1).

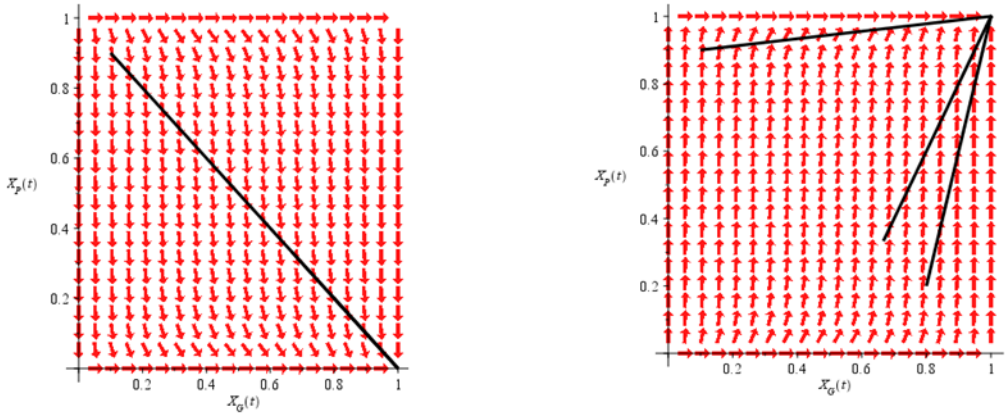


CP_m =0(MIRR) CP_m =4000(MIRR)

Figure 8. The Effect of the Cost of Moral Hazards (CP_m) on the Long-Term Strategies

The Effect of the Proportion of the Private Sector That Violates Ethics on the Long-Term Behavior

To illustrate the effect of the proportion of the private sector that violates ethics on policy selection, a sensitivity analysis was conducted, the results of which are shown in Figure 9. The proportion of the private sector that violates ethics has a considerable effect on the game results. If the private sector violates ethics, the government will tend towards adopting incentive policies and the private sector will not tend towards engaging in technology development. If the private sector cares for ethics, the government will in the long run shift towards the adoption of regulation policies and performing contracts truly. This is obviously illustrated by the convergence of the trajectories in Figure 9.



X=1 X=0

Figure 9. The Effect of the Proportion of the Private Sector That Violates Ethics (X) on the Long-Term Strategies

6. Conclusions and Policy Implications

Based on the analysis of the technology development model for ten groups of the petroleum industry within a megaproject in a developing country, the following policy outcomes and suggestions are drawn to improve the cooperation of policymakers on technology development:

1. Based on the results of the PTCG as the largest technology development project in Iran, the main approach of the government with minimal incentive mechanisms should be legal monitoring. Costs and data may remain at the existing level. If costs are increased, the incentive mechanism should be increased, and if the costs of companies exceed a certain level, then incentive mechanisms must be designed to mitigate the underlying problems of private companies. When this development creates risks, the development of technology will be limited to strict and direct regulations, and the welfare of private companies will be reduced. Therefore, this contract will not result in the development of technology and will have high losses for Iran.
2. The minimum level of the income of private sector companies should be equal to 3600 MIRR, the maximum cost of CHR, R&D, and currency fluctuations, and production should be equal to 3250 MIRR. If the amount of revenue is less than the revenue threshold and the costs are higher than the cost threshold, the behavior of companies will change and the result will be the lack of technology development.
3. When a situation is set for technology development, the state should pay attention to corporate feedback, must maintain a high level of transparency, and must reduce the conflict between firms and government by designing incentive mechanisms and regulations and an appropriate monitoring system. This will result in mutual respect of the parties, which will be a win-win situation, leading to both the development of equipment and technology and the enhancement of the companies' welfare.
4. Although the results show that the main policy should be legal monitoring, the government's lack of attention to the welfare of the private sector will lead to an increase in moral problems in the private sector. As a result, the government must consider at least incentive mechanisms, including subsidies and so on.
5. The most important and interesting item regarding the analysis is that the important factor in project implementation is the attention to private sector revenues and expenditures, and government revenues and expenditures have little effect on the results and behavior change. This again demands the government's attention. Choosing the right policy options will result in improving the companies' welfare, transparency, and trust, and finally, the proper implementation of the contract and technology development.
6. It is very important to have better coordination and collaboration with various government policymakers to provide better mechanisms and motivational cases. Many of the incentives offered by the companies are beyond the control of the Ministry of Petroleum. The cooperation and coordination of Iranian institutions such as the Ministry of Industry, the Vice-President of Science and Technology, and the Tax and Customs Organization with the Ministry of Petroleum is very important and influential.
7. Public sector flexibility is very important in cooperation with private companies. Given the economic turmoil, such as fluctuations in the price of foreign exchange, various laws, and internal and external conditions, the government should be flexible in implementing the contract and, to some extent, be flexible in its dealings and expectations with companies, and adjust its costs and commitments as per the environmental conditions.

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