

Application of the Iterated Prisoner's Dilemma and Evolutionary Game Theory in Siting Nuclear Power Plants in South Korea

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Abstract—The quality of an urban living environment largely depends on the planning and development of public facilities, which are often halted or delayed due to the NIMBY (not in my backyard) phenomenon. In such facilities, environmental costs are borne solely by the residents of proximity to the facility, while public goods/services produced by the facility are reaped equally by residents across the greater region, which in turn presents a complex dynamic of public and self-interest. This paper uses repeated games and evolutionary game theory to identify the optimal negotiation strategy for the government when siting nuclear power plant facilities in South Korea. This study simulated a tournament containing 36 selected iterated prisoner's dilemma strategies and considered factors including mean payoff values, payoff matrices, and Axelrod's Ecological Variant to deduce an optimal strategy. The results showed that AON2, a memory-2 strategy of direct reciprocity, would provide the most stable and high return negotiations.

Keywords—Game Theory, Iterated Prisoner's Dilemma, Evolutionary Game Theory, Nuclear Power Plant Siting, NIMBY

I. INTRODUCTION

The construction of facilities, including roads, railways, power plants, composting plants, and waste incineration plants, require large amounts of land and extensive planning. Negotiations and deliberations on the best construction site for such facilities may go on for years and are often delayed due to public opposition to the project. The term 'NIMBY,' which stands for "not in my backyard," an attitude that is thought to be behind much local opposition, often appears in discussions on the construction of new facilities [1]. The roots of the NIMBY phenomenon stem back to the nature of siting and construction of such facilities. Several production costs exist associated with NIMBY facilities, including

environmental costs (e.g., the noisy environment around the facility), which are borne solely by the residents in proximity to the facility. In contrast, the public goods/services produced by the facility are reaped equally by residents across the greater region, which in turn presents a complex dynamic of public and self-interest. As a result, when a government plans to construct a facility that produces local public goods/services, controversy often arises among residents about where the facility should be sited [2]. While private or public facility proponents search for workable strategies to gain public acceptance, opposition groups regularly demonstrate a capacity to halt or delay new projects using a variety of legal and political tactics. Such actions persistently thwart efforts to implement rational planning to meet environmental needs and expose the weaknesses of state siting processes in effectively balancing regional needs and local impacts [3].

Against this backdrop, compensation has become an essential policy tool for achieving equity and efficiency in facility siting [4]. From an economic standpoint, compensation helps internalize the total social and environmental costs associated with unwanted facilities, thereby achieving a more socially desirable mix of facility locations and sizes than would be the case where the locality shoulders the adverse impacts without offsets [5]. From an equity perspective, compensation for hosting communities and households is a necessary adjustment mechanism for achieving fairness, especially when integrated with risk reduction and sharing mechanisms [6], [7], [8]. From both perspectives, compensation plays an increasingly promising role in resolving various siting disputes like NIMBY. When properly deployed, compensation can serve as an incentive for residents to resolve NIMBY conflicts [9].

Due to the societal and environmental significance of NIMBY facilities, many studies have been conducted to identify the best siting method. Maarten Wolsink studied the assumptions behind the NIMBY theory on facility siting in 1992, where he examined six implicit assumptions which can be distinguished in the backyard theory [10].

In 2016, Melike Erdoğan and İhsan Kaya of Yıldız Technical University used a combined fuzzy multi-criteria decision-making (MCDM) methodology that consists of Interval type-2 fuzzy analytical hierarchy process (AHP) [11]. Euston Quah and K.C. Tan study the existing conflict-resolution instruments used in the siting of these facilities and highlight in particular legal and command instruments, such as zoning and compulsory acquisition of land, and economic incentives, such as compensation and mitigation [12].

A study by Chiou et al. explores the different types of compensation to host communities, including direct monetary payments, in-kind infrastructure grants, tax or expenditure reduction, property value guarantees, individual welfare assurances, and funds for non-profit-making activities. They further identify the critical variables of negotiated compensation, namely:

1. Types of compensation
2. Distribution of compensation fund
3. Use of compensation fund
4. The negotiation process

They later examine the limitations and feasibility of compensatory measures in the case of Taiwan's incinerator facilities [13]. Himmelberger et al. conducted a similar study where recent negotiations connected with siting 24 solid-waste landfills in Wisconsin were analyzed. The association between the type and amount of compensation paid to host communities by facility developers and the size of facilities, certain facility characteristics, the timing of negotiated agreements, the host community's size, and the host area's socioeconomic status were studied [9].

A 2018 study by Basheer et al. proposes a novel nonlinear programming model called Risk and Distance Minimization in Process Units Siting (RIDIMPUS), where safety and cost factors were modeled using various governing parameters and expressions were designed to integrate safety and economic concerns [14].

II. NEED FOR RESEARCH

One NIMBY phenomenon in particular that has recently become relevant is the siting of nuclear power plants under South Korea's Yoon administration. Nuclear power is a clean energy source that provides pollution-free power and generates no greenhouse emissions. Cooling towers in reactors emit water vapor, thus not releasing any pollutant or radioactive substance into the atmosphere. Additionally, 90% of the nuclear waste that forms as a byproduct of nuclear reactors can be recycled. Furthermore, according to the US Office of Nuclear Energy, nuclear power has by far the highest capacity factor, with plants requiring less maintenance, capable of operating for up to two years before refueling, and able to produce a maximum power of more than 93% of the time during a year, making them three times more reliable than wind and solar plants [15].

