

# The Impact of Bounded Rationality on Strategy Selection in the Prisoner's Dilemma

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**Abstract.** This study investigates the profound and often overlooked impact of bounded rationality on strategic decision-making, using the prisoner's dilemma as a foundational model. A questionnaire issued by the author reports that over 70% of people prefer to cooperate rather than betray, which is completely different from what is predicted in theory. This stark empirical discrepancy not only challenges the core assumption of perfect rationality in classical game theory but also underscores the critical need to incorporate behavioral elements for accurate prediction of real-world outcomes. Bounded rationality is an important part that is always ignored by game theorists when analyzing cases. Although an increasing number of papers are describing the causes of bounded rationality, there is still a gap about how to optimize bounded rationality and prevent possible loss from being irrational. To bridge this gap, this study first analyzes the core causes and dualistic effects (both positive and negative) of bounded rationality, supported by real-world case studies. It then proposes and evaluates a series of practical optimization strategies—including a hybrid stochastic approach and a minimax regret framework—designed to leverage the cooperative potential of bounded rationality while insulating decision-makers from its associated risks.

**Keywords:** Bounded Rationality; Prisoner's Dilemma; Decision-Making Optimization; Behavioral Game Theory; Hybrid Strategy.

## 1. Introduction

Game theory's most foundational assumption—perfect rationality—stands in stark contrast to the reality of human decision-making, where cognitive limitations inevitably bound rationality. In a recent study by the author, a questionnaire was released to the public to collect opinions of Chinese people in different age groups when facing the typical prisoner's dilemma. The results revealed a stark discrepancy: the observed cooperation rate (77.78%) significantly exceeded the near-zero rate predicted under the assumption of strict, self-interested rationality. This illustrates that the theory is not always compatible in the real world. This discrepancy underscores the profound influence of bounded rationality—encompassing factors like trust, reciprocity, and heuristic decision-making—which can dramatically alter strategic outcomes in ways classical models cannot predict. Since the traditional game theory always assumes that players are completely rational when analyzing cases, this paper will focus on the real-world examples to illustrate the impact of limited rationality (both positive and negative) and to propose some practical solutions to optimize the strategies to avoid loss caused by irrationality. Incorporating bounded rationality is therefore critical for game theory, as it transforms the discipline from a normative ideal into a predictive and empirically grounded framework for understanding real-world strategic behavior. It can also help game theorists and people to gain a better understanding of their strategy selection and exactly how to behave in the game, given that some irrationality factors cannot be prevented.

Roy Radner, in his seminal work, examined the implications of bounded rationality in the repeated Prisoner's Dilemma, though his analysis remained largely theoretical and offered little connection to real-world applications [1]. On this foundation, Neyman demonstrated that in iterated games, bounded rationality can enhance the emergence of equilibrium, suggesting that cognitive limitations may at times promote cooperative behavior rather than hinder it [2]. Extending from this perspective, Pass and Halpern developed a game-theoretic framework that incorporates the costs of computation, arguing that such an approach provides a more realistic account of bounded rationality and produces equilibrium outcomes that diverge from classical predictions [3]. Empirical research by Tillett has

further reinforced this view: studies on the iterated prisoner’s dilemma indicate that when cognitive resources are unconstrained, players often adopt more complex strategies, while under memory load, they tend to rely on simpler cooperative rules such as generous tit-for-tat [4].

While these studies have substantially advanced our quantitative understanding of bounded rationality, a significant gap persists. While most of these studies highlight important theoretical and experimental insights, they leave open the question of how bounded rationality influences strategic choices in concrete real-world scenarios and how its effects can be optimized—an issue that this paper seeks to address. Moreover, few studies have systematically examined the practical manifestations of these deviations in real-world strategic scenarios or proposed concrete frameworks to harness their potential benefits while mitigating their drawbacks.

This paper addresses this gap by situating bounded rationality within concrete scenarios of strategic interaction. It analyzes both the positive and negative consequences of imperfect rationality on the probability of cooperation and defection, and further proposes optimization strategies that leverage the cooperative potential of bounded rationality while mitigating its adverse effects. These optimization strategies aim not to eliminate bounded rationality, but to design mechanisms and environments that nudge naturally biased actors toward more mutually beneficial and stable outcomes.

