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Modeling the Development and Market Enhancement of Iran's Oil in OPEC with Game Theory

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Highlights

- Analyzed the sales and export of Iranian oil from 1997 to 2013.
- Modeling the Iranian oil market in OPEC with the game theory and three main players.
- Determining practical strategies for cooperation, reducing pressure, and minimizing sanctions for Iran, the United States, and Saudi Arabia.
- The impossibility of bringing Iran's oil exports to zero considering the strategies for circumventing sanctions.

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Abstract

In this paper, the competitive market for crude oil exports in Iran and globally is modeled using game theory. The research focuses on OPEC's internal competition within the game theory framework to analyze the economic conflicts among its members in detail. Under conditions where each producer has distinct goals and constraints, the extent to which they achieve their objectives depends not only on their own decisions but also on the prevailing conditions in the oil market, including the strategies of other competitors, sanctions, and varying levels of economic growth and oil prices. In recent years, Western countries—particularly the United States—have imposed extensive sanctions on Iran. In this context, three players—Iran, Saudi Arabia, and the United States—were defined, and a game model among them was developed. The model was then solved as a cooperative game, and the equilibrium point was determined. The results indicate that the three main players can cooperate under options such as "reducing pressure and fewer sanctions," "reducing pressure and cooperation," and "cooperation." Additionally, Iran can improve its position only by competing with Saudi Arabia within OPEC.

Keywords: Game theory, Oil market, Crude oil, OPEC, Iran

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1. Introduction

Today, oil, as both a political and strategic economic commodity, plays a crucial role in global developments. One of the most important variables in the crude oil market is its price and the mechanisms by which it is determined (Burrows et al., 2023). Since fluctuations in oil prices

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significantly impact the interests of many countries, nations—depending on their level of dependence on crude oil—strive to exert greater influence over its pricing (Abdoli & Nakhoda, 2016). Since its establishment, the Islamic Republic of Iran has faced various forms of international sanctions. Economic sanctions, often considered an alternative to war or coercive force, target all types of economic relations, including both commercial and financial interactions. In recent years, the United States has increasingly employed economic sanctions to advance its foreign policy objectives, either unilaterally or through its influence on the United Nations and Security Council, against countries that challenge its demands (Cooper, 2012; Hufbauer et al., 2021).

The evolution of energy markets over time has revealed several phenomena that are difficult to explain theoretically, yet these events have produced significant economic and political consequences. Studies suggest that these phenomena remain inadequately explained and are more frequently discussed in industry and academic circles (Wei et al., 2020). One such phenomenon is the emergence of the Organization of Petroleum Exporting Countries (OPEC), which leveraged its influence to wrest control of part of the oil market from the well-known major oil companies' cartel[†] (Wälde, 2010).

The framework of this study is organized as follows: after the introduction, it presents the theoretical foundations, a brief historical review of OPEC, and then the principles of game theory and evolutionary games within agent-based systems.

Regarding the oil market, it can be characterized as a bilateral monopoly. In economic literature, such a market does not have a single equilibrium price; rather, a price range is proposed, determined by the relative bargaining power of the market participants. Numerous theoretical discussions address both the bargaining power of the parties and the profits derived from oil trade, one of which is the determination of equilibrium price using game theory (Angerhofer et al., 2021; Jiang et al., 2020).

Since its formation, OPEC has successfully attracted a number of developing countries whose economies heavily depend on oil production and exports, gradually incorporating members from different continents. As the first group of developing countries whose oil reserves were historically exploited under the political and economic pressure of major powers and multinational companies, OPEC has a unique and enduring status. Considering the central role of oil in the economies of OPEC member states, long-term maximization of oil revenues can be seen as the primary motivation for the organization's formation. Globally, OPEC is assumed to act as a monopolist in crude oil sales, while industrialized countries constitute the main buyers (Navarro, 2020; Almutairi et al., 2023; Ghoddusi et al., 2022).

Oil, as the primary energy source, offers substantial economic benefits due to its low cost and high energy density relative to other fuels. Consequently, crude oil and its refined products dominate international trade both in terms of value and volume, making oil trading a strategic, international, and highly significant market (Kisswani et al., 2022; Gkillas et al., 2021).

