



# OPEC, the Seven Sisters, and oil market dominance: An evolutionary game theory and agent-based modeling approach



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## ABSTRACT

A methodological toolkit comprised of evolutionary game theory and agent-based modeling is used to study OPEC and the Seven Sisters as they struggled for control over global petroleum markets during the 1960s and 1970s. An evolutionary game theory model incorporates heterogeneous populations, energy-specific variables, and behavioral considerations to capture the fundamentals of the applied problem. An agent-based model is used to provide detailed results and demonstrate the importance of the natural resource to the outcome of the model.

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## 1. Introduction and historical background<sup>1</sup>

This paper examines the struggle between OPEC and the Seven Sisters as the two cartels competed for control over global petroleum markets during the 1960s and 1970s. With vast economic and political consequences, this conflict is well-known anecdotally within academia and industry, but the intertemporal transition of market dominance from the Seven Sisters to OPEC has not been satisfactorily explained in the economics literature. By combining an evolutionary game theory (EGT) model featuring heterogeneous populations of agents and natural resource-specific variables with the computational power of agent-based modeling (ABM), we describe agent learning and gain insight into the problem. In particular, we highlight the key role of natural resource stocks and learning in an evolutionary environment in driving the switch in market dominance.

The historical interval begins with the Seven Sisters major oil firms as the dominant force in global petroleum markets in the decades following World War II. Consisting of Royal Dutch Shell, British Petroleum, Gulf, Exxon, Mobil, Texaco, and Chevron, the anti-competitive cartel held concessions to oil in sovereign nations with abundant petroleum resources (Sampson, 1975). A concession offered an exclusive right to search for oil in a nation's territory, along with the right to produce and distribute any oil that was discovered (Wagner, 2009). In exchange, the firm gave a share of the profit in royalties to the nation in which it operated. This arrangement gave the Sisters property rights over oil in Venezuela and oil-

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producing Middle Eastern nations, and by 1950 the cartel possessed a 98.3% market share of world petroleum production (Engen, 2009).

This arrangement was potentially beneficial to both parties; the particular Sister earned profits, and the sovereign state earned revenue from its non-renewable resource at a time when it lacked the expertise to discover, extract, and market its petroleum (Yergin, 1992). However, the producing nations grew dissatisfied with the share of oil receipts that they received from the Seven Sisters, as the terms of the concessions were favorable for the western firms (Libecap and Smith, 2004; Adelman, 1997). The nations also became discontented over having little control over the resources located in their respective territories. In 1960, Saudi Arabia, Iraq, Iran, Kuwait, and Venezuela formed OPEC to serve as a defensive organization designed to stabilize world petroleum prices and defend the interests of the member states (Al-Otaiba, 1975).

OPEC was initially ineffectual, as internal rivalries and unilateral actions precluded the group from gaining a greater share of oil profits from the major firms or in capturing control over their own resources. It took nearly a decade for the OPEC nations to figure out how to multilaterally bargain for a larger share of the rents from oil, and it wasn't until 1973 that the cartel learned how to operate cohesively and leverage its natural resources as a means to obtain dominance over world oil markets. OPEC, despite having possession of the vast majority of world oil reserves, was unable to capture control of world petroleum markets for well over a decade.

This multiple-year delay between when OPEC was founded and its ascent to the position as the leading force in global petroleum markets is difficult to model with orthodox economics techniques; despite the popularity of this historical story, no comprehensive model has explained the behavior of the agents across the time horizon. Traditional models that have investigated OPEC's behavior have examined the cartel once it captured control of oil markets by using traditional game-theoretic approaches (Salant, 1976; Gilbert, 1978) or by taking snapshots of particular agents at specific points along a time horizon (Dutta, 1999). However, the historical epoch examined in this paper is one dynamic problem that evolved slowly and in starts across over a decade, and it is a contest in which OPEC agents had to learn and adapt as they struggled to capture control away from the Sisters.

For a variety of reasons, this dictates the use of an alternative methodological approach to model this episode in the history of energy markets. First, the interplay between the Seven Sisters and OPEC is inherently strategic, dictating the use of game theory rather than constrained optimization. Second, the interaction between the parties in the two cartels was not a singular occurrence; rather, it took place over several decades. This requires an intertemporal approach. Third, the actions of agents reflected emotions like envy and discontent, and they engaged in learning and adaptation over time (Yergin, 1992; Maugeri, 2006). This requires a behavioral approach that models agents who use heuristics to guide evolving behavior.

In our view, a combination of theoretical EGT and computational ABM provides an appropriate toolkit for this application. EGT is the theoretical component of the toolkit, and it combines strategic interdependence with an evolutionary learning process that is based on behavioral agents who learn, experiment, and use heuristics to guide their choices as they interact in intertemporal, game-theoretic settings. While the EGT framework provides an attractive modeling approach to this sort of learning and adaptation, EGT models can quickly become analytically intractable, particularly when the complexity of the environment is non-trivial (as in this application). To transcend this limitation, we bolster our EGT work with ABM. ABM computes emergent, system-wide behaviors that arise as a consequence of individual-level interactions. In this work, ABM serves as a laboratory to test the assertions of the theoretical EGT model, and the combination of EGT and ABM emerges as an evolutionary, behavioral analogue to the "theory and data" structure common to the economics literature.

The combined approach allows the incorporation of a behavioral description of agents' learning and adaptation in OPEC and the Seven Sisters with an energy-specific variable that captures the state of a cartel's market share. Results show that a market share advantage and discontent over comparatively low payoffs allow OPEC agents to learn to operate as a collusive cartel and drag their rivals to an equilibrium in which OPEC controlled global oil markets. This transition in power over global oil markets was stimulated by groups of agents who acquired new information, imitated others, acted on emotion, relied on heuristics, experimented with new strategies, and learned from their mistakes as they interacted strategically. These characteristics not only inform the problem studied, but also have general appeal. The appeal stems from the creation of a research methodology for a class of applied problem that orthodox techniques struggle to address; EGT and ABM are well-suited to the study of any dynamic, game-theoretic problems in which agents reflect behavioral considerations. It presents one approach to advance economics as an evolutionary science, and the applicability of combining EGT and ABM extends beyond cartel problems and energy issues to any situation in which strategy and behavioral economics are present.

The balance of this paper proceeds as follows. Section 2 provides a literature review of previous cartel research with respect to OPEC and global oil markets, evolutionary game theory, and agent-based modeling. Section 3 presents the methodology of the evolutionary game theory model and the agent-based model. Section 4 discusses the results of the agent-based model. Section 5 concludes. Two appendices provide mathematical and computational support.

## 2. Literature review

Previous research on OPEC and global oil has largely studied the cartel once it already emerged as the dominant force in world petroleum markets, and this research has relied on a variety of cartel modeling approaches and frameworks. A Nash-Cournot approach is used by Salant (1976) to model OPEC as a unified group maximizing profits without strife amongst its members. Other papers that model OPEC as the dominant firm in world oil markets include Pindyck (1978), who structures OPEC as a unified monopolist solving a wealth-maximizing optimal control problem, Cremer and Weitzman (1976), and

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