By doing so, the study bridges theoretical insights with practical mechanisms, contributing to a more comprehensive understanding of strategic behavior under bounded rationality. The paper will firstly focus on using theoretical analysis to list both positive and negative impacts of several kinds of bounded rationality on the strategy making in the prisoner’s dilemma, and then showcase the real-world scenarios, hence pointing out any optimization methodology to decision makers.

## 2. Case Description

The analysis begins with a brief exposition of the prisoner’s dilemma. The payoff matrix for a typical two-player game is presented in Table 1.

**Table 1.** Payoff matrix of a prisoner’s dilemma

Player 1 / Player 2	Silence (Cooperate)	Confess (Betray)
Silence (Cooperate)	(+8, +8)	(0, +10)
Confess (Betray)	(+10, 0)	(+5, +5)

The left number represents the payoff for player 1 and the right number represents the payoff for player 2.

For each player, choosing to betray ensures a secure payoff (at least 5), whereas mutual cooperation yields the highest collective payoff. In game theory, the best response is to choose to confess, because this is a dominant strategy. However, if both players exhibit trust and opt to cooperate—a move deemed irrational under strict rationality—they achieve the highest collective payoff, an outcome frequently observed in real-world scenarios.

Till now, a number of papers have investigated the influences of limited rationality in the iterated game of prisoner’s dilemma, and they discovered the factual impacts of a series of bounded rationality on the process of decision making. Bounded rationality, encompassing emotional biases and concerns for social status, causes the actual probability of strategy choices to deviate significantly from the predictions of the Nash equilibrium. In the theory, predicted result of the game is 100% betray rate(confess), though the data collected in reality is much deviated from that, this means that the prediction made by theoretical analysis in game theory is impossible to be found in real world, therefore it is essential to investigate on bounded rationality as this series of factors will bring a huge difference between predicted value in theory and true probability.

From the previous research done by the author, it is shown by the data collected that when concerning emotional bound, approximately 10% more respondent prefer to cooperate in a game held between their friends with them than in the game held between them and strangers; when considering social status (choosing betray will hurt their social reputation), nearly 89% of the participants claim

that they will play “cooperate” rather than play “betray”. The experimental results, which deviate markedly from the theoretical expectation of universal defection, underscore the powerful effect of bounded rationality. These results quantitatively demonstrate that social and emotional factors can dramatically increase cooperation rates, challenging the canonical game-theoretic assumption of self-interested rationality. These factors are counted as external payoff, which are not considered when calculating the theoretical Nash equilibrium, but are significantly essential when predicting people’s behavior. These factors effectively alter the players’ utility functions, embedding social and emotional preferences into their decision-making calculus in a way that traditional models overlook.

Through the data provided, it is known that human’s decision-making mechanism is deeply affected by bounded rationality, which can sometimes bring better outcomes to the game. However, in many cases, the bounded rationality can lead to a strategic loss in the game without arousing the decision-maker’s attention to their less rational behavior. Consequently, there is a pressing need for optimization frameworks that account for these irrational yet impactful behaviors. After explaining the impacts of bounded rationality, a discussion of how to optimize the decision-making process is proposed.

### **3. Analysis of the Phenomenon**

#### **3.1. Positive Impacts**

Although seemingly suboptimal for an individual, bounded rationality can, in aggregate, foster a societal atmosphere conducive to trust and cooperation.

##### **3.1.1 Foster cooperation**

Investigating the basis of Neyman’s research, Zemel suggested that small talk (casual chat) and limited rationality (which also limits a player’s memory) will ultimately lead to a high possibility of collaboration [5]. His research highlighted a key benefit of bounded rationality: it enhances the propensity for cooperation, yielding outcomes superior to the inefficient equilibrium predicted by classical game theory.