In June 2017, former South Korean President Moon Jae-in held a press conference in front of the KOR-1 nuclear facility, during which he announced the plant's decommissioning and a complete phase-out of nuclear power in the country. President Moon remarked that South Korea would "abolish our nuclear-centered energy policy, and move towards a nuclear-free era." As a result, according to Rep. Yoon Han-hong of the ruling People Power Party, the combined sales of more than 270 nuclear power vendor companies in South Gyeongsang Province declined by 38 percent to 10.4 trillion won (\$8.03 billion) in 2018 from 16.1 trillion won in 2016. During the same period, the number of jobs at those companies also dropped by 14 percent [16].

Following President Yoon-Suk-Yeol's inauguration in May 2022, former President Moon's nuclear phase-out policies have been completely scrapped. Yoon, an avid supporter of nuclear power in the South Korean energy portfolio, has placed orders worth 92.5 billion won, particularly spare parts for existing nuclear power plants and the designs of Shin-Hanul 3 and 4 reactors, whose construction was halted in 2017. The ministry added further orders worth 1 trillion won that will be continued until 2025. In addition to Yoon's plans to revamp many of South Korea's currently operating power plants, he plans on building four more nuclear reactors by 2030 [17]. Due to the economic and environmental benefits that come with the construction of additional nuclear reactors, the siting of these power plants must be executed without delay, hence demonstrating the significance of analysis on negotiation strategies. The objective of this paper will be to craft a policy proposal for the Korean government, and indeed other governments in similar situations, that can be implemented in interactions with residents. Through this strategic negotiation proposal, government and affiliated organizations will be able to expedite the nuclear power plant construction process while residents would be able to reap the advantages of compensation and services brought by the power plants.

Unlike past literature, the present paper uses the Iterated Prisoner's Dilemma game theoretic model to investigate further which strategies the government and public sectors should apply to negotiate realistic situations with residents in the context of the NIMBY phenomenon. Repeated games allow us to simulate interactions that are closer to real-world interactions since strategic negotiations, including the siting of nuclear power plant facilities, are conducted over a series of interactions. We use Axelrod's Ecological Variant from evolutionary game theory to determine the stability of our strategies. We further, uniquely, look at government vs. resident interactions in the context of siting nuclear power plant facilities in South Korea, in which various situation-specific factors were used to adjust the payoff values in the Prisoner's dilemma payoff matrix. Lastly, we use a collection of 36 iterated strategies from the Axelrod Python library and simulate all possible interactions, including classic and novel strategies ranging from Tit for Tat to Memory-One Strategies. Our simulation proposes an optimal negotiation strategy the

government can implement when discussing siting options with the residents. The research implications may provide insights into how resident-government interactions should be held when siting nuclear power plant facilities and the NIMBY phenomenon as a whole. Through our research, we hope to create a negotiation strategy that not only resolves the siting issue and expedites construction for the government but also allows residents to reap the goods/services and compensation that come with the construction of the facility.

III. DEFINITIONS

A. Game Theory

Game theory is a field of mathematical modeling involving strategic interaction between rational decision-makers. Originally, it addressed two-person zero-sum games, in which each participant's gains or losses are precisely balanced by those of other participants. Its applications range from social science, economics, logic, and computer science, including military [18], collective negotiations [19], transportation [20], environmental management [21], industrial development [22], finance [23], property development [24], and biological evolution [25]. Following von Neumann and Morgenstern's works on zero-sum games, Tucker further developed the field with his works on non-zero-sum games, which involve interactions of *cooperate* and *defect* strategies between agents. Hence, Prisoner's dilemma games are the most promising among all theories for games because of their wide applications [26].

B. Cooperative/Non-Cooperative and Evolutionary Games

Within the field of game theory, there exist several types of games, including cooperative, symmetric, sequential, and evolutionary games. Cooperative game theory involves the prediction of which coalitions form, the joint actions groups take, and the resulting collective payoffs [27]. Noncooperative game theory focuses on predicting individual players' actions and payoffs and establishing Nash equilibria [28]. In this paper, we will look into which negotiation strategies would be most beneficial to the local government and the society as a whole in siting NIMBY facilities, either in a cooperative or a noncooperative context. Evolutionary game theory focuses more on the dynamics of strategy change in a population over time which is influenced by the frequency of the competing strategies in the population [29], [30].

C. Iterated Prisoner's Dilemma and Axelrod's Tournaments

An iterated prisoner's dilemma game is one where two players play the Prisoner's dilemma more than once in succession while changing strategies in accordance with decisions and results from previous rounds. Within the Prisoner's dilemma game, there exist payoff values – rewards and punishments the players would receive as a result of their decisions which are described by the 4-tuple: (R, P, S, T) .

Each of these corresponds to one particular set of payoffs in the following generic Prisoner's dilemma:

Table 1. Payoff Structure in the Prisoner's Dilemma [31]

		COL	
		C	D
ROW	C	(R, R)	(S, T)
	D	(T, S)	(P, P)

For the above to constitute a Prisoner's dilemma, the following must hold: $T > R > P > S$ and $2R > T + S$ to prevent alternating cooperation and defection, giving a greater reward than mutual cooperation.

These payoffs are commonly referred to as

- R: the **Reward** payoff
- P: the **Punishment** payoff
- S: the **Sucker** payoff
- T: the **Temptation** payoff

IV. LITERATURE REVIEW

Interest in the iterated Prisoner's dilemma (IPD) traces its roots back to Robert Axelrod's work in *Evolution of Cooperation* [10]. In it, he reports on a tournament he organized of the n step prisoner's dilemma in which participants have to choose their mutual strategy repeatedly and have the memory of their previous encounters. Axelrod invited academic colleagues worldwide to devise computer strategies to compete in an IPD tournament.