The rise of OPEC as a major power in global oil markets reflects the fact that its member countries control a substantial share of global oil exports and hold the majority of the world's oil reserves. More than 75% of the world's oil reserves are concentrated in 12 OPEC member countries, creating a strong dependency on OPEC for many nations. Simultaneously, OPEC members themselves depend on the organization's survival, as 80–99% of their foreign currency income comes from oil sales, and the organization can regulate prices to maximize member revenues (Abdoli & Nakhoda, 2016; Kheiravar et al., 2020; Economou et al., 2021). Nonetheless, the diversity of OPEC member countries—including

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[†] Cartels are groups of companies operating in the same industry that collaborate while maintaining their financial and legal independence, agreeing on market division, production volumes, and product prices.

political, economic, social, and cultural differences—represents a potential source of weakness. Members differ significantly in population size, financial and investment needs, oil reserves, production capacity, and per capita income, resulting in internal divisions (Brunetti et al., 2024; Pirani, 2022).

OPEC countries can be divided into two groups based on these differences. The first group, led by Saudi Arabia, includes Kuwait, Qatar, the United Arab Emirates, and Libya. These countries, termed “future-compatible,” have high per capita income and substantial per capita proven reserves. The second group—comprising Iran, Nigeria, Iraq, Venezuela, and Algeria, referred to as “compatible countries”—aims to limit production to rapidly increase prices. These countries have lower per capita income, smaller per capita oil exports, and larger populations. While the first group focuses on long-term, sustainable development, the second group primarily seeks to address short-term financial needs (Agbogun et al., 2022; Yu et al., 2024; Abdoli & Nakhoda, 2016).

2. Literature review

In 1921, the French mathematician Emile Burrell was the first to study several common casino games and published a series of articles on them. In these works, he emphasized the predictability of such games through logical reasoning. Although Burrell was the first to address the topic seriously, he did not make sustained efforts to expand his ideas. As a result, many historians credit the Hungarian mathematician John von Neumann with the creation of modern game theory. Neumann was motivated to develop the theory further through his study of a card game, where he realized that the outcome could not be explained by probability theory alone. He introduced the concept of bluffing within the game (Capshaw, 2021; Rédei, 2022).

In 1944, von Neumann, together with Austrian economist Oskar Morgenstern, published *Theory of Games and Economic Behavior*. Although initially written for economic applications, the book soon proved relevant to psychology, sociology, politics, warfare, recreational games, and many other fields. Using strategies derived from a chess-like game, von Neumann modeled interactions between the United States and the Soviet Union during the Cold War as a zero-sum game between two players. Since then, the development of game theory has accelerated across numerous disciplines (Sakai, 2024; Stark, 2024).

In 1994, John Forbes Nash, along with John Harsanyi and Reinhard Selten, received the Nobel Prize in Economics for their innovative contributions to game theory. In the following years, many other Nobel laureates in economics have been selected from experts in game theory, with the most recent being the French economist Jean Tirole, who received the award in 2014 (Watson, 2021; Syzdykov, 2022).

3. Materials and methods

In this research, considering that Iran must act through a determined process and strategic decision-making with each opposing party, the application of game theory is suggested. Game theory is the study of mathematical models that describe decision-making processes and the logical, strategic choices of decision-makers in a game. Using mathematical tools, game theory aims to predict behavior in strategic situations, where an individual’s success depends on the choices of others. This interdependence arises whenever a person’s outcome is influenced by the strategies adopted by other participants. The primary goal of game theory is to identify the optimal strategy for each player (Bauso, 2014; Fang et al., 2021). Different classifications of game theory models are illustrated in Figure 1.

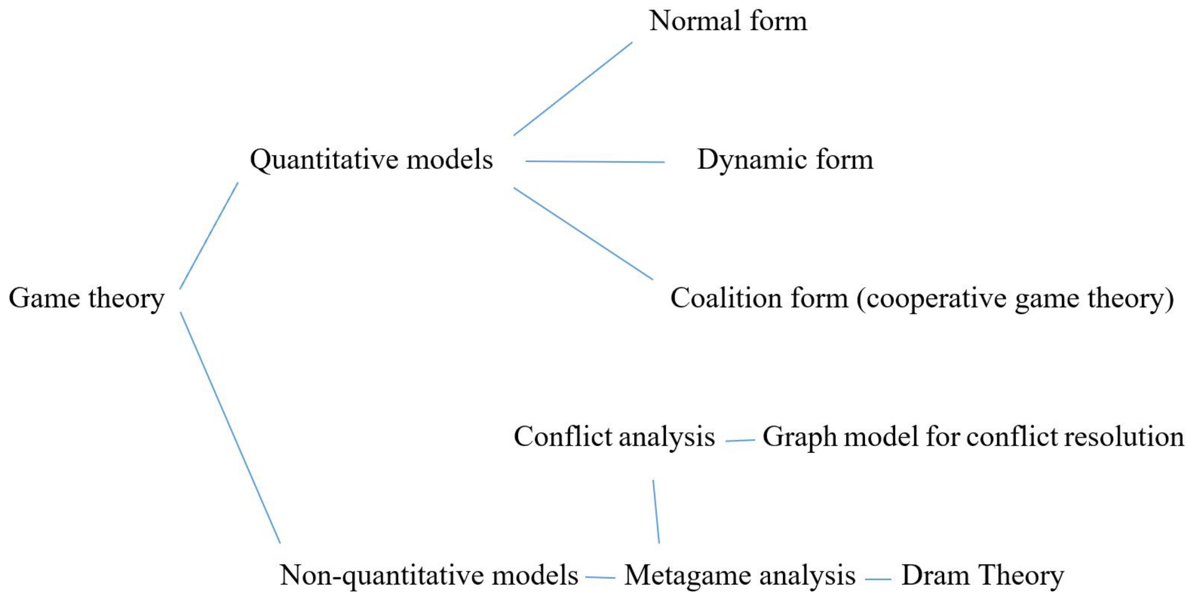

Figure 1

Different types of game theory models

Originally, game theory was associated with zero-sum games, in which the gains (or losses) of one participant are exactly balanced by the losses (or gains) of the other participants, so that each player obtains what another player loses. This model consists of a finite set of *N* players, where each player *i* has a set of actions *Ai* and a preference relation defined over these actions. Each action is considered an outcome, and the set of all possible outcomes is denoted by *A*. The key difference between a strategic game and a decision problem is that in a strategic game, the preference function must be defined over the set of all outcomes *A*, rather than just the individual player's actions *Ai*. Each player must consider not only their own actions but also the actions of other players.

Formally, a strategic game can be defined as follows:

- A finite set *N* of players.
- For each player i *N i €,* a (possibly infinite) set of actions *i*.
- For each player i *N i €*,, a preference function (or priority relation) over the outcomes.

If the set of actions *Ai* for each player *i* is finite, the game is called a finite game (Colman, 2016; Chatterjee et al., 2020). At this level of abstraction, few insights can be drawn from the game's outcomes; to obtain significant results, it is necessary to consider the specific characteristics of the problem.

3.1. Components of the game

Every game in this theory can be described using five major components:

1. **Players:** Every decision-maker in a game is called a player. A player can be an individual or a group. Depending on the type of game, the number of players can change between two, three, or *n* players.

2. **Strategies of each player:** A strategy is a sequence of actions that a player can choose at different stages of the game. Each possible choice available to a player constitutes a strategy. The set of all possible strategies for each player determines the various consequences that may result from their choices.
3. **Order of the game:** This defines which player moves at each stage of the game.
4. **Information structure:** At any given moment, each player may have knowledge about the actions and preferences of their opponents.
5. **Game outcomes:** These are the final results or payoffs for each player at the end of the game. The payoff, or utility, can be expressed as a numerical value (e.g., in dollars) or as an ordinal ranking. Players always aim to maximize their outcomes in the game (Pourahmadi et al., 2016; Barron, 2024; Ghani et al., 2018).

3.2. Types of games

Games can be classified into the following types:

1. **Zero-sum game:** In this type of game, one player's gain is exactly equal to another player's loss.
2. **Non-zero-sum game:** Here, a player's decisions can potentially benefit all players.
3. **Cooperative game:** In this type of game, players can form agreements and collaborate with one another.
4. **Non-cooperative game:** In this type, collaboration or agreements among players are not possible (Oh, 2016; Osborne, 2004).

3.3. Nash equilibrium

This non-cooperative equilibrium was first introduced by John F. Nash, who won the Nobel Prize in Economics in 1994. In this equilibrium, each player adopts the best possible strategy in line with their own interests, without collusion or cooperation with others, and irrespective of the welfare of society or other players. The Nash equilibrium provides a framework for achieving a mutually stable outcome. It has been widely used to analyze the results of strategic interactions among multiple decision-makers (Kreps, 1989). In other words, it predicts the outcome when several individuals or institutions make simultaneous decisions, with each outcome dependent on the choices of others. Nash's fundamental insight was that analyzing decisions individually does not allow us to predict results; instead, we must consider what each player does while accounting for the decisions of others (Giocoli, 2004).

The Nash equilibrium identifies the point where no player can increase their payoff by unilaterally changing their strategy, assuming all other players' strategies remain fixed. At this point, all players are in a state of relative or absolute satisfaction and have no incentive to alter their strategy, as doing so would result in a loss. In Nash equilibrium theory, three core components must be analyzed: the players, their available actions, and their behaviors, along with the determination of preferences and the evaluation of each player's behavior relative to others.

However, in situations such as environmental pollution or armed conflict, where competition among producers occurs at the expense of countries, people, or consumers, the resulting non-cooperative equilibria are ineffective. In such cases, mechanisms like arms control treaties can shift the equilibrium toward a less harmful state, allowing competitors to improve their security and welfare outcomes (Duffy, 2015; Holt et al., 2004).

3.4. Pareto efficiency principle

This concept refers to a state of resource allocation in which it is impossible to improve the condition of one individual without worsening the condition of another. In an initial allocation of resources among a group of individuals, any change that improves an individual's condition without negatively affecting others is called a **Pareto improvement**. An allocation is considered **Pareto optimal** when no further Pareto improvements can be made (Backhaus, 1980). If an economic allocation lacks Pareto efficiency, there exists the potential for improvement through reallocation, allowing the well-being of at least one individual to increase without reducing the well-being of others. It should be noted, however, that moving from a suboptimal allocation to an optimal allocation is not necessarily a Pareto improvement (Lin et al., 2022).

4. Results and discussion

In this article, the oil market is modeled as a three-player game. Oil-producing countries are divided into two categories: Saudi Arabia, representing the first category (countries with long-term interests due to large oil reserves), is selected as one player, while Iran, representing the second category (countries with short-term interests due to limited oil reserves), is chosen as another oil-producing player. The United States, as the world's largest oil consumer and the country that has imposed the most sanctions on Iran, is selected as the third player. Iran is denoted by the symbol **IR**, Saudi Arabia by **SA**, and the United States by **US**. The set of players can be represented as follows:

$$N - (IR\,, SA\,, US) \tag{1}$$

The United States generally pursues two main policies and strategies. The first is to increase pressure on Iran by imposing sanctions and aligning the international community to issue resolutions against it. The second strategy involves negotiating to reduce sanctions and ease pressure in exchange for Iran limiting its nuclear program and reaching an agreement. Each strategy entails certain costs for the United States.

Saudi Arabia, with its vast oil reserves, prioritizes market stability. As noted earlier, countries like Saudi Arabia focus on long-term plans more than other oil producers. Consequently, it aims to supply oil at lower prices in the long term to maintain its dominance over other energy sources. One possible strategy for Saudi Arabia in the current context is to increase pressure on Iran and withhold cooperation. Given its substantial reserves, Saudi Arabia can easily offset Iran's share in the oil market. This approach would reduce Iran's market share and weaken one of Saudi Arabia's key regional competitors. Additionally, the political geography of Iran cannot be ignored.

Alternatively, Saudi Arabia could adopt a strategy of reducing pressure and cooperating with Iran, which would enhance market stability and lower the risk of military conflict in the region. However, due to Iran's control of the Strait of Hormuz, it would hold a superior position in the event of conflict, and this strategy would require granting Iran a larger share of the oil market, potentially strengthening its regional power.

Iran's strategies can also be classified into two approaches: non-cooperation and cooperation. By choosing non-cooperation, Iran can continue its nuclear program without making concessions to other countries. The cooperative strategy, on the other hand, involves easing sanctions by limiting nuclear activities, offering concessions to other nations, and ensuring its nuclear program remains peaceful. This approach would allow Iran to attract much-needed foreign investment for the development of its oil industry and expansion of production capacity.

The complete set of strategies is summarized in Table 1.

Table 1

Strategies of the three players, the United States, Saudi Arabia, and Iran

Country	Strategy	symbol
USA	Applying more pressure and sanctions	A
	Less pressure and sanctions	B
Saudi Arabia (SA)	Increasing pressure and lack of cooperation	C
	Reducing pressure and cooperation	D
Iran (IR)	Non-cooperation	E
	Cooperation	F

The set of strategies is denoted by the symbol **S**. Accordingly, the strategies available to each player can be represented as follows:

$$S_{US} = \{A, B\} \tag{2}$$

$$S_{SA} = \{C , D\} \tag{3}$$

$$S_{IR} = \{E, F\} \tag{4}$$

The central question in bargaining is why individuals or parties engage in the process. The reason is that the parties recognize that the total outcome achievable through an agreement exceeds the total outcome if no agreement is reached. Thus, bargaining focuses on determining how the resulting benefits will be shared, with the aim of achieving a win-win outcome.

In such scenarios, the goal is to identify the most appropriate and effective solution, typically by maximizing or minimizing several objective functions subject to a set of constraints. Mathematically, these problems can be formulated as follows:

$$\begin{aligned} &Max: F(X) = [f_1(X), f_2(X), \dots, f_m(X)]^T \\ &g_i(X) \begin{matrix} \geq \\ \leq \\ = \end{matrix} b_i i = 1, 2, \dots, n \qquad X \in E^n \end{aligned} \tag{5}$$

where, $[f_1(X), f_2(X), \dots, f_m(X)]^T$ are the components of the vector of the objective function. Each objective function can be minimized or maximized. The decision vector $X = [X_1, X_2, \dots, X_n]^T$ contains n decision variables in the problem, which must be located in the justified space of the existing constraints of the problem. $G(x)$ is the components of the inequal constraints vector that are less than, greater than, or equal to zero (Gunantara, 2018).

In the context of the problem discussed, there are three players—**US**, **SA**, and **IR**—each bargaining to protect their minimum interests. The outcomes corresponding to each player's choice of strategy are presented in Table 2:

Table 2

The outcome of each player depends on their choice of different strategies

	E	***F***
AC	(1, 1, 0)	(1, 2, 3)
AD	(0, 1, 1)	(1, 3, 1)
BC	(1, 0, 1)	(3, 1, 1)

BD	(1 ,1 ,3)	(2, 2 ,2)

Assuming that the minimum acceptable outcomes for **US**, **SA**, and **IR** are all equal to one, the bargaining solution is as follows:

$$MAXZ = (f_1 - 1)(f_2 - 1)(f_3 - 1) \quad f_1 \geq 1 \quad , \quad f_2 \geq 1 \quad , \quad f_3 \geq 1 \tag{6}$$

We can now calculate the value of ***Z*** for the different strategies, as shown in Table 3:

Table 3

The *z* value for different strategies

	E	***F***
AC	(1−1)·(1−1)·(0−1)=0	(1−1)·(2−1)·(1−1)=0
AD	(0−1)·(1−1)·(1−1)=0	(1−1)·(3−1)·(1−1)=0
BC	(1−1)·(0−1)·(1−1)=0	(3−1)·(1−1)·(1−1)=0
BD	(1−1)·(1−1)·(3−1)=0	(2−1)·(2−1)·(2−1)=1

Therefore, the strategy (D, B, F) can be considered a limiting point on the Pareto frontier[‡]. Assuming a minimum outcome of one for the game, all three players adopt a cooperative strategy to maximize their respective outcomes. This strategy, which entails the lowest cost for all players, is achievable only through cooperative play. It represents the unique equilibrium point where all three players can simultaneously achieve the greatest possible benefit.

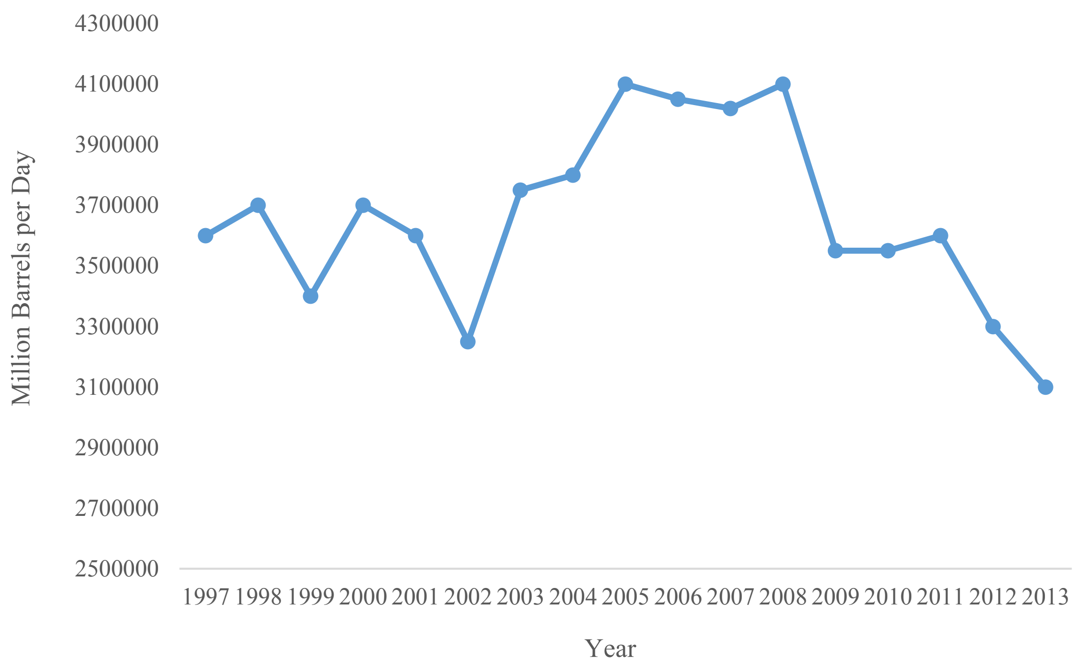

Figure 2

Iran's daily oil production from 1997 to 2013

[‡] The Pareto principle states that, in many cases, roughly 80% of effects result from 20% of causes. In other words, if 20% of your activities account for 80% of your results, you have identified the most effective way to achieve your goals.

As shown in Figure 2, Iran's oil production capacity has declined sharply since 2008. This reduction coincides with the third round of UN sanctions, causing Iran's daily oil output to fall from over 4 million barrels to approximately 3.5 million barrels per day.

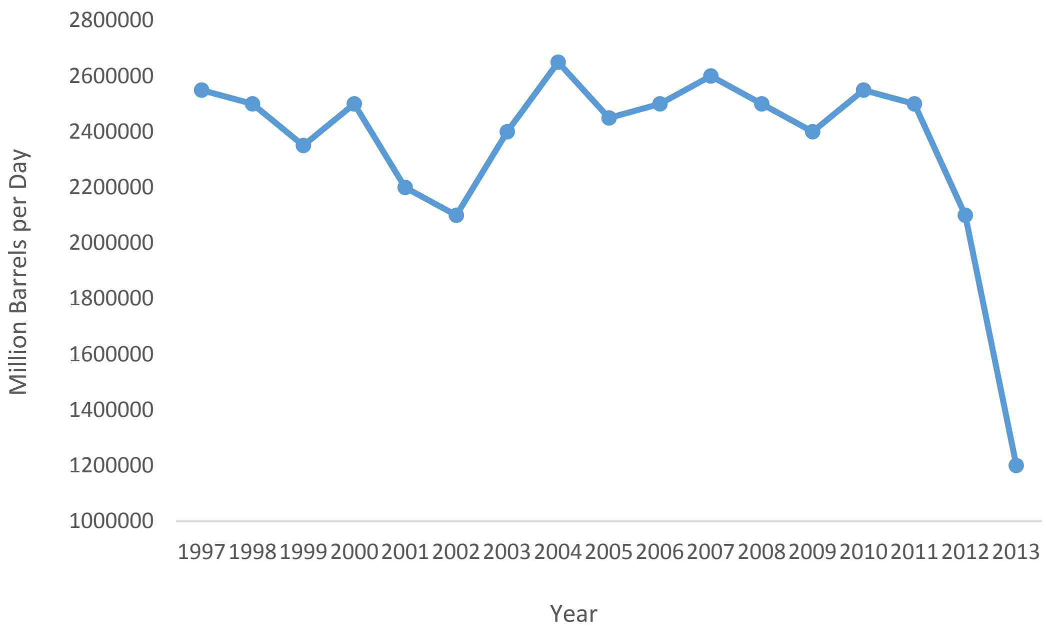

Figure 3

Iran's oil export amount from 1997 to 2013

As shown in Figure 3, Iran's oil exports exceeded two million barrels per day from 1997 to 2011. However, beginning in 2011, exports experienced a sharp decline, coinciding with the U.S. announcement of new sanctions targeting companies that supplied Iran with more than five million dollars' worth of refined oil products annually.

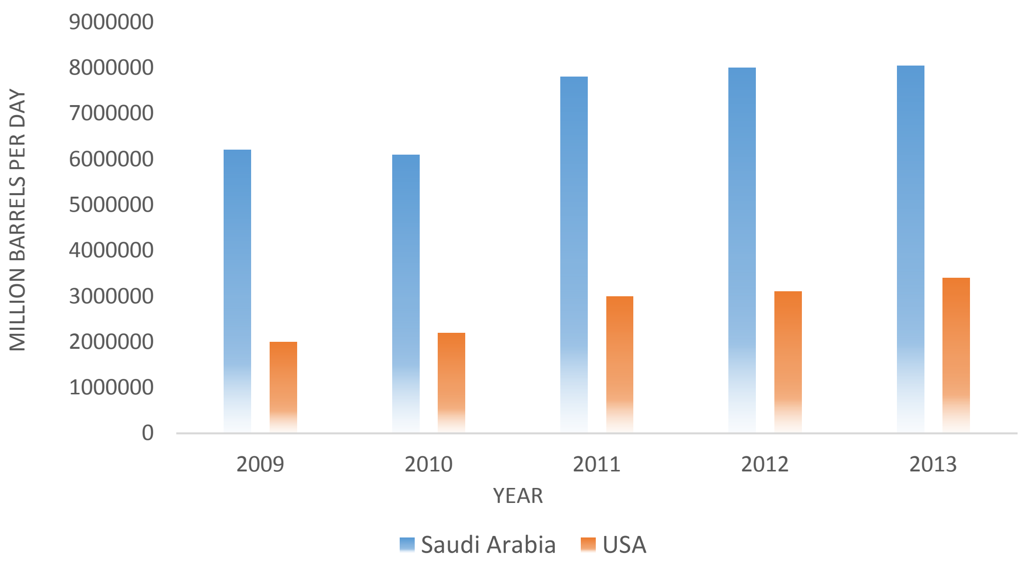

Figure 4

Volume of export and import of oil products of Saudi Arabia and the United States of America (USA)

According to Figure 4, Saudi Arabia's oil exports and imports are more than twice those of the United States. As the world's largest consumer of crude oil, the U.S. produced 5.4 million barrels per day in 2010, 6.4 million barrels per day in 2012, and 8.7 million barrels per day in 2016, with production continuing to grow rapidly in subsequent years. The U.S. Energy Information Administration predicts that this trend will continue until 2050, indicating that the United States is likely to maintain a competitive advantage in energy and economic influence.

