

Game Theory in Urban Birds: A Nash Equilibrium Analysis Using Crows and Pigeons

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ABSTRACT

Nash equilibrium, otherwise popularly known as the game theory or Prisoner's Dilemma is a concept developed by John Nash, a Nobel laureate who was awarded the Nobel Prize for his concept of Game theory. This is a very important concept which has been frequently used in various branches of social sciences, psychology and also in biology. Though the theory or the concept may sound abstract, but has its application in all walks of life, including in our daily activities. The theory has been applied in many situations in social sciences, political scenarios, etc., but the theory has not been extensively studied in biology. Limited studies have been reported on this concept as that of Hawk and dove game, and also to explain certain concepts in behavioural ecology. In the present study, we have modelled the success of two urban bird populations, the crow and the pigeon using the concept of Game theory. According to this concept no player, can gain or change their outcome, by changing their strategy or game alone. In summary it may be said the cooperation is the best way to gain or acquire maximum benefit. This has been explained by modelling the two birds as producers and scroungers. The payoff matrix illustrates that when both the bird's strategy (s1, s -1) is producers (P,P), then the gain is 4 units each. If the bird's strategy (s 1, s -1) is that of producer and scrounger (P, S) then the payoff is 2 units each, but if both the bird's strategy is (s 1, s -1) is that of scroungers (S, S) then the payoff is 0 each. (null). Suggesting that if both the bird populations, cooperate in their food collecting and eating strategy, there is a greater benefit rather than one acting as a producer, or both acting as scroungers. The success of these two birds, crow and pigeon in highly polluted and populated urban scenario, may be attributed and explained by game theory as proposed by John Nash.

KEYWORDS: Nash equilibrium, Game theory, Crow, Pigeon, Pay off matrix

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INTRODUCTION

Game theory or otherwise referred to as Nash equilibrium was developed by John Nash in 1950, which revolutionized the economics and also impacted Sciences. (C.A. Holt, & A.E. Roth, 2004). It may be simply defined as a situation in a game where **no player can improve their outcome by changing their strategy alone**, as long as the other players keep their strategies unchanged (Heiko Hotz, 2006; Martin J. Osborne 1995). In simple words, it means that in any situation or when playing a game, the outcome or success will depend upon the one who is playing the game and also other players who are playing with you. This concept is also referred to as game theory, whose application has been quite relevant in the field of biology. Game theory has been frequently studied in evolutionary biology to learn about the interactions between different individuals (Durlauf, S.N., Blume, L.E. (2010). Evolution of animal fighting, animal behaviour, (Maynard Smith and Price (1973) and also in cooperative interactions (Trivers, 1971) It also plays a significant role in signalling mechanism between sexes (Grafen, 1991). One of the interesting biological phenomenon of sex allocation (investment of food, resources and energy to produce either male or female off springs) was explained using game theory (Charnov EL. 1982). Authors like Olof Leimar and John M. McNamara, (2023) have suggested that Game theory is relevant to all areas of biology where reproductive success depends on how common certain phenotypes are. In such cases, the optimal phenotype for an individual is influenced by the phenotypes of others in the population. There are quite a number of examples and studies which involve the concept of game theory or prisoner's dilemma with reference to animal behaviour, mating mechanism etc. Studies by authors like Phillips, *et.al*, (2018) have studied, the foraging behavior of juvenile coho salmon (*Oncorhynchus kisutch*). In their studies, they have highlighted the advantage of living and foraging as a group, as this behaviour is known to increase efficiency and reduces the need for constant vigilance. Similarly, a study by Rueffler, & Lehmann, (2024), who have mathematically modelled the sea bird population on an isolated island. They studied the concept of predator prey concept on

an isolated island and suggested that, the number of offspring successfully raised depends on how much prey the parents can capture while foraging in the surrounding ocean and successfully deliver to their off springs. Apart from these studies, the most popular or famous concept in explaining Nash equilibrium is that of Hawk and dove game which is frequently used in understanding situations of conflict between two partners (Arieli *et al* 2024; Hammerstein P. 1981 Mesterton-Gibbons M. 1994). Though there are quite a number studies, reported involving the concept of Nash equilibrium, in different aspects of biology, not many studies have been reported about the foraging behavior of urban birds, involving crows and pigeons, which compete for the same food source. Therefore based upon these studies, it is quite evident that the success of a bird species, when competing for limited food source may be explained by Nash equilibrium as proposed by John Nash and is often referred famously as game theory or prisoner's dilemma. In the present study we have mathematically modelled the conflict between the crows and pigeons in urban scenario, to explain and understand the conflict between two bird species, competing for same food source.

MATERIAL AND METHOD

There is no real time, observation, this study, uses the game-theoretical model of Producer-Scrounger (P-S) game to simulate interactions between two urban bird species: **crows** (*Corvus spp.*) and **pigeons** (*Columba livia*). There is no exact field time data collected, but based on theoretical assumptions. To simulate interactions between the two bird species, the following assumptions were made:

- The total number of birds (N) is fixed at 10.
- Birds can adopt one of two strategies: **Producer (P)** or **Scrounger (S)**.
- The payoff for each strategy depends on the food value (f) and the cost of searching (c).
- Food is found only by producers and is shared among nearby scroungers.
- The interaction is frequency-dependent and played simultaneously in a shared foraging environment (e.g., city street or garbage site).
- A payoff matrix was created and calculated using Microsoft Excel (M.S. Excel)

The details about the matrix and the calculations are outlined under results section.

RESULTS

In the present study, to analyse and understand the conflict between two bird species, crows and pigeons which are commonly found in urban scenario, the concept of game theory was employed. According to concept the birds can adopt any of the two strategies i.e. either act as producers (P) or act as Scroungers (S).

A **producer** is an individual which actively searches for food or resources in the environment. It uses its time and energy in locating resources, and once it finds them, it may consume them or be joined by **scroungers** who share the resource.

In this example Crows may be considered as **producers**.

A **scrounger** is an individual that does not search for food on its own but instead attempts to exploit the efforts of producers by joining them after

they've found food. Scroungers save their effort and time, but depend on the success of producers.

In this scenario, pigeons may be considered as **scroungers**

The Nash equilibrium in this situation is as follows

Players:

1. Crow
2. Pigeon

Strategies:

P = Producer (searches and finds food)

S = Scrounger (waits and exploits other's success)

Assumption

Each food item = 4 units

Producer finds 1 food item

If both choose Producer: each gets 4 units individually

If one is Producer and the other is Scrounger:

Producer gets 2 units

Scrounger gets 2 units

If both are Scroungers: no one finds food = 0 units

Payoff matrix

S. No:		Pigeon producer (P)	Pigeon: Scrounger (S)
1	Crow: Producer (P)	Crow=4 Pigeon=4	Crow=2 Pigeon=2
2	Crow: Scrounger (S)	Crow=2, pigeon=2	Crow=0, pigeon=0

Now plugging values in to the matrix.

- A producer finds 1 food item worth **4 units**.
- If both are **producers**, they both find food separately: **4, 4**

- If one is **producer** and the other is **scrounger**, they share: **2, 2**
- If both are **scroungers**, no food is found: **0, 0**

S No:	Crow/pigeon	Producer (P)	Scrounger (S)
1	Producer (P)	4,4	2,2
2	Scrounger (S)	2,2	0,0

In game theory S stands for strategy chosen by the players.

S_1 or s_1 refers to strategy adopted by player 1 (Crow)

S_{-1} or s_{-1} refers to strategy adopted by other players, but not by player 1 (Here it is the pigeon)

s_i → strategy chosen by **player i (index=crow)**

(For example, if the crow is player 1, then s_1 is the crow's strategy, either Producer (P) or Scrounger (S).

s_{-i} → strategies chosen by **other player but not by i**

(So for the crow, s_{-1} refers to what the pigeon does).

Utility or pay off function for Nash equilibrium

$$u_i (s_i, s_{-i}) = u_i (\text{producer, scrounger}) = 2$$

Scenario 1 =if crow and pigeon are producers then the payoff function will be

$$u \text{ crow } (P,P) = 4 \text{ and } u \text{ pigeon } (P,P) = 4$$

Scenario 2, if crows is a producer and pigeon is a scrounger then the payoff function will be

$$U \text{ crow } (P, S) \text{ and } u \text{ pigeon } (P, S) = 2$$

Scenario 3, Crow and pigeon both are scroungers then the payoff function will be

$$U \text{ crow } (S, S) = 0 \text{ and } u \text{ pigeon } (S, S) = 0$$

Therefore it may be said that

When food value = 4 units

- Producers benefit more when no one else scrounges.
- Scroungers can get food only if Producers are present.
- If all scroungers then there is no food.

In conclusion, according to Nash equilibrium in game theory, no player (crow /pigeon) can

unilaterally change their strategy and gain more if the other players keep their strategies unchanged. Mutual cooperation can benefit both players, but if one defects while the other cooperates, the defector gains more while the co-operator loses. However, if both defect, neither of them will gain.



DISCUSSION

In the present study, two urban bird species, crows and pigeons have been taken as test subjects, to explain the concept of Nash equilibrium. The success of these two populations in the urban scenario where they seem to compete for the same food source, may seem to follow, the producer scrounger concept. It is a common observation, that both the bird populations, co-existing and these two bird species, are the two players and may seem to

follow either producer, producer or producer scrounger strategy, such that both the players are benefited in the game of searching food. Neither of the two players, seem to act as scroungers, as they don't benefit from this strategy, which is quite obvious by the present day populations of the two birds. The success of these birds, may be treated as a most suitable example where in game theory plays a significant role in evolution of cooperation between these birds, leading to successful sustenance of their individual populations and maintaining their societies. This

assumptions, aligns with the observations and studies of S. N. Durlauf *et al.* (2010), where the authors, have suggested the most important application of game theory in evolution, is that of cooperation. According to these authors, cooperation has been a key driving force in the evolution of biological systems, from the organization of chromosomes and cells to the development of complex organisms and animal societies. One of the most striking examples of such cooperation is found at the genetic level, where thousands of genes work together to regulate cellular functions, all contributing to the overall health and survival of the organism. In addition to these observations, studies by authors like Maynard Smith, J. and Price (1973), have described about the conflicts among different species, and suggested that in biological populations, aggression among the populations, might be common, but rarely leads to lethal injuries. This is a behavioural strategy which may seem to be advantageous in evolution. According to studies by Hilbe, *et al.*, (2023), it is believed that all animal interactions, do not necessarily resemble a conflict, but many a times, species try to coexist such that both the species, can gain benefit. This very concept of coexistence may have led to multicellularity as opined by authors like Kaveh K, (2016), Rokas A (2008) and Tarnita CE *et al.*, (2013). The most prominent example of application and existence of game theory, is that of cooperation in evolution and this concept has been extensively studied by authors like Leimar O, McNamara JM (2023) and Hilbe *et al.*, (2023). Apart from this, it is interesting to note that, game theory has been applied for the understanding of microbes and diseases. (Brown (2016); Merlo *et al.* (2006)) and also to explain and understand the onset and progression of cancer (Martin *et al.*, (1992); Tomlinson IPM (1997) Vincent TL (1996). Based on these observations, it can be inferred that in the present study of crows and pigeons in an urban environment, the **producer strategy** appears to be the most advantageous for both bird populations. This strategy likely represents an **evolutionarily stable strategy (ESS)**, offering optimal benefits under current conditions. The continued presence and success of these species, despite challenges such as pollution and anthropogenic structures like cell phone towers and electric poles can be effectively explained using concepts from **game theory**, particularly

the **Prisoner's Dilemma** and **Nash Equilibrium**. These theoretical models help illustrate how cooperative or mixed strategies may enable these urban birds to coexist and thrive.

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