The programs that were entered varied widely in algorithmic complexity, initial hostility, capacity for forgiveness, and so forth. Axelrod discovered that when these encounters were repeated over a long period with many players, each with different strategies, greedy strategies tended to do very poorly in the long run, while more altruistic strategies did better, as judged purely by self-interest. He used this to show a possible mechanism for the evolution of altruistic behavior from initially purely selfish means by natural selection.

The winning deterministic strategy was tit for Tat, which Anatol Rapoport developed and entered into the tournament. It was the simplest of any program entered, containing only four lines of BASIC, and won the contest. The strategy is simply to cooperate on the game's first iteration; after that, the player does what their opponent did on the previous move. Therefore, we hypothesize that Tit for Tat will be the most effective strategy in the simulation for this paper.

By analyzing the top-scoring strategies, Axelrod stated several conditions necessary for a strategy to be successful:

1. Nice

The most important condition is that the strategy must be “nice,” that is, it will not defect before its opponent does (this is sometimes referred to as an “optimistic” algorithm). Almost all of the top-scoring strategies were nice. A purely selfish strategy will not “cheat” on its opponent for purely self-interested reasons first.

2. Retaliating

However, Axelrod contended that a successful strategy must not be blindly optimistic. It must sometimes retaliate. An example of a non-retaliating strategy is Always Cooperate. This is a very bad choice, as “nasty” strategies will ruthlessly exploit such players.

3. Forgiving

Successful strategies must also be forgiving. Though players will retaliate, they will once again fall back to cooperating if the opponent does not continue to defect. This stops long runs of revenge and counter-revenge, maximizing points.

4. Non-envious

The last quality is being non-envious, that is, not striving to score more than the opponent.

One of the many approaches to deriving the optimal negotiation strategy is through game theory, which has recently been used in many political and socioeconomic applications. The Prisoner's dilemma pervades our daily lives, from personal situations to government negotiations. In the issue of siting NIMBY facilities, most negotiation results arise, at least in South Korea, when both parties –local government officials and residents– sit down at the table and reveal their alternative intents simultaneously. These variants provide us with a deeper understanding of how cooperation would emerge in general under conditions different from the standard formulation. In contrast, our purposes here are to look into which negotiation strategies would be most beneficial to the local government and the residential community as a whole in siting NIMBY facilities, either in a cooperative or noncooperative context. Hence, the two-person Prisoner's dilemma game is a fundamental approach to such social interactions and can be applied to analyze the cooperative behavior present in NIMBY interactions.

Game theory has not been implemented to the issue of facility siting until relatively recently. In 2009, Chiu and Lai conducted an experimental comparison of iterated negotiation strategies in government vs. resident interactions. They modeled their experiment on Taiwan's incinerator NIMBY syndrome. Test subjects were used to replicate Axelrod's Prisoner's dilemma simulations in which four strategies (Tit for Tat, Faithful, Trigger Punishment, and Random) were compared. The conclusions showed that Tit for Tat was the optimal negotiation strategy, as Axelrod concluded in his first and second tournaments [32].

More recently, in 2020, Sen Eguchi conducted a game theoretic analysis of resident vs. resident interactions in a NIMBY context. Eguchi analyzed three prominent mathematical cases: Prisoner's Dilemma, War of Attrition, and a third edge case [33]. It was seen that the NIMBY phenomenon only persists in the Prisoner's Dilemma game, and the other two cases do not fit the characteristics of the NIMBY syndrome.

In 2021, Yu et al. analyzed the conflict and resolution of Pollution NIMBY Facility Construction using evolutionary game theory. They construct a three-party evolutionary game model of the local government, the new media, and the local people and carries out numerical simulation on the evolutionary model using MATLAB [34].

V. RESEARCH METHODOLOGY

A. Assumptions

In this study, a government vs. residents interaction will be examined. Several assumptions must be defined before describing the parameters for our simulation.

First, due to the sheer number of residents involved in the negotiation with the government, we will assume that an elected leader will represent the residents and be responsible for the negotiation with the government. Therefore, the government vs. residents' interaction will be between two individuals allowing us to use the Prisoner's dilemma model.

Secondly, the payoff structure for the government and the residents is generalized in Table II. The government (player 1) will adopt a move of either cooperate or defect, while the residents (player 2) also have the same choices of making a cooperate or defect move. A cooperate move means agreeing with the opponent, regardless of the strategy or requisition brought into play, whereas the opposite response constitutes a defect move.

Table 2. Generalized Payoff Structure

		Player 2 (Residents)	
		Cooperate	Defect
Player 1 (Government)	Cooperate	(δ_1, δ_1)	(δ_2, δ_2)
	Defect	(δ_3, δ_3)	(δ_4, δ_4)

The payoff for the government represents the net external economic benefits obtained from the construction of the NIMBY facility (gross benefits minus the gross costs). The gross costs include all physical costs, including the construction cost, the cost of attaining the land, the construction costs of related facilities, and all human resources, while non-physical costs include resident dissatisfaction and protests during the time elapsed to settle the siting issue. The gross benefits of the construction of the facility include the resolution of the nuclear power plant siting

issue and physical (e.g., environment) and non-physical (e.g., resident utility) benefits from siting the facility.

B. Selection of Strategies

The Axelrod Python library consists of over 230 iterated prisoner's dilemma strategies, from which several criteria were used to select the final 36 used in our simulated tournament. These strategies include classic strategies, including Tit-For-Tat, WSLs, and variants, as well as Zero-Determinant and other Memory-One strategies.

From the library's collection of strategies, most were either infeasible to implement from a socioeconomic perspective, while others involved chance/randomness, which is unrepresentative of how the government makes policy choices. Therefore, the following three factors were used to eliminate certain strategies: 1) Memory Depth, 2) Indefinite/Random Game, 3) Feasibility to Real World. Here, memory depth refers to the number of previous decisions that the player can use as history when making their decision.