As mentioned before, in a real-world test conducted by the author, over 70% of respondents preferred to cooperate in the game for a range of reasons, from emotional bond to reputation concern. On a larger scale, businesses also have tacit agreement on the price making. Coca-Cola and Pepsi are the two biggest soft drink companies in the world. Whenever they enter a market, instead of launching a price war, they have an order to the price: Coca-Cola proposes the price at first, and Pepsi follows. They both know the negative impact of malicious price reduction, so they will choose to cooperate, and this situation is commonly seen in the world. Members of OPEC will always follow the lead price maker and therefore form an equilibrium that is beneficial for all members. Coca-Cola and Pepsi have a close relationship in the market. When the price of raw materials rises, they can choose whether to raise the price or not. A more nuanced example involves their response to cost pressures: the Nash equilibrium in this game is both choosing to remain the price and both experience a less significant loss; however, they both choose to raise the price per unit volume (shrinkflation) for about 4% because they believe the other firm will not keep the price at the current level and successfully maintain their market share along with profits. This exemplifies how bounded rationality—in this case, a shared cognitive bias that the competitor will act adversarially—can lead to coordinated outcomes that deviate from the static Nash equilibrium yet are stable in practice. This example verifies the positive return of cognitive bias effect (a kind of bounded rationality).

##### **3.1.2 Forming a mutual-trust society**

As shown, the research introduced in the previous part showed that in the traditional prisoner’s dilemma without any additional context, 70% of respondents prefer to cooperate. Just as mentioned in Hofstede’s article, China is a nation with prevalent collectivism, so Chinese people will naturally prefer to cooperate due to the impact of their educational background [6].

Crucially, such cooperative norms are not formed spontaneously but are the product of long-term cultural evolution and social learning. Trusting others is a traditional Chinese virtue, and that is what Chinese kids are taught to do. It is therefore reasonable to assume that in the very distant past, human ancestors were affected by bounded rationality over a very long time period, and in the very long term, a habit or a custom formed, which always tries to cooperate. This will allow society to be mutually trusting so that everyone can believe in each other. Also noteworthy is the fact that in Western countries, the tendency to cooperate with a stranger is even higher than that in Eastern countries, which stress collectivism and relationships too much. This counterintuitive finding may stem from stronger institutional trust and formal contract enforcement mechanisms in individualistic societies, which reduce the perceived risk of cooperating with strangers. So this is one of the very positive effects of bounded rationality. Thanks to this impact, the world is now more likely to be a world where every person thinks about both their own benefits and others' rather than a selfish world where everyone only cares about their personal benefits.

### **3.1.3 Keep a good reputation**

At the beginning of this paper, the importance of social reputation is stressed. Many people will quantify the impact on their social status and hence incorporate it into their consideration. Many firms consider reputation to be highly strategic and valuable. This is very reasonable because a good reputation is even more valuable than the extra payoff the player can get from choosing to betray.

Thus, bounded rationality not only facilitates cooperation but also indirectly helps individuals preserve their social reputation, even if they are not consciously calculating its value. This means that regardless of whether the player considers social reputation issues or not, the player can achieve a good result.

## **3.2. Negative Impacts**

However, irrationality can sometimes lead to a strategic loss and may cause a significant decrease in payoff because other decision-makers can be more rational and do not choose to cooperate.

### **3.2.1 Suboptimal outcomes**

Obviously, if a player is irrational while another player is more rational than he, he may not choose to cooperate but to betray because he will secure a high payoff by doing so. In game theory, a Nash equilibrium is a situation which every player is at the best response to the other player's choice, so if the irrationality causes a deviation from the predicted Nash equilibrium to cooperation, the player may incur a loss because there is a better outcome that player can get by changing the choice, according to the definition of the Nash equilibrium.

Consequently, less rational players are vulnerable to exploitation by more rational counterparts, consistently receiving payoffs below the theoretical Nash equilibrium. This illustrates how bounded rationality can systematically lead to suboptimal outcomes for the irrational agent.

### **3.2.2 Rigidity of strategy**

In iterated games, irrationality (limited memorising ability) can lead to a rigid pattern of gaming habits (e.g., a player will take turns choosing between cooperation and betrayal, his strategy will be easily detectable, and the other player can know what he is choosing and use the strategy that is the best response to his current strategy). As Liu and Halpern mentioned in their research on the finite automata, complex game settings and limited cognitive ability will always lead to a simple strategy and even a rigid strategy in repeated games [7].

