GAME THEORY AND FISHERIES

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Contents

Summary

This chapter investigates the role of game theory in fisheries economics applications. The purpose is to illustrate why and how game theory can be used to explain world's fisheries problems. A selection of both non-cooperative and cooperative games is undertaken in order to show fundamental principles in the strategic interactions between fishery agents. First, a two-player non-cooperative game is presented. The solution of the game shows the classical "prisoner's dilemma", in which non-cooperation is chosen despite cooperation yielding higher returns. Then, through a non-cooperative game of coalition formation it is shown that free rider incentives can undermine cooperative agreements on fisheries and may lead to complete non-cooperation. Finally, cooperative games and their solutions are introduced. The analysis shows that fair sharing rules,

such as the Shapely value may not guarantee the stability of cooperative agreements. Furthermore, stability may be affected by new-entrants.

1. Introduction

According to recent research, fisheries are severely overexploited in many areas of the world. There are too many vessels catching too few fish, which causes conflicts among fishermen, and fishing states. However, there are also cases of successful fisheries management. How can these differences be explained? This chapter illustrates how game theory can be used to explain the origin of fisheries conflicts and the emergence of cooperation.

Whenever there are at least two fishermen, fleets, countries or other agents harvesting a common fish resource strategic interaction among these agents is inevitable. Game theory is a tool that can be used to analyze such interactions. The decisions of one agent are not only affected by the biological and socio-economic characteristics of the fishery, but also the behavior of the other agents. The question then arises, what are the bioeconomic consequences of such interactions, specifically are cooperative and non-cooperative behavior biologically and economically efficient?

Game theory is typically divided in two branches: non-cooperative and cooperative. A game is non-cooperative if commitments (agreements, promises, and threats) are not enforceable. These games are focused on the strategic choices of the individual: how each player plays the game and what strategies he chooses to achieve his goals. A game is cooperative if commitments are fully binding and enforceable. These games are used mainly to analyze which coalitions form, their payoffs and its division among coalition members. This classical division is followed in the current chapter. A selection of both non-cooperative and cooperative games is undertaken in order to illustrate the potential of game theory to show fundamental aspects of the strategic interactions between players.

The chapter is organized as follows. Section 2 presents non-cooperative fishery games based on the classical Gordon-Schaefer bioeconomic model. It starts with a two-player game and proceeds to a game of coalition formation. Section 3 introduces cooperative games and its solution concepts. The Stability of fisheries agreements is discussed... sustainable fisheries agreements Finally, Section 4 provides some concluding remarks.

2. Non-Cooperative Games

This section uses non-cooperative games to show the consequences of non-cooperation in fisheries. Two games have been selected in order to illustrate the potential of game theory to capture the strategic interactions between agents. The first is a static two-player game in a fishery represented by the classical Gordon-Schaefer bioeconomic model. The second is a game in partition function form in which players can form coalitions. Finally, an overview of the applications of these non-cooperative games is presented.

2.1. A Two-Player Game

The present approach to non-cooperative fishery games starts with a very simple setting. It is assumed that a fish stock is harvested by two symmetric players, i.e. identical decision makers regarding the game rules, which can be fishermen, fleets or countries. Let us start by presenting the underlying bioeconomic model.

2.1.1. The Bioeconomic Model

The present game is based on the standard Gordon-Schaefer bioeconomic model. Thus, the fish stock dynamics can be represented through the following equations.

$$\frac{dX}{dt} = G(X) - \sum_{i=1}^{2} H_i \quad (1)$$

$$G(X) = rX\left(1 - \frac{X}{k}\right) \quad (2)$$

$$H_i = qE_iX \quad i = 1,2 \quad (3)$$

where X represents fish stock biomass; t the time; $G(X)$ the logistic growth function; r the intrinsic growth rate of fish; k the carrying capacity of the ecosystem; H_i the harvest of player i; q the catchability coefficient; and E_i the fishing effort of player i. Note that the variables X, H_i and E_i are all functions of time (t). This has been omitted in the equations for simplification.