In a socioeconomic setting like the case of NIMBY facilities, individuals avoid using outdated information from an excessively distant past. Therefore, selecting strategies that rely on data points that occurred several iterations before the current turn is unrealistic. As a result, we limited the maximum memory depth of our strategies to 10, meaning that individuals will only take into account the results of the most recent 10 interactions. Next, indefinite/random games were removed. Indefinite strategies are those in which the players' decisions do not depend on the player's circumstance (i.e., opponent's decision, player's past decisions, etc.). These include strategies like Cooperator (always cooperating) and Defector (always defector). In reality, it is only logical to make a decision based on contextual information rather than indefinitely making a decision. Similarly, random strategies (including those with probability involved) were removed since individuals in the real world don't rely on chance to make their final decision. Lastly, the feasibility in the socioeconomic context was considered. These were primarily composed of strategies with unrealistic complexity and irrelevance to the context of NIMBY facilities. A comprehensive table of the 65 strategies with a memory depth less than or equal to 10 are listed in Appendix A. The final chosen 36 strategies are also listed.

C. Payoff Values

In Table I, the payoff for the government stands for the possible economic benefits derived from the NIMBY facilities plan, which are made externally. In other words, the plan's economic benefits are the gross benefits less the gross costs. To simplify, these benefits are defined as currency, not property rights, as economists might argue. The benefits consist of physical benefits such as currency before and after the construction and non-physical benefits, such as social welfare. However, the gross costs should include all physical costs, such as money and human resources, as well as non-physical costs, such as social costs before and after the facility's construction. The gross benefits to the government include the resolution of the solid waste problem and the

physical and non-physical benefits derived from the resolution of the solid waste problem. The gross costs must include all the physical and non-physical costs involved in implementing this plan. The physical costs may include the construction cost, the cost of attaining the land, and the construction costs of related facilities. The time elapsed and uncertainties caused by protests are accounted for as the non-physical costs. The residents' payoff structure measures the total non-physical benefits, such as increased or decreased public space, as well as the compensations received from the government when the NIMBY facilities are to be preceded or abandoned.

Morell (1984) summarizes four major factors which would put the public against NIMBY facilities. These factors are

1. The psychological fear of possible threats to health and life
2. A lack of fairness in terms of taxation/ compensation
3. Concerns over environmental pollution, resulting in the depreciation of properties
4. Government negligence of environmental protection issues.

Cooperate – cooperate is one combination of moves, with the payoff of $(\delta 1, 1)$. In this fully cooperative mode, the plan has the following advantages. Firstly, there are no protests, which can help reduce the cost of preventing the plan from implementation. Secondly, the time spent on implementing the plan will be relatively short because of the lack of protests, which also decreases interest costs. Thirdly, as the plan is more easily implemented, the benefits gained by both parties also make the plan more effective.

In contrast, defect – is a different combination of moves, with the payoff being $(\delta 4, \delta 4)$. This combination indicates that both the government and the residents defect during the negotiation process of siting the NIMBY facilities. Owing to the continuous protests by the residents, the plan cannot be implemented successfully. The following disadvantages reduce the plan's effectiveness. Firstly, protests and the costs spent on mitigating them arise. Secondly, the plan is expected to be delayed owing to the protests, which results in an increase in operation and interest costs. Thirdly, the plan benefits are significantly reduced because of the failure in plan implementation

In addition, cooperate – defect and defect – cooperate both indicate that one of the players decides to defect, with the other cooperating. When one of the parties chooses to make a defect move while the opponent player cooperates, the temporary benefits will rise for the defecting player. In contrast, the burden of the costs for the cooperating player will be increased, causing reduced benefits. For instance, when the government adopts a cooperative move, it may attempt to match all requisitions made by the residents. This situation may consequently result in higher costs and lower benefits as the government's goal is simply to construct the NIMBY facilities.

Table 3. Payoff values used in the tournament (units are \$100 million)

		Player 2 (Residents)	
		Cooperate	Defect
Player 1 (Government)	Cooperate	(8, 8)	(2, 15)
	Defect	(15, 2)	(3, 3)

Table III shows the realistic numbers of payoffs used in the experiment. These numbers provide sufficient information derived from the logic of the Prisoner’s dilemma game. Larger numbers represent better outcomes for the respective player. A higher payoff value for the government would indicate that it saved unnecessary expenses, such as the costs of preventing protests. Thus an increase in compensation for the residents and improvements in community facilities can be expected. The hypothetical values of (8, 8) for this combination are given for the experiment. However, the benefits will increase for the player who decides to defect while the opponent cooperates. The payoffs will be represented by currency (in \$100 million) to make the experiment more realistic.

D. Experimental Design

The code for simulating the tournament consisted of 7 parts:

1. Initializing payoff values
2. Defining the tournament players list
3. Running the tournament
4. Recording the tournament summary in a designated CSV file
5. Plotting the boxplot
6. Plotting the payoff matrix
7. Plotting the evolutionary game theory model (Axelrod’s ecological Variant).

The final implemented code is shown in Figure I.

36 simulated players were created and stored in a list titled “players.” All simulations were run on a MacBook Pro (16-inch, 2019), and the Google Colab interface was used. The simulation was held for 30 turns (replicating 30 real-life interactions between the government and residents), while this entire process was repeated three times to account for any deviation. A hypothetical population of 300 was used for Axelrod’s ecological Variant, meaning that 300 players represented each of the 36 chosen strategies.