Other than this, a rigid strategy-making pattern will cause a series of negative impacts on the decision-maker. The most prevalent one is losing high-level cognitive skills. Adhering to a familiar strategy may provide psychological comfort; however, it can also induce cognitive rigidity, limiting the exploration of superior alternatives. E.g., a high school student always prefers to use the formula that he learned in class, but does not want to use other approaches in exams. Without thinking about other possible, better solutions, they will end up trapped in a fixed mindset and lose innovative ability.

This cognitive inertia is analogous to the rigid strategies observed in iterated games, where players fail to adapt to new information or changing contexts, ultimately settling on a suboptimal long-term strategy. As Jiang mentioned in his research, 71% of students in class reveal the tendency to use familiar formulas instead of utilizing an easier way, verifying the credibility of this statement [8].

### 3.2.3 Systematic effects

As the title suggests, at the group level, the existence of irrational people will cause systematic impacts. This is because, since they prefer to cooperate instead of being rational and choose to betray, other rational people will maximize their payoff by observing irrational people's strategy habits and always choosing the best response to their actions. However, irrational players will know the negative effects of choosing to cooperate, so in the long term, all the irrational choice-makers will know that only choosing to betray can help them secure the highest possible benefits.

When all choice-makers in a region form a habit of betraying, a culture is formed, telling all other members (as well as offspring) not to believe in others, hence excluding the possibility of the occurrence of an equilibrium that is better than the Nash equilibrium. This dynamic mirrors Gresham's Law in economics, where 'bad' behavioral drives out 'good', and bounded rationality can lead to an inequality in the game, finally making the possibility of cooperation drop to 0%.

## 4. Real Example: Bounded Rationality Fostering Tacit Cooperation in Oligopolies

The theoretical analysis finds its empirical validation in real-world oligopolistic markets, where bounded rationality—manifested as trust, learned reciprocity, and reputation concerns—repeatedly leads to stable, cooperative outcomes that defy the static Nash equilibrium. As mentioned earlier, Coca-Cola and Pepsi provide a salient example of an irrational commercial game. Historical records of their pricing strategies show that when faced with a sudden rise in the cost of raw materials for cans and plastic bottles, both companies responded by raising the effective price per unit volume through reducing container size. Rather than pursuing short-term self-interest by maintaining the original price (i.e., defecting, as predicted by classical game theory), they tacitly chose to cooperate without explicit communication. This behavior aligns with their long-standing commercial practice: throughout the twentieth century, Coca-Cola typically set the initial price in new markets and Pepsi followed. Although theory suggests that Pepsi could gain higher profits by undercutting Coca-Cola's price, such a move often provoked retaliation and triggered destructive price wars. Hence, cooperation, while seemingly irrational in a strict game-theoretic sense, proved more sustainable and mutually beneficial.

A similar yet distinct pattern of bounded rationality-driven cooperation is observable in the Organization of the Petroleum Exporting Countries (OPEC). When global oil demand fluctuates, member states face strong incentives to deviate from production quotas: by secretly producing more oil, an individual country could increase short-term revenue. However, such unilateral defection frequently destabilizes the market and drives down oil prices, ultimately harming all producers. Despite the temptation to defect, OPEC members have repeatedly demonstrated tacit cooperation by adhering to agreed production limits. This illustrates how bounded rationality—shaped by historical experience with market collapses and the recognition of mutual interdependence—encourages cooperative strategies that deviate from the predictions of purely rational game theory. Unlike the dyadic cooperation of Coca-Cola and Pepsi, OPEC represents a multi-lateral cooperation challenge, where the temptation to defect is even higher. Their sustained adherence to quotas underscores an even stronger form of boundedly rational learning: the collective memory of past market collapses (e.g., the 1980s oil glut) serves as a powerful deterrent against defection, overriding short-term incentive calculations.”

Both of the examples demonstrate that imperfect rationality can lead to better results because bounded rationality can foster cooperation.

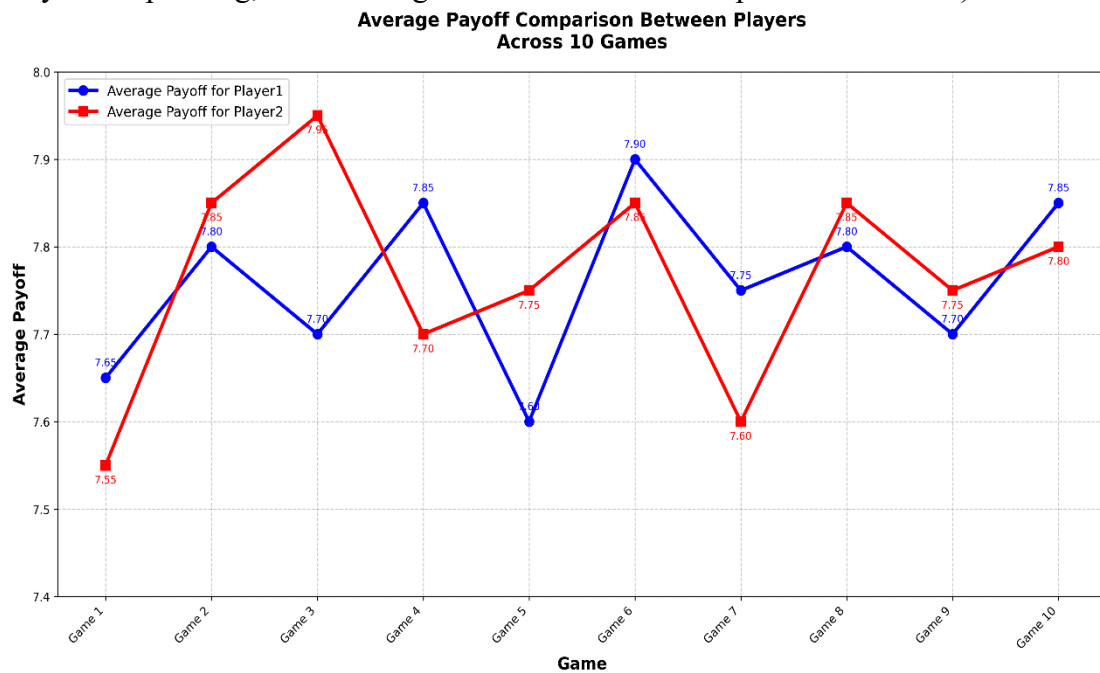
## 5. Pragmatic Frameworks for Optimizing Decisions Under Bounded Rationality

However, considering the inconvenience caused by bounded rationality, some strategies should be adopted to improve the game efficiency.

### 5.1. A Hybrid Stochastic Strategy to Mitigate Exploitation and Rigidity

To mitigate the risk of exploitation and strategic rigidity associated with bounded rationality, a Hybrid Heuristic Strategy introduces controlled randomness. With a well-designed randomization, the risk of strategic loss is much lower because it is hard to predict. To randomize the strategy making process, different kinds of strategy must be combined. For example, in the typical iterated prisoner's dilemma game, three mechanisms: following strategy, Tit-for-Tat strategy, and cooperation strategy can be combined together, each takes up 33% weight of the decision-making mechanism. A simple code, e.g. `RandInt#(1,3)`, can be used to represent the random choose of a strategy, with result 1 corresponding to following strategy (always choose what the other player choose in the last turn), 2 corresponding to TFT strategy (choose betray after the other player betray in the last turn), 3 corresponding to cooperation strategy (always choose to cooperate). And this process should be executed every 3-5 turns (to prevent ineffective change in strategy caused by too few turns and to prevent the other player from recognizing the strategy itself). McKelvey and Palfrey's Quantal Response Equilibrium (QRE) is employed. Under QRE, players choose strategies with probabilities that increase with expected payoffs, so-called sensitivity parameter  $\lambda$ . This QRE structure has proven useful for rationalizing experimental deviations from Nash and provides a parametric way to compare the simulation's stochastic strategies to empirically grounded choice behavior [9].

A computer simulation will be made, and in this example, mixed strategies will be re-chosen every 5 turns, and the total rounds are 20. The payoff matrix is the same as shown in Figure 1 (When the randomization algorithm chooses the first strategy, it is assumed that a player has a 70% probability of cooperating; this data is gained from the author's previous research).



