Game Theory in Medical Aesthetics Industry: Evidence from Consultation and Plastic Surgery Department

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Abstract. Currently, the medical aesthetic industry is experiencing rapid growth. On this basis, this study develops the potential usage of game theory in medical aesthetic industry. To be specific. This research mainly focuses on decision making processes in consultation and competition between public and private medical institutions. Based on the analysis of strategic interactions between doctors and patients during consultations, as well as the competitive dynamics between public and private institutions, this study reveals how game theory models, such as the Stackelberg competition, can evaluate pricing strategies and market behaviors. However, several limitations are worth noted during applications due to the variable real-life condition according to the analysis and suggestions for further exploration are proposed at the same time. Those external factors may influence the accuracy of the predictions and decisions made by the model. Overall, despite those uncertain factors existed, game theory is a valuable tool in medical aesthetic industry.

Keywords: Game theory, medical aesthetics industry, consultation, plastic surgery department, Nash equilibrium.

1. Introduction

The medical aesthetic industry has witnessed significant growth over the past decade, driven by increasing demand for cosmetic procedures [1-3]. The history of medical aesthetics dates back to ancient civilizations like Egypt, Greece, and Rome, where rudimentary cosmetic procedures were conducted using kohl, ointments, and plant-based cosmetics. Plastic surgery, originating in ancient India, marked a significant advancement with physicians like Sushruta performing reconstructive surgeries using skin grafts. During the Renaissance, surgeons like Gaspare Tagliacozzi pioneered techniques that laid the groundwork for contemporary procedures. Advancements in the 19th and 20th centuries, such as anesthesia and sterilization, energized the field. The latter half of the 20th century saw the introduction of non-invasive techniques like chemical peels, Botox, and dermal fillers, revolutionizing aesthetic procedures. Technology-driven treatments like laser hair removal emerged, paving the way for efficient non-surgical procedures. These milestones illustrate the rich history and evolution of the medical aesthetics industry.

The research history of game theory spans centuries, with significant milestones marking its evolution. One such crucial event occurred in 1944 with the publication of "Theory of Games and Economic Behavior" by John von Neumann and Oskar Morgenstern [4]. This seminal work laid the foundation for modern game theory, introducing concepts like Nash equilibrium [5] and cooperative game theory [6].

Over the following decades, game theory expanded its reach into various fields, from economics to biology and political science. In 1985, a notable breakthrough occurred when the Talmud's ancient marriage contract problem was recognized as anticipating modern cooperative game theory principles. This revelation highlighted the enduring relevance of game theory across cultures and time periods. As game theory continued to advance, key contributions emerged, such as John Harsanyi's work on Bayesian games and Reinhard Selten's refinement of Nash equilibrium. These developments led to deeper insights into strategic decision-making and laid the groundwork for applications in diverse areas, including economics, biology, and law [7, 8]. Overall, the research history of game theory enables more rational decision making in various context .

In the medical aesthetics industry, game theory can be applied to variant circumstances. During consultation, doctors may suggest different treatment plans, including medication and surgery. With their own preferences and concerns, patients may assess both advantages and disadvantages of each plan and ultimately reach a consensus with the doctor. Besides, doctors may give different quotes for the same plastic surgery procedure, based on the patient's clothing or behaviors reflecting their financial capability. If the quoted price is low and accepted by the patient, the profit will be less. On the other hand, if the quoted price is high and scares away the patient, the profit will be zero. The negotiation process between doctors and patients regarding the surgical price is a form of game theory. What's more, the pricing competition between public and private hospitals is a game theory scenario. Each adjusts prices to attract patients while public hospitals face budget constraints and private hospitals pursue profit. Both of them are attempting to maximize the profits. Their pricing decisions influence each other's strategies.

Previous research has yielded some findings regarding the application of game theory in the medical industry [9, 10]. The application of game theory in healthcare management is not just about making financially sound decisions; it's about strategically navigating a landscape where every decision can have far-reaching implications on health outcomes and societal well-being. Besides, game theory can be applied to medical spending and pricing in order to encourage hospitals, physicians, and insurance companies to cooperate. This paper aims to explore the significance of applying game theory in different scenarios of medical aesthetics industry. With the rapid development of a medical aesthetics industry, pricing adjustments among patients and doctors, public and private hospitals become increasingly common. Understanding the mechanism of decision making in these process become increasingly crucial.

2. Basic Descriptions

Game theory is a mathematical tool and analytical method used to study interactions and strategy choices among decision makers. It studies the impact of choices made by different participants on each other under certain rules. In game theory, each participant is called a player, and they choose their strategy according to their own interests and goals, and the outcome depends on the combination of strategies of all players. Nash equilibrium is a basic concept in game theory which represents a circumstance at which each player's strategy is maximizing the outcome given the strategies chosen by the other players.