According to Eq. (1) the variation of the stock in time is given by the difference between stock growth and total harvest. Stock growth is defined by a logistic function (2). This is an inverted U-shaped function. Stock growth increases as the stock level rises to a maximum value, often designated as maximum sustainable yield. As the stock continues to increase the growth starts to decrease, and upon reaching zero the stock stabilizes at the carrying capacity of the ecosystem. Thus, for low levels the fish multiply, however once they begin to compete for food, growth reduces and the stock tends to the level that can be sustained by the environment. The harvest functions (3) indicate that the harvest of each player increases with the stock level and the fishing effort – an aggregate measure of the inputs devoted to harvesting such as days at sea.

Equations (1) to (3) can be used to determine the equilibrium, or steady-state, stock level that corresponds to a given fishing effort that is constant through time. This steady-state relation is given by:

$$X = \frac{k}{r}\left(r - q\sum_{i=1}^{2} E_i\right) \quad (4)$$

As expected, Eq. (4) indicates a negative relation between the equilibrium stock level and the players' fishing effort.

The economic dimension of the fishery is represented by the players' economic profit. Assuming that price and cost per unit of effort are constant, this is given by:

$$\pi_i = pH_i - cE_i \tag{5}$$

where π_i denotes the profit of player i, p the price and c the cost per unit of effort.

The Gordon-Schaefer model is still the main reference in theoretical approaches to fisheries bioeconomics. This aggregated model has shown significant potential in showing fundamental economic principles in fisheries management. Nonetheless, the scope of application of this model to empirical studies is limited, due to its simplicity.

2.1.2. The Fishing Strategies and Payoffs

Having presented the bioeconomic model, let us turn to the players' behavior. It is assumed that each player chooses a constant level of fishing effort that maximizes its steady-state, or long-run, profit given the fishing effort of the other. This can be represented by:

$$\max_{E_i} \pi_i = pH_i - cE_i = pqE_i \frac{k}{r}\left(r - q\left(E_i + E_j\right)\right) - cE_i \tag{6}$$

The solution of (6) yields the players' reaction functions:

$$E_i = \frac{r}{2q}\left(1-b\right) - \frac{1}{2}E_j, \quad i, j \in \{1,2\} \tag{7}$$

where $b = \dfrac{c}{pqk}$. This is usually designated as an "inverse efficiency parameter", as it increases with the cost per unit of effort and decreases with price and catchability coefficient. Therefore, the higher the value of b, the lower players' efficiency.

The reaction function can be interpreted as the best-response of a given player to the fishing effort level of the other. Graphically this function is represented by a line with a negative slope: as the fishing effort of one player increases the best-response of the other is to reduce its fishing effort.

The solution of the game is given by the Nash equilibrium. This is the most important solution concept for non-cooperative resource games and is adopted throughout the chapter. A Nash equilibrium occurs when each player chooses a strategy that maximizes his payoff given the other players' strategies. Thus, it is a strategy profile from which no player has incentive to deviate unilaterally. The Nash-equilibrium fishing effort strategies and the corresponding payoffs are given, respectively, by:

$$E_1 = E_2 = \frac{r}{3q}\left(1-b\right) \tag{8}$$

$$\pi_1 = \pi_2 = \frac{1}{9}\frac{r(pqk-c)(1-b)}{q} = \frac{1}{9}\theta \qquad (9)$$

From Eq. (8) it can be concluded that the fishing effort of each player at the equilibrium depends positively on the intrinsic growth rate of fish and on its efficiency.

The steady-state equilibrium stock level is the following:

$$X = \frac{k}{3}(1+2b) \qquad (10)$$

The equilibrium stock depends positively on the carrying capacity of the ecosystem and negatively on players' efficiency.

This simple non-cooperative game illustrates a central issue in the use of a common pool resource: the presence of externalities. It is said that an agent causes an externality to others if its actions causes a cost or benefit, which is not compensated. In the present game, when an increase of fishing effort by one player reduces the stock available for the other and consequently the catch per unit of effort and profit. This externality is usually known as "stock subtractability" and is a fundamental characteristic of common pool resources.

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Biographical Sketches

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