**Fig. 1** Simulated Payoff Evolution of the Hybrid Stochastic Strategy in an Iterated Prisoner's Dilemma (Photo Credit: Origin)

The simulation demonstrates that this strategy effectively navigates the trade-off between exploration and exploitation. It sacrifices a small amount of potential maximum payoff (from 8 to  $\sim 7.77$ ) to dramatically reduce the downside risk of being exploited or locked into a predictably bad pattern, thereby providing a robust and practical optimization for boundedly rational actors.

## 5.2. A Minimax Regret Framework for Robust Satisficing

Complementary to the first strategy, which modifies the strategy space, a second approach seeks to modify the decision-making objective itself. Instead of pure payoff maximization—which is vulnerable to miscalculation and misunderstanding—players can adopt a Bounded Regret Minimization criterion. The natural way for players to consider a situation is to maximize the payoff, but this will always cause loss due to the potential risk of misunderstanding the game rules. By changing the thinking model, this kind of problem can be addressed. A regret minimization strategy is then adopted. For an irrational player, this strategy can make sure that he will not feel regret after making a decision. A formula is provided.

$$R(a,s)=u^*(s)-u(a,s) \quad (1)$$

R means the “regret value”, while a and s represent the “action” and “state”. To minimize the R, a further formula can be deduced. The regret value equals the difference between the payoff for the best choice and the payoff when the player chooses action “a”.

$$\min(a \in A) \max(s \in S) R(a,s) \quad (2)$$

This formula means that a player should think about the worst situation and the best action he can choose to keep his regret value R at the lowest level.

The term “regret” was first introduced by John Hannan. In his paper, external regret is defined as the difference between the best strategy and the actual strategy payoff. He proved that if the player considers the external regret when making a decision, they will get an actual payoff that is only a little lower than the payoff brought by the best choices, indicating the credibility of the strategy of minimizing regret [10].

## 6. Conclusion

### 6.1. Key Findings

This study has systematically analyzed the profound and dualistic impact of bounded rationality on strategic decision-making within the framework of the prisoner’s dilemma. It demonstrates that deviations from perfect rationality are not merely noise but systematic factors that can both enhance and impede cooperative outcomes. For the first part, a brief introduction is made to claim the real world cases to illustrate the significance of bounded rationality, which is always ignored in the theoretical research of game theory. This paper examines the impacts of bounded rationality when experiencing a prisoner’s dilemma, including the positive impact of keeping a good reputation, forming a mutual trust society, and fostering cooperation. It is also common to see the detrimental effects of bounded rationality; just by contrast to the advantages, not only will suboptimal outcomes occur, but systematic impacts and rigidity of strategy will also make the cost of being irrational larger. Faced with this dual nature of bounded rationality, the critical question becomes how to mitigate its risks while harnessing its benefits. To this end, this paper proposed two pragmatic optimization frameworks. After analyzing the problem, a series of question-solving mechanisms is proposed. A randomized heuristic strategy is first recommended for its ability to cover the irrationality. The data collected from simulations can prove that it is useful to secure players’ benefits. Another approach is to shift the thinking method to avoid regret. This allows players to think more comprehensively, with the help of a specific formula, a player can check their external regret at any time in the game and try to find a way to minimize regret instead of maximize profits (as framing effect will put a irresistible effect forcing irrational player to choose the less optimal strategy).

### 6.2. Research Significance

This research contributes to the field both theoretically and practically. Theoretically, it moves beyond merely cataloging the effects of bounded rationality to proposing computationally tractable

frameworks that operationalize this concept for strategic optimization. The integration of QRE-like stochasticity and minimax regret principles provides a bridge between normative game theory and descriptive behavioral economics. Practically, the proposed strategies offer actionable tools for decision-makers in oligopolistic markets, joint ventures, or any scenario resembling a repeated prisoner's dilemma. Firms can adopt these frameworks to design mechanisms that nudge interactions toward more stable and cooperative equilibria. The algorithms and simulation results provide a quantified basis for assessing the trade-offs between optimality and robustness.

In conclusion, by acknowledging, modeling, and strategically channeling bounded rationality, this study provides a pathway to transform a perceived limitation of human cognition into a tool for enhancing strategic outcomes, paving the way for more realistic and effective applications of game theory in business and policy.

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