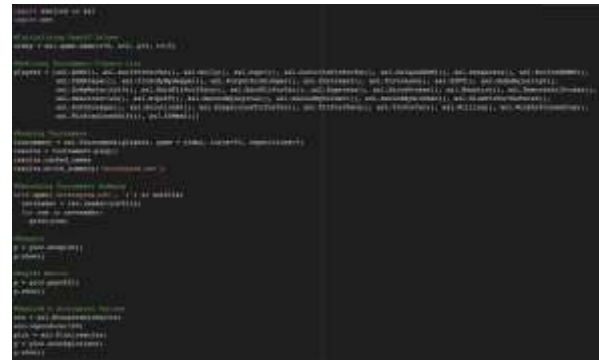


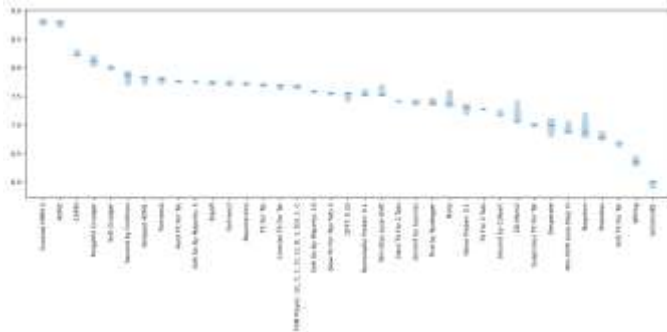
Figure 1. Code using the Axelrod Python Library for simulating NIMBY interactions

VI. RESULTS AND DISCUSSION

The results showed that the strategies placed in the following order from best to worst in performance:

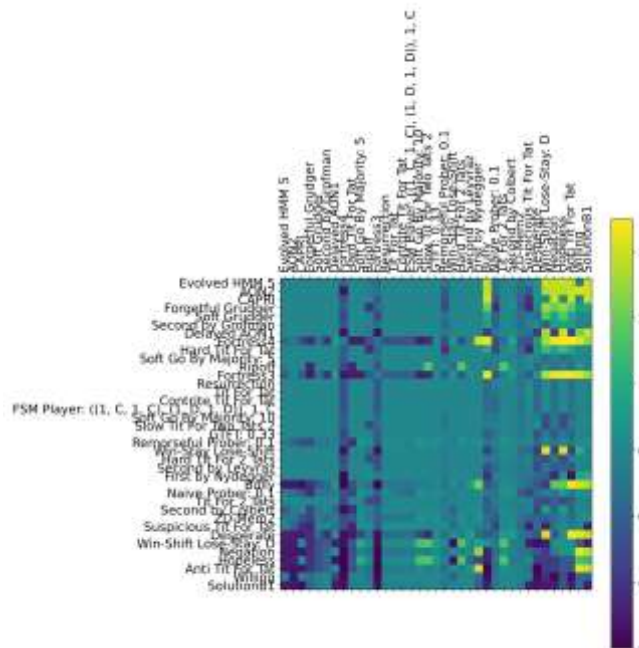
- Evolved HMM 5
- AON2
- CAPRI
- Forgetful Grudger
- Soft Grudger
- Fortress4
- Soft Go By Majority: 5
- Hard Tit For TatFortress3
- Tit For Tat
- Second by Grofman
- Delayed AON1
- Ripoff
- FSM Player: ((1, C, 1, C), (1, D, 1, D)), 1, C
- Resurrection
- Bully
- Contrite Tit For Tat
- Soft Go By Majority: 10
- GTFT: 0.33
- Slow Tit For Two Tats 2
- Win-Stay Lose-Shift
- Hard Tit For 2 Tats
- Second by Leyvraz
- First by Nydegger
- Remorseful Prober: 0.1
- ZD-Mem2
- Second by Colbert
- Tit For 2 Tats
- Suspicious Tit For Tat
- Naïve Prober: 0.1
- Negation
- Desperate
- Hopeless
- Win-Shift Lose-Stay: D
- Anti Tit For Tat
- Willing
- SolutionB1

It is further seen that the two most optimal strategies (Evolved HMM5 and AON2) performed significantly better than the remaining strategies, from which there was a gradual linear decrease in performance. Evolved HMM5 performed by far the best with minimal deviation with a median score of 8.76 (\$876 million), closely followed by AON2 with a median score of 8.68 (\$868 million). Tit for Tat, the optimal strategy for Axelrod's first and second tournaments, placed 10th with a median score of 7.73 (\$773 million). A comprehensive summary of the tournament results can be viewed in Appendix B. The boxplot displaying the mean/median payoffs from the simulated tournament can be seen in Graph I below.



Graph 1. Mean and Median Payoffs of 36 strategies from the Simulated Tournament

Next, we can view each strategy's performance consistency across all the other strategies using a payoff matrix, as shown in Graph 2.

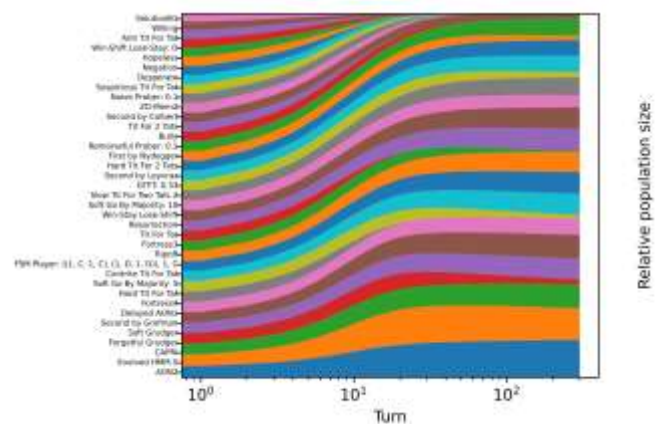


Graph 2. Payoff Matrix of 36 strategies from the Simulated Tournament

The payoff matrix shows that the majority of strategies perform in a relatively consistent manner. All strategies perform suboptimally against Fortress 3 and Fortress 4. 'Evolved HMM 5', 'AON2', 'CAPRI,' 'Forgetful Grudger,'

'Soft Grudger,' 'Fortress4', 'Soft Go By Majority: 5', 'Hard Tit For Tat' all display exemplary performance against 'Negation,' 'Desperate,' 'Hopeless,' 'Win-Shift Lose-Stay: D,' 'Anti Tit For Tat,' 'Willing,' 'SolutionB1'. We can also see the general trend that as the median score of a strategy decreases, so does its consistency. Strategies including 'Negation,' 'Desperate,' and 'Anti Tit For Tat' perform optimally against a select few strategies while performing poorly in others. 'Evolved HMM5' and 'AON2', the two top scoring strategies, are consistently successful or high performing, with the exception of Fortress 4.

Finally, we can view Axelrod's ecological Variant, which allows us to view the performance of a select population representing each of the 36 strategies over a series of generations. The ecological graph can be seen in Graph 3.



Graph 3. Ecological Variant of the Simulated Tournament

We can see that strategies 'Remorseful Prober: 0.1', 'ZD-Mem2', 'Second by Colbert', 'Tit For 2 Tats', 'Suspicious Tit For Tat', 'Naïve Prober: 0.1', 'Negation', 'Desperate', 'Hopeless', 'Win-Shift Lose-Stay: D', 'Anti Tit For Tat', 'Willing', 'SolutionB1', 'Hard Tit for 2 Tats', and 'Second by Grofman' quickly die off after approximately 10 generations. Excluding 'Evolved HMM 5', 'AON2', 'CAPRI', 'Forgetful Grudger', and the aforementioned list of strategies, the relative population size remains the same from the start until the end of the tournament.

We can first conclude from our results that 'Evolved HMM5' and 'AON2' are by far the best performing strategies from our selected players. 'Tit for Tat' placed 9th with a median payoff value noticeably worse than the two best-performing strategies. We can also see that both 'Evolved HMM5' and 'AON2' perform relatively consistently against all other strategies. A strategy's consistency is valuable since, in the context of NIMBY interactions, certain strategies can be applied with successful returns against a select few strategies. In contrast, less than optimal payoff returns can be exhibited in other interactions. As the main objective of this paper is to craft a proposal for the government, there is no room for inconsistency since there is a need to select a strategy that ensures success in all cases. Finally, both 'Evolved HMM5'

and ‘AON2’ were shown to be evolutionarily stable throughout all interactions, both of which the relative population size increased from the start to the end of the tournament.

From the original 36, we can now condense our final strategies list to two: ‘Evolved HMM5’ and ‘AON2’. As seen in the summary of the tournament results in Appendix B, the median score difference between the strategies ‘AON2’ and ‘CAPRI’ was shown to be 0.4463 (44.63 million dollars). This drastic difference in median score can be seen in the boxplot where a significant gap can be seen between the first two strategies and the remaining strategies. To choose between the two, it is crucial to further inspect the characteristics and mechanics of each of the strategies and examine whether it agrees with Axelrod’s proposed characteristics of a successful strategy.

A Markov model is a stochastic model composed of a set of states to describe a sequence of events. It has the Markov property, which means that the process is memoryless, i.e., the next state depends only on the present state. A Hidden Markov Model (HMM) is a Markov model in which the states are partially observable. In a hidden Markov model, we have a set of hidden states called “hidden chain,” which is precisely like a Markov chain, and we have a set of observable states. Each state in the hidden chain is associated with the observable states with a probability. We do not know the hidden chain, nor the actual state, but we know the actual observation. The idea is that after a series of observations, we can get information about the hidden chain [35].

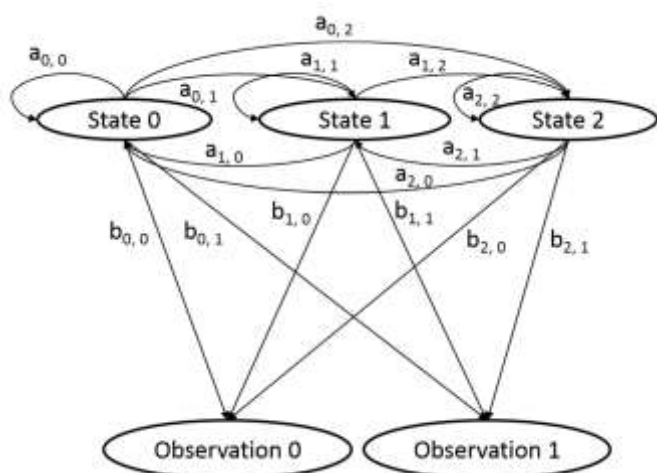


Figure 2. Definition of Hidden Markov Model (HMM) [35]

The main flaw with the ‘Evolved HMM5’ strategy is that it is memoryless, meaning that the history of the player and opponent’s decisions cannot be accounted for. This directly contradicts Axelrod’s third requirement of being “Forgiving.” To be forgiving, a strategy must be able to recount its opponent’s past decisions and make a choice accordingly. Due to HMM’s 0-depth memory characteristic, this strategy should be ruled out.

AON2 belongs to a completely different class of strategies called memory- n strategies of direct reciprocity. Direct reciprocity is one of the fundamental mechanisms for cooperation. It is based on the idea that individuals are more likely to cooperate if they can expect their beneficiaries to remember and return their cooperative acts in the future. In repeated social dilemmas, humans often show conditionally cooperative behaviors. When there is a temptation to defect at the expense of other group members, subjects consider whether they or others defected before and react accordingly. However, modeling conditional cooperation is not straightforward, as it is difficult to capture how humans make their decisions in reality. Economic models often consider rational subjects who remember all past interactions and follow a predefined equilibrium plan. Evolutionary models, on the other hand, usually take the opposite approach. With a few notable exceptions, evolutionary models focus on naïve subjects who can only choose from a restricted set of strategies or who do not remember anything beyond the outcome of the very last round [36].

Both approaches represent idealizations, which serve the purpose of making the models computationally tractable. Already for the simplest example, the repeated Prisoner’s dilemma, calculations are greatly simplified if one assumes that the players’ strategies depend on the last round only. These so-called memory-1 strategies represent a four-dimensional space, which can be explored systematically. Previous studies identified several successful memory-1 strategies, including Tit-for-Tat (*TFT*), Win-Stay Lose-Shift (*WLSL*), or the class of generous zero-determinant (*ZD*) strategies. However, once we allow subjects to remember more than one round, the number of possible strategies increases dramatically. To limit the number of strategies to be inspected, researchers at the University of California, Berkeley have created particular strategies that meet three requirements: (i) mutually cooperative, (ii) able to correct errors, and (iii) sufficiently retaliating against defectors, as shown in Figure 3.

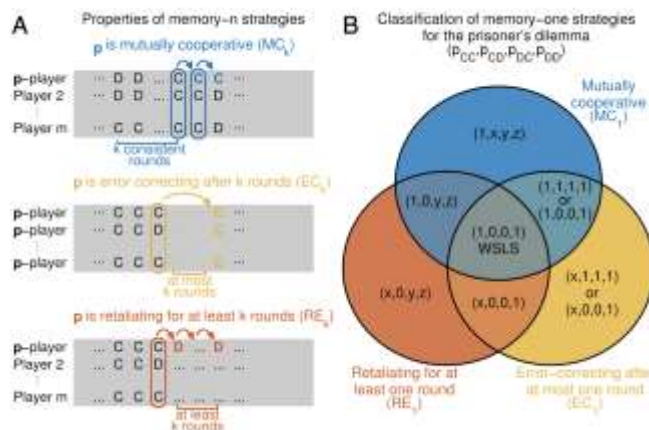


Figure 3. A) Properties of memory- n strategies. B) Examination of Win Stay Lose Shift Strategy [36]

A player with this strategy only cooperates if all players used exactly the same actions in the past, that is, if, in each of the last k rounds, either everyone cooperated or no one did. We

refer to this behavior as an all-or-none strategy or as AON. Since AON strategies meet the three given requirements; they are used much more frequently in social dilemmas. Strategies resembling AON2 were also observed by Hauert and Schuster (6) and by Lindgren (5) when simulating the Prisoner's dilemma with memory-2 players. As a result, it is seen that given the context of siting nuclear facilities, AON2 is the optimal negotiation strategy.

However, it's essential to acknowledge the limitations of this research. Although payoff values and iterated strategies were selected tailored for nuclear siting interactions, there is a limitation to which computerized simulations can represent reality. Axelrod wrote in *On Six Advances in Cooperation Theory* that there exist two basic techniques to generate results from models: deduction and simulation. Here, deduction involves specifying a set of axioms and proving theorems based on them, while simulation involves the use of assumptions and the generation of "histories" which can be analyzed for patterns. Axelrod explains that to the extent that the desired results can be attained by deduction, simulation is the second-best technique. This is because the detection of a pattern in simulated data is characterized by only a certain degree of confidence, whereas any theorem that is proved is definitely true. Furthermore, deduction reveals the roles of parameters, whereas simulation has to rely on trying out specific values of the parameters. Therefore, even after doing many simulations runs, one cannot confirm that there would be some unexplored combination of parameters that may lead to a different result [37].

Furthermore, the projected costs that were involved when calculating the hypothetical payoff values can potentially vary by case. Factors including specific location of the nuclear power plant, number of residents in the region, and size of the nuclear power plant can all potentially affect the real-world rewards/punishments for each player based on each decision.

VI. CONCLUSION

In this paper, game theory was applied to identify the optimal negotiation strategy for government vs. resident interactions in the context of siting nuclear power plants in South Korea. Two strategies were derived using a payoff boxplot, matrix, and Axelrod's ecological Variant: Evolved HMM5 and AON2. It was seen that the characteristics of direct reciprocity included in memory-n strategies (mutual cooperation, error correction, retaliation) was in agreement with Axelrod's proposed characteristics from his initial research. AON2 demonstrated consistently robust returns across all other strategies while having relatively minimal deviation across each game. Our initial hypothesis that Tit for Tat would be the optimal negotiation strategy was flawed as the median payoff value was noticeably lower than other strategies, placing 9th.

In conclusion, we propose that the government adopt a negotiation strategy with the following three properties:

1. Mutual cooperation after 2 consistent rounds of co-player's cooperation
2. Error correction after at most 2 rounds
3. Retaliation for at least 2 rounds

That is, a strategy is mutually cooperative if there are histories for which the strategy prescribes to cooperate, and if it continues to cooperate after rounds with mutual cooperation (provided the last 2 decisions of the focal player were actually consistent). A strategy is error-correcting if it takes at most 2 rounds before both players revert to mutual cooperation. Finally, the strategy is retaliating if after any round in which the focal player cooperated whereas a coplayer defected, the focal player defects for the following 2 rounds [36].

In the future, we hope to explore various game theoretic models and additional strategies to identify an even more effective strategy. Beyond Axelrod's simulations, we hope to use additional tools and mathematical deduction to more accurately deduce an optimal strategy.