Game theory has applications in many fields of social science, used extensively in economics as well as in logic, systems science and computer science. When focusing on its usage in economics, there's basically four common models. Firstly, the Cournot Model, proposed by French mathematician Augustin Cournot in his book, Researches Into the Mathematical Principles of the Theory of Wealth in 1838. This model is used in oligopoly market, it's applicable when companies produce identical or standardized goods. Due to the law of supply and demand, the price increases as quantity demanded increases and the price decreases as the quantity demanded decreases. Companies must consider how much quantity a competitor is likely to churn out to have a better chance of maximizing profits. In other words, efforts to maximize profit are based on competitors' decisions and each firm's output decision is assumed to affect the product price. This model can generate a stable Nash equilibrium. Secondly, the Bertrand Model, which is introduced in 1883 by the French economist Joseph Bertrand is defined as an oligopoly model where firms producing homogeneous products compete in price. Firms compete by adjusting their prices to attract customers. The Nash equilibrium of this model is not as stable as the Nash equilibrium of Cournot Model. Thirdly, the Stackelberg Model, which has great similarities with the Cournot Model, happens in an oligopoly market. It's a cooperative strategic game that a leader firm makes a action first and decides how much to produce. All other firms, known as followers, follow the action of the leader and decide how much to produce. The core difference between these two models is the sequence of the action making. Finally, the prisoner dilemma. Assuming that there are two prisoners who must decide whether to

confess to a crime, determining their respective prison sentences. If both confess, they will each serve 5 years in prison. If both deny the crime, they will each serve 1 year. If one confesses while the other denies, the confessor will go free while the denier serves 10 years. The best outcome is for both to confess. However, since neither prisoner can guarantee the other's cooperation, confessing becomes the rational choice. As both act in self-interest, they both end up serving 5 years in prison, which exemplifies the prisoner's dilemma. In economics scenarios, this may also happen within the competitions between hospitals' pricing.

3. Situations

3.1. Situation 1

Consultation, in medical aesthetic industry, is an negotiating process between doctor and patient, together figuring out the treatment plan and negotiate the price. In the context of a medical aesthetic consultation, doctor and patient are two players of the game. Their strategies may include various kind of surgical plan while the patient's goal is to maximize the treatment outcome and minimize their expenditure and doctor's goal is to maximize their profit. The objective is to reach a mutually beneficial outcome, often encapsulated in a Nash equilibrium. Table 1 explains a basic scenario during consultation.

Table 1. Basic scenarios during consultation.

	Patient: Low price	Patient: High price
Basic Treatment	(2, 2)	(-2, 4)
Advanced Treatment	(9, 0)	(5, 2)

Seen from Table 1, the first number in each cell represents the payoff of patient and the second number represents the payoff of doctor. For example, when the patient choose high price to purchase basic treatment, he received bad treatment outcome with big expenditure, so his payoff is expected to be extremely low. In contrast, the doctor finish the surgery with small effort and the expenditure of medicine is small, but the doctor received high profit, so his payoff is expected to be extremely high. In order to reach the Nash equilibrium in this context, one can first observe the best strategy for the doctor. If the patient chooses Low Price: For Basic Treatment, the doctor's payoff is 2, and for Advanced Treatment, the doctor's payoff is 0. So the best response is basic treatment. If the patient chooses High Price: For Basic Treatment, the doctor's payoff is 4, and for Advanced Treatment, the doctor's payoff is 0. So the best response is also basic treatment. This means basic treatment is the dominant strategy for the doctor. Given that the doctor choose to give basic treatment. Given that the doctor will give the basic treatment, the patient will choose to give low price in order to achieve better payoff. So the Nash equilibrium in this context is basic treatment and low price, both of them get a payoff of 2.

However, the real life situation is much more complex. Doctors always seek to gain more benefits, even if the surgery fee they charge exceeds the value of the surgery itself. The issue is that high surgery fees can sometimes scare away patients, so some doctors, during consultations, will observe a patient's behavior, demeanor, and attire to determine their social class and income level, and then propose a corresponding surgery fee. For example, in some private clinics, a double eyelid surgery that normally costs $1000 might be quoted at $1500 to a person wearing a Rolex and exhibiting refined manners, whereas the same surgery might be quoted at $800 to someone wearing casual sportswear and speaking with an accent. Game theory also happens in this scenario, how much should the doctor quoted? If a people with high income is willing to purchase this surgery at $2000, but the doctor quoted 1500, he will receive an opportunity cost of $500. In contrast, if he quoted $3000, the high surgery fee may scare the patient away and the doctor get nothing. So it's really important to control the extent of rising the price appropriately.

3.2. Situation 2

Game theory also play a role in the competition between private and public medical aesthetic institutions. There's several assumptions between this competition:1) Both institutions aim to maximize their payoffs. 2) Patients choose institutions based on price sensitivity, perceived quality, and brand reputation. 3) There is incomplete information(Institution can't exactly predict the preferences of patients).

Marketing strategy of private and public medical aesthetic institutions differ from each other. For pricing strategy, private institution tends to attract high income patients with premium services while public institution provide wider range of services, and with government subsidies, often pricing lower than private institution, aims to attract those price-sensitive patients. What's more, for service quality, private institution are more willing to invest imported service with higher prices and advanced technology in order to differentiate itself to attract higher income class to purchase advanced services. But public institution will tend to purