GAME THEORY APPLICATIONS IN COMPETITIVE STRATEGIES FOR NIGERIAN OIL COMPANIES

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Abstract
The Nigerian oil sector is highly competitive, with both local and international firms engaging in strategic decision-making to maximize profits and market share. Game theory provides a mathematical framework for analyzing competitive behaviors and strategic interactions among these companies. This paper explores the application of game theory in various aspects of Nigeria's oil industry, including pricing strategies, market entry and exit decisions, exploration investments, and government regulations. Different game-theoretic models such as the Nash equilibrium, Cournot competition, Bertrand Competition and Stackelberg leadership are examined to understand how oil firms can optimize their strategies in a dynamic market. The study also highlights real-world applications and provides policy recommendations for ensuring a balanced competitive environment in Nigeria's oil sector.

Keywords: Bertrand Competition, Competitive Strategy, Cournot Competition, Game Theory, Nash Equilibrium, Nigeria, Oil Industry,

Introduction
Game theory is a powerful mathematical framework that provides a structured approach to strategic decision-making, particularly in industries where competition and interdependent choices and marketers shape market outcomes. It has been extensively applied in economics, business strategy, military tactics, and the oil and gas industry to model competitive behaviors and optimize decision-making processes (Myerson, 1991; Osborne and Rubinstein, 1994). The Nigerian oil industry, which serves as the backbone of the country's economy, generates a significant portion of government revenue and foreign exchange earnings. However, it operates in a complex and volatile market influenced by fluctuating global crude oil prices, regulatory constraints, geopolitical dynamics, and the strategic actions of both domestic and multinational corporations (Oyakhire, & Akpan, 2021; Energy Information Administration, 2022).

Within this intricate landscape, firms must continuously make strategic decisions related to production levels, pricing mechanisms, investment in exploration, technology adoption, and partnerships. These decisions are not made in isolation; rather, they depend on the anticipated actions of competitors, the government, and international market forces. The Nigerian oil industry features a mix of cooperative and competitive interactions, as companies engage in price wars, output adjustments, and strategic alliances to maximize profitability while complying with government policies and international agreements such as the Organization of the Petroleum Exporting Countries (OPEC) production quotas (OPEC Reports, 2024).

Game theory offers valuable insights into these strategic interactions by modeling different competitive scenarios. Various game-theoretic models, such as Nash equilibrium, Cournot and Bertrand competition, Stackelberg leadership, and cooperative bargaining help firms understand how to respond optimally to competitors' actions. For example, the Cournot model can be used to analyze how firms decide output levels to maximize profit while considering market demand and competition, whereas the Bertrand model focuses on price-setting strategies. (Nash, 1951; Fudenberg & Tirole, 1991).

Additionally, in an industry where entry barriers are high and capital investment is substantial, game theory helps firms evaluate market entry strategies, mergers, acquisitions, and investment decisions. Sequential-move games, for instance, illustrate how an incumbent firm might set prices or adjust output levels strategically to deter new entrants or establish a dominant position in the market (Ogunbukola, 2024). Similarly, cooperative game theory is useful in assessing joint ventures and strategic alliances, such as the partnerships between international oil companies (IOCs) and the Nigerian National Petroleum Corporation (NNPC), where profit-sharing agreements and collaborative investments determine market control (Aniche, 2015).

This paper explores the application of game-theoretic models in various aspects of Nigeria's oil sector, including static and dynamic competition, cooperative and non-cooperative strategies, and sequential decision-making. By analyzing these competitive scenarios through the lens of game theory, it is aimed to provide industry stakeholders, including oil firms, regulators, and policymakers with valuable insights. A deeper understanding of these strategic interactions can contribute to improved decision-making, fair competition, and a stable economic environment that supports long-term growth and sustainability in Nigeria's oil industry.

Game Theory Concepts Relevant to the Nigerian Oil Industry

Game theory examines strategic interactions where the outcome of one player's decision depends on the actions of others. The following key game-theoretic concepts are applicable to Nigeria's oil sector:

Nash Equilibrium:

The Nash Equilibrium is a strategic balance in competitive environments and one of the most fundamental concepts in game theory, named after the mathematician John Nash, who introduced it in his groundbreaking work on non-cooperative games (Nash, 1951).

It describes a strategic situation in which no player has an incentive to unilaterally deviate from their chosen strategy, assuming all other players maintain their current strategies. This equilibrium state implies that each player has optimized their decision given the expected actions of their competitors, and no individual participant can achieve a better outcome by independently altering their strategy.

Mathematically, a Nash equilibrium in a game with n players is defined as a set of strategies $(s_1^*, s_2^*, \dots, s_n^*)$ such that

$$U_i(s_i^*, s_{-i}^*) \geq U_i(s_i, s_{-i}^*) \quad \forall s_i \neq s_i^* \qquad (1)$$

Where

U_i represents the payoff function of player i,

s_i^* the strategy chosen by player i in equilibrium,

s_{-i}^* refers to the strategies chosen by all other players except player i,

The inequality signifies that any deviation from s_i^* does not improve the player's payoff.

Example: A Simple Oil Pricing Game

Consider two competing oil firms, Firm A and Firm B, that must choose between setting a high price ($80 per barrel) or a low price ($70 per barrel) for their oil. Their profits depend on both their own pricing choice and that of their competitor. The payoff matrix is as follows:

	Firm B: High Price	**Firm B: Low Price**

Firm A: High Price	(700, 700)	(500, 800)
Firm A: Low Price	(800, 500)	(600, 600)

i. If both firms set a high price, they each earn $700 million in profits.
ii. If Firm A lowers its price while Firm B maintains a high price, Firm A gains market share and profits $800 million, while Firm B drops to $500 million.
iii. If both firms set low prices, they engage in a price war and each earns only $600 million.

Finding the Nash Equilibrium

i. If Firm A believes that Firm B will set a high price, it benefits from choosing a low price to maximize profits ($800 million vs. $700 million).
ii. If Firm A expects Firm B to set a low price, its best response is also to set a low price ($600 million vs. $400 million).

The same reasoning applies to Firm B. Since both firms anticipate the other will lower prices to avoid losing market share, the Nash Equilibrium occurs at (Low Price, Low Price) = (600, 600).

Although (High Price, High Price) offers higher profits, it is not stable because each firm has an incentive to lower prices if the other does not.

Explicitly, when a Nash Equilibrium is reached, no player benefits from changing their strategy alone, as they are already making the best possible decision given the strategies of their opponents.

Cournot Competition:
Cournot Competition, a model of quantity-based rivalry is a fundamental economic model in game theory that describes an industry in which firms compete based on the quantity of output they produce rather than price. Named after the French economist Antoine Augustin Cournot, who first introduced it in 1838, this model assumes that firms decide their output levels independently and simultaneously, taking into account the expected production decisions of their competitors (Cournot 1838; Fudenberg and Tirole 1991).

In contrast to Bertrand Competition, where firms compete by setting prices, Cournot Competition assumes that each firm sets its production quantity and that market price is determined by the total supply available in the market. The equilibrium reached in this setting, known as the Cournot-Nash Equilibrium, occurs when no firm can improve its profit by unilaterally changing its output level.

Mathematical Representation of Cournot Competition
Consider a duopoly a market with two competing firms (Firm A and Firm B). Each firm determines its production quantity, denoted as q_A and q_B respectively. The total market output is:

$$Q = q_A + q_B \quad (2)$$

where Q affects the market price $P(Q)$, which follows an inverse demand function:

$$P(Q) = a - bQ \quad (3)$$

where:

a represents the maximum price consumers are willing to pay,
b is a constant that determines how price decreases as quantity increases.

The revenue for each firm is given by:

$$R_A = P(Q)q_A = \big(a - b(q_A + q_B)\big)q_A \quad (4)$$

Each firm also incurs production costs, assumed to be linear:

$$C_A(q_A) = cq_A, \qquad C_B(q_B) = cq_B, \quad (5)$$

where c is the unit cost of production.
The profit functions for each firm are:

$$\Pi_A = \big(a - b(q_A + q_B)\big)q_A - cq_A \quad (6)$$

$$\Pi_B = \big(a - b(q_A + q_B)\big)q_B - cq_B \quad (7)$$

To maximize profit, each firm takes the derivative of its profit function with respect to its own output and sets it to zero (first-order condition for profit maximization):

$$\frac{d\Pi_A}{dq_A} = a - b(q_A + q_B) - bq_A - c = 0 \quad (8)$$

$$\frac{d\Pi_B}{dq_B} = a - b(q_A + q_B) - bq_B - c = 0 \quad (9)$$

Solving these equations simultaneously

$$a = b(q_A + q_B) + bq_A + c \quad (10)$$

Substituting equation (10) into equation (9), it becomes

$$b(q_A + q_B) + bq_A + c\ - b(q_A + q_B) - bq_B - c = 0 \quad (11)$$

Equation (11) becomes

$$bq_A - bq_B = 0 \quad (12)$$

Hence,

$$bq_A = bq_B \quad (13)$$

Bertrand Competition:

Bertrand Competition, a price-based rivalry model is a fundamental game-theoretic model that describes market interactions in which firms compete by setting prices rather than output levels. Named after the French economist Joseph Bertrand, this model assumes that firms produce homogeneous goods and that consumers always choose the firm offering the lowest price (Bertrand 1883; Fudenberg and Tirole 1991).

The Bertrand model predicts that in a market with identical firms and no capacity constraints, price competition drives prices down to marginal cost. This happens because:

i. If one firm sets a price slightly higher than its competitor, it sells nothing.
ii. If both firms charge the same price, they share the market.
iii. Each firm has an incentive to undercut the other until prices reach marginal cost, leaving no economic profit (Bertrand Paradox) (Osborne and Rubinstein, 1994).

Mathematical Representation of Bertrand Competition

If two firms, A and B, set prices P_A and P_B, then their profit functions can be modeled as:

$$\Pi_A = (P_A - C_A)D_A(P_A, P_B)\Pi_B = (P_B - C_B)D_B(P_A, P_B) \quad (10)$$

Where C_A and C_B are production costs, D_A and D_B represents demand functions dependent on competitor pricing.

Comparison: Cournot vs. Bertrand Competition

It is important to distinguish Cournot Competition from Bertrand Competition, another common market model:

Table 1: Showing the differences between Cournot and Bertrand competition.

Feature	Cournot Competition	Bertrand Competition
Strategic Variable	Output (Quantity)	Price
Market Influence	Firms indirectly influence price via output	Firms set prices directly
Outcome with Identical Costs	Firms produce at a stable level with positive profits	Price war leads to marginal-cost pricing and zero economic profit
Application	Oil, gas, manufacturing industries	Retail markets, telecom, airlines

In the oil industry, Cournot Competition is more relevant than Bertrand Competition because firms often compete by adjusting output rather than engaging in price wars. Due to high production costs and market regulations, price competition is less intense than in retail sectors like telecommunications or consumer goods.

Stackelberg Leadership Model:

The Stackelberg leadership model, a first-mover advantage in competition is a strategic game theory model that describes a market where one firm (the leader) moves first by setting its output or price, while the other firm(s) (the follower(s)) make decisions afterward, taking the leader's choice into account. Named after Heinrich von Stackelberg, this model highlights the advantage of being a first mover in a competitive market (Stackelberg 1934; Fudenberg and Tirole 1991).

Mathematical Representation

In a duopoly with a leader (Firm A) and a follower (Firm B), the demand function is:

$$P(Q) = a - bQ \qquad \text{where } Q = q_A + q_B$$

Each firm's profit function is:

$$\Pi_{\mathrm{A}} = \big(a - b(q_A + q_B)\big)q_A - C_A(q_A), \tag{11}$$

$$\Pi_{\mathrm{B}} = \big(a - b(q_A + q_B)\big)q_B - C_B(q_B), \tag{12}$$

Firm B, as the follower, sets its best response function based on Firm A's choice, which the leader anticipates when selecting q_A. Solving this yields the Stackelberg equilibrium quantities, where the leader produces more and earns higher profits than in Cournot competition.

Table 2: Showing the comparison between Stackelberg and Cournot Competition

Feature	Stackelberg Competition	Cournot Competition
Strategic Variable	Output (Quantity)	Output (Quantity)
Decision Timing	Sequential (Leader-Follower)	Simultaneous
Market Influence	Leader has a first-mover advantage	No first-mover advantage
Outcome	Leader produces more and earns higher profits	Firms produce equal quantities at equilibrium

Cooperative vs. Non-Cooperative Games: Strategic Interaction in Decision-Making

In game theory, interactions between players can be classified as either cooperative or non-cooperative games, depending on whether players form binding agreements or act independently in pursuit of their interests (Myerson, 1991; Osborne & Rubinstein, 1994).

Cooperative Games

A cooperative game is one in which players can form binding agreements or collaborations to improve their collective outcomes. These agreements are enforceable, ensuring that all participants adhere to the agreed-upon strategy.

Examples in the Nigerian Oil Industry

(i) OPEC (Organization of the Petroleum Exporting Countries): Nigeria, as a member of OPEC, engages in cooperative decision-making by agreeing to oil production quotas to stabilize global oil prices (OPEC 2024).

(ii) Joint Ventures in Oil Exploration: NNPC collaborates with multinational companies (e.g., Shell, Chevron) to share risks and maximize production efficiency.

Non-Cooperative Games

A non-cooperative game is one in which players act independently without forming enforceable agreements. Each participant seeks to maximize their individual payoff, often leading to competitive and strategic interactions.

Examples in the Nigerian Oil Industry

(i) Price Competition Among Fuel Stations: Independent fuel retailers set prices based on market demand, leading to competition rather than cooperation.

(ii) Market Entry Strategies: New entrants in the Nigerian oil sector (e.g., Dangote Refinery) must compete with established players like NNPC, influencing pricing and market share dynamics.

Table 3: The Comparison between Cooperative and Non-Cooperative Games

Feature	Cooperative Game	Non-Cooperative Game
Agreements	Binding (enforceable)	No binding agreements
Player Interaction	Collaboration & coalition formation	Competition & independent strategies
Outcome Focus	Collective benefit	Individual gain
Example in Oil Industry	OPEC production agreements, joint ventures	Price wars, independent refining strategies

Pricing Strategies and Market Dynamics

In the Nigerian oil industry, firms compete on pricing strategies while responding to fluctuations in global oil prices (NBS, 2021). Game theory helps in modeling pricing interactions through the following approaches:

(i) Bertrand Model: Assumes firms set prices simultaneously, leading to price wars or stability based on the number of competitors.

(ii) Price Leadership Model: Involves one firm setting a benchmark price that others follow to maintain market stability.

(iii) Cartel Behavior and OPEC Influence: Coordination among oil-producing nations, such as Nigeria's participation in OPEC, demonstrates cooperative game strategies where collective production decisions impact global prices (OPEC2024).

Table 4: Price Competition Model in the Nigerian Oil Sector

Company	Price Set ($ per barrel)	Market Share (%)
Company A	75	30
Company B	72	35
Company C	74	25
Company D	73	10

Market Entry, Mergers, and Competition

Game theory also applies to market entry decisions, where firms evaluate their potential investments and the reactions of existing players. Entry deterrence strategies (Akinyele, 2010) include:

(i) Limit Pricing: Incumbent firms setting low prices to discourage new entrants.
(ii) Predatory Pricing: Temporarily lowering prices to drive competitors out before increasing them again (Babaei *et al.* 2020).
(iii) Strategic Alliances: Collaborations between firms to enhance competitive advantage and influence market control (Hansen *et al.* 2022; Aniche 2015).

The Sequential Entry Game models a scenario where a new entrant decides whether to enter the market based on the incumbent's pricing response:

$$V_{entry} = max(\Pi_{entrant} - F, 0)$$

where V_{entry} is the entrant's expected value, $\Pi_{entrant}$ is potential profit, and F represents fixed entry costs.

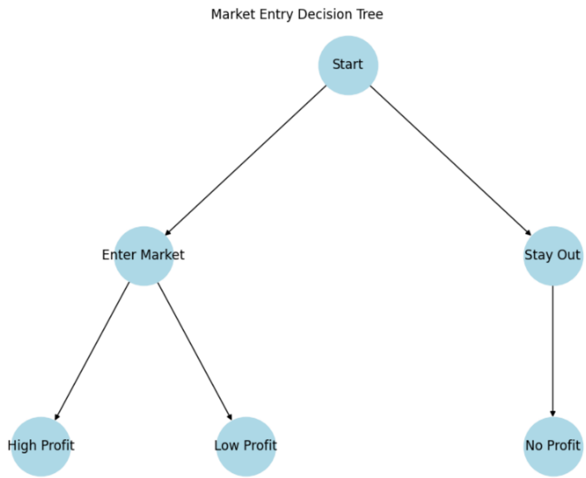

Figure 1: Market Entry Decision Tree

A graphical representation of a decision tree for market entry strategies based on game theory.

Exploration and Investment Decisions

Oil exploration involves high-risk investments, where firms must decide whether to invest in new reserves based on expected payoffs or not. Game theory aids in risk assessment using:

(i) Real Options Game: Evaluating when to invest in exploration projects under uncertainty.
(ii) Auction Theory: Understanding competitive bidding for oil blocks awarded by the Nigerian government to companies.

The Exploration Payoff Function can be expressed as:

$$E[V] = \sum_{t=1}^{T} \frac{R_t - C_t}{(1+r)^t} \qquad (13)$$

where $E[V]$ is the expected value of investment, R_t and C_t are revenue and cost in period t, and r is the discount rate.

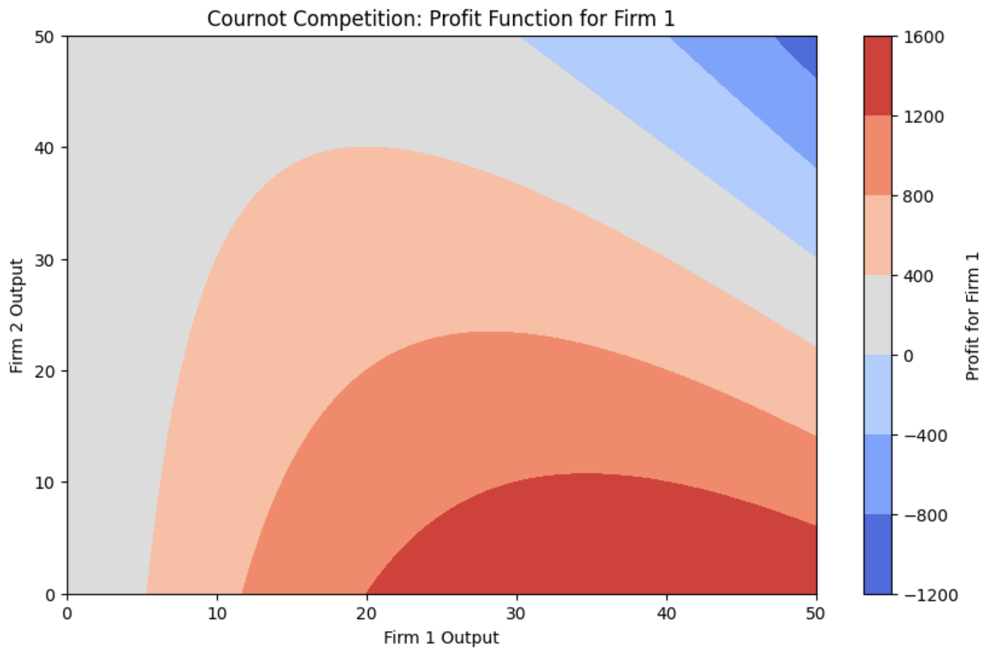

Figure 2: Investment Payoff Model for Oil Exploration

A graph showcasing investment return projections over time for different exploration strategies.

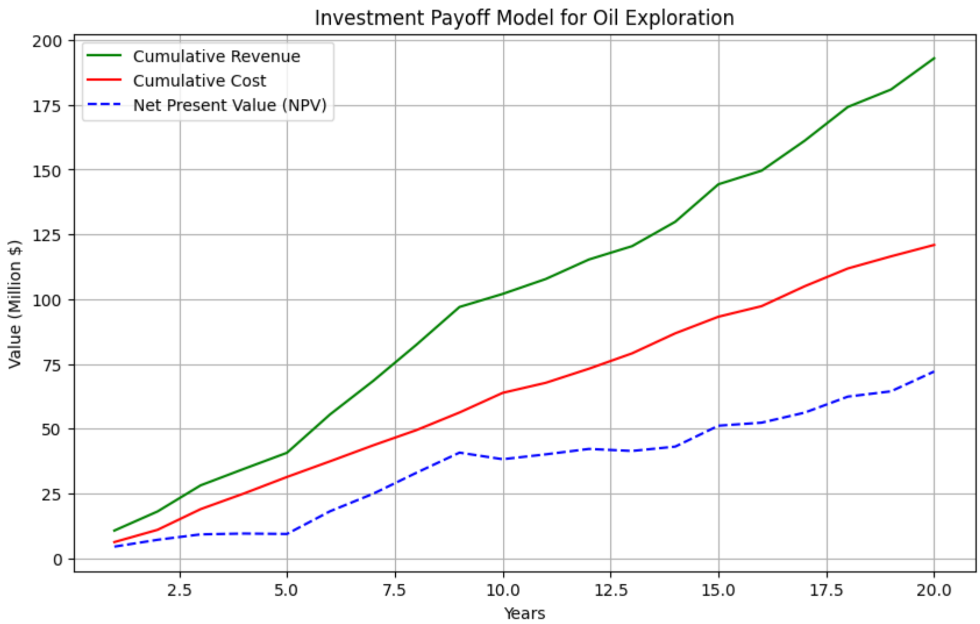

Figure 3: Investment Payoff Model for Oil Exploration

A graph showcasing investment payoff model for exploration strategies over the years.

Government Regulations and Policy Implications

Government interventions significantly impact competition in Nigeria's oil industry. Regulatory policies create additional constraints and influence firm behavior through:

(i) Taxation and Subsidies: Affecting firm pricing and investment incentives.

(ii) Production Quotas: Enforced through OPEC agreements, shaping output decisions (Chang *et al.* 2014).

(iii) Environmental Regulations: Encouraging cleaner energy transitions and compliance strategies.

Table 5: Government Policy Impact on Oil Market Competition

Policy Type	Effect on Firms
Tax Increase	Reduces profit margins
Production Quotas	Limits output capacity
Subsidies	Encourages investment
Environmental Rules	Increases operational costs

Case Studies of Game Theory in Nigeria's Oil Industry

This section presents real-world applications, such as:

i. Shell vs. NNPC (Nigerian National Petroleum Corporation): The partnership between Shell and NNPC highlights cooperative game theory applications in joint ventures. Shell, as a foreign investor, collaborates with NNPC to explore and develop oil blocks while optimizing production-sharing contracts to maximize profits (Akinyele, 2010).

ii. OPEC Decision-Making: Nigeria's participation in OPEC involves cooperative game theory, where production quotas are agreed upon to stabilize global oil prices. The game theoretic model ensures mutual benefit, preventing price wars among oil producing nations (Losáñez *et al.* 2018).

iii. OPEC and Oil Production Quotas: The Organization of the Petroleum Exporting Countries (OPEC) functions in a manner that can be analyzed using Cournot Competition. Although OPEC coordinates output decisions among member countries, individual members such as Nigeria still make strategic choices about how much oil to produce. Each country knows that increasing its output will reduce overall oil prices, affecting total revenue. The Cournot framework helps explain why OPEC imposes production quotas to stabilize market prices (OPEC 2024).

iv. Local Refinery Investments and Dangote Refinery's Entry: The Dangote Refinery, the largest in Africa, alters Nigeria's oil refining landscape. Existing players, including NNPC and modular refineries, must adjust strategies to maintain market share. The entry of Dangote Refinery follows a Stackelberg leadership model, where it takes a dominant role while influencing pricing and supply chain decisions of competitors (Ogunbukola 2024).

v. Nigerian Oil Refinery Competition: Consider two major oil refining companies in Nigeria, such as the Dangote Refinery and the Nigerian National Petroleum Corporation (NNPC). Both firms produce refined petroleum products and must decide how much gasoline and diesel to refine and supply to the market. If Dangote increases production, NNPC may respond by adjusting its output accordingly. The equilibrium refining levels can be determined using Cournot's model.

Conclusion and Future Directions

Game theory offers critical and valuable insights into strategic decision-making in Nigeria's oil industry, enabling firms to refine pricing, investment, and competition strategies. Nash Equilibrium serves as a key analytical tool, helping companies anticipate competitors' responses and make rational decisions that balance profitability and competition. Cournot Competition provides a framework for understanding production-based strategic interactions, particularly in OPEC decisions and refinery competition, while Bertrand Competition sheds light on price wars in the fuel retail sector. The Stackelberg Leadership Model highlights the influence of dominant firms in shaping market dynamics through strategic first moves. Future research should focus on integrating advanced machine learning techniques to enhance predictive analytics and improve decision-making in the evolving oil market.

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