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APPENDIX A: SELECTION CRITERIA FOR SIMULATION STRATEGIES

Strategy Type	Memory Depth	Indefinite/Random Game	Feasibility
AON 2.00	2		
All C or ALL D	1	O	X
Alternator	1	O	X
Anti Tit For Tat	1		
Bully	1		
Capri	3		
Contrite Tit For Tat	1		
Cooperator	0	O	X
Cycler	2	O	X
Defector	0	O	X
Delayed AON1	2		
Desperate	1		
Double Ressurrection	5	O	X
Evolvable FSM Player	1		
Evolved HMM 5	5		
FSM Player	1		
First By Grofman	1	O	X
First By Nydegger	3		
Forgetful Grudger	10		
Fortress3	2		
Fortress4	3		
Generous Tit For Tat	1		
Go By Majority 5	5		
Go By Majority 10	10		
HMM Player	1		
Hard Go By Majority 5	5		
Hard Go By Majority 10	10		
Hard Tit For 2 Tats	3		
Hard Tit For Tat	3		
Hopeless	1		
LR Player	1		X
Memory Two Player	2	O	X
Memory One Player	1	O	X
Naïve Prober: 0.1	1		

Negation	1		
Random	0	O	X
Random Tit For Tat	1	O	X
Remorseful Prober	2		
Resurrection	5		
Ripoff	3		
Second By Black	5	O	X
Second By Leyvraz	5		
Second by Colbert	4		
Second by Grofman	8		
Slow Tit For Two Tats 2	2		
Soft Grudger	6		
Solution B1	2		
Suspicious Tit For Tat	1		
Tit For 2 Tats	3		
Tit For Tat	1		
Tricky Cooperator	10		X
Two Tits For Tat	2		
Willing	1		
Win Shift Lose Stay (Reverse Pavlov)	1		
Win Stay Lose Shift (Pavlov / AON1)	1		
ZD Extort 2	1		X
ZD Extort 2v2	1		X
ZD Extort 3	1		X
ZD Extort 4	1		X
ZD Extortion	1		X
ZD GTFT2	1		X
ZD Gen2	1		X
ZD Mem2	2		
ZD Mischief	1		X
ZD Set2	1		X

APPENDIX B: STRATEGIES RANKED WITH SUMMARY OF TOURNAMENT RESULTS

Rank	Name	Median Score	Cooperation Rating	Wins	Initial Cooperation Rate
0	Evolved HMM 5	8.75925925925926	0.7645061728395060	8.0	1.0
1	AON 2.00	8.675	0.7373456790123460	8.0	1.0
2	CAPRI	8.228703703703710	0.7253086419753090	5.0	1.0
3	Forgetful Grudger	8.137037037037040	0.6771604938271610	12.0	1.0
4	Soft Grudger	8.02962962962963	0.8123456790123460	8.0	1.0
5	Fortress4	7.794444444444450	0.1416666666666700	22.0	0.0
6	Soft Go By Majority: 5	7.7666666666666700	0.8518518518518520	4.0	1.0
7	Hard Tit For Tat	7.756481481481480	0.6975308641975310	12.0	1.0
8	Fortress3	7.740740740740740	0.27870370370370400	27.0	0.0
9	Tit For Tat	7.726851851851850	0.8351851851851850	0.0	1.0
10	Second by Grofman	7.720370370370370	0.8049382716049380	7.0	1.0
11	Delayed AON1	7.705555555555560	0.7907407407407410	5.0	1.0
12	Ripoff	7.683333333333330	0.6598765432098770	9.0	0.0
13	FSM Player:	7.678703703703700	0.8299382716049380	0.0	1.0
14	Resurrection	7.6462962962963000	0.8336419753086420	0.0	1.0
15	Bully	7.62962962962963	0.49104938271604900	18.0	0.0
16	Contrite Tit For Tat	7.625	0.8219135802469140	0.0	1.0
17	Soft Go By Majority: 10	7.571296296296300	0.8746913580246910	4.0	1.0
18	GTFT: 0.33	7.529629629629630	0.9157407407407410	0.0	1.0
19	Slow Tit For Two Tats 2	7.5166666666666700	0.8709876543209880	3.0	1.0
20	Win-Stay Lose-Shift	7.512962962962960	0.787962962962963	5.0	1.0
21	Hard Tit For 2 Tats	7.417592592592590	0.897222222222220	0.0	1.0
22	Second by Leyvraz	7.412962962962960	0.8694444444444450	0.0	1.0
23	First by Nydegger	7.404629629629630	0.9117283950617280	4.0	1.0
24	Remorseful Prober: 0.1	7.372222222222220	0.6101851851851850	18.0	1.0
25	ZD-Mem2	7.3314814814814800	0.662962962962963	19.0	1.0
26	Second by Colbert	7.253703703703700	0.8256172839506170	8.0	1.0
27	Tit For 2 Tats	7.246296296296300	0.9138888888888890	0.0	1.0
28	Suspicious Tit For Tat	7.121296296296300	0.5351851851851850	19.0	0.0
29	Naïve Prober: 0.1	7.087962962962960	0.5638888888888890	24.0	1.0
30	Negation	7.0509259259259300	0.5280864197530870	15.0	0.4537037037037040
31	Desperate	6.868518518518520	0.3419753086419750	16.0	0.5462962962962960
32	Hopeless	6.85	0.6975308641975310	11.0	0.5648148148148150
33	Win-Shift Lose-Stay: D	6.8351851851851900	0.5932098765432100	12.0	0.0
34	Anti Tit For Tat	6.686111111111110	0.5685185185185190	15.0	1.0
35	Willing	6.3805555555555600	0.9345679012345680	2.0	0.48148148148148100
36	SolutionB1	5.906481481481480	0.8564814814814820	6.0	0.0