Notably, as Iran's oil exports have declined, U.S. production and exports have increased, demonstrating a clear inverse relationship between Iran's decreasing exports and the rise in U.S. oil exports. Meanwhile, China, the world's second-largest economy, has repeatedly opposed unilateral U.S. sanctions on Iran. According to Giovanni Staunovo, an analyst at the wealth management unit of UBS, China is expected to be a significant obstacle to U.S. efforts to reduce Iran's oil exports to zero. However, given the support of other countries for the U.S., reducing Iran's oil exports to less than one million barrels per day is plausible. Even in the worst-case scenario, Iran's exports are unlikely to drop to zero.

India, historically one of Iran's largest oil customers, purchased approximately 23.5 million tons of Iranian oil in 2018–2019. After temporary sanctions exemptions expired in early May, India completely ceased imports from Iran while simultaneously increasing imports of American oil. This shift was challenging, as Iran had offered India and other buyers favorable prices and facilities to facilitate oil sales. Nevertheless, intense U.S. political pressure ultimately compelled New Delhi to abandon Iranian oil.

Regarding tensions in the Persian Gulf, former President Trump suggested that countries such as China, Japan, and other Asian nations dependent on regional oil should take measures to secure the Strait of Hormuz and other energy routes. While this is accurate in terms of Asian dependence on Persian Gulf oil, it is somewhat exaggerated regarding U.S. interests, as the United States imports only about 9% of its oil needs (roughly 900,000 barrels per day). If the Persian Gulf becomes insecure and global oil prices rise, U.S. crude imports would also be affected.

Overall, the United States has successfully captured many of Iran's oil customers, redirecting exports to itself through embargoes and market pressure. New markets for U.S. oil are also likely to remain under American influence. However, due to the economic costs of sanctions on Iran, imperfect coordination between the U.S. and Europe, and Iran's capacity to circumvent sanctions with the support of countries like China and India, it is unlikely that the U.S. can completely eliminate Iran's oil exports. To significantly impact Iran's economy, at least a 30% restriction on its oil exports is necessary to ensure that sanctions are effective.

5. Conclusions

In game theory, three players were initially defined: Iran, Saudi Arabia, and the United States. The value of the game for each possible strategy was estimated, and the equilibrium point in the cooperative game was determined. It was observed that the U.S., Saudi Arabia, and Iran chose the strategies of pressure reduction and fewer sanctions, pressure reduction and cooperation, and cooperation, respectively.

Subsequently, the trend of Iran's oil sales and exports from 1997 to 2013 was analyzed. The analysis revealed that Iran was unable to significantly increase its export capacity for consecutive years, and in recent years, the intensification of sanctions further reduced exports. As shown in Figure 3, since 2011, oil exports have declined sharply, leading to a decrease in Iran's oil revenue, with high oil prices unable to offset the drop in export volumes.

To explore a potential solution within the game theory framework, the formation of a "grand coalition" in OPEC's cooperative game should be considered. This would involve creating a coalition to counterbalance Saudi Arabia's dominant position. The Organization of the Petroleum Exporting Countries (OPEC) functions as a cartel with a powerful leader and several follower members. Member countries are generally expected to follow the leader—Saudi Arabia—to maximize profits, and each country's optimal policies are determined by the leader-follower equilibrium. Disrupting this balance in the current context would require cooperation among other members to form a large coalition against the dominant member, Saudi Arabia.

Declarations

Ethical Approval: Not applicable.

Consent to Participate: Not applicable.

Consent to Publish: Not applicable.

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Competing Interests: The authors declare no conflicts of interest.

Data Availability Statement: The data supporting the findings of this study are available from the corresponding author upon reasonable request.

Nomenclature

A	Symbol of applying more pressure and sanctions for the USA
Ai	An infinite set
B	Symbol of less pressure and sanctions for the USA
C	Symbol of increasing pressure and lack of cooperation for Saudi Arabia
D	Symbol of reducing pressure and cooperation for Saudi Arabia
E	Symbol of non-cooperation for Iran
F	Symbol of cooperation for Iran
$F(x)$	Components of the vector of objective function
$G(x)$	Components of the inequal constraints vector
i	Player
IR	Iran
N	A finite set
SA	Saudi Arabia
S_{IR}	Strategy for Iran
S_{SA}	Strategy for Saudi Arabia
S_{US}	Strategy for the USA
UN	United Nation
US	USA
Z	Consequence of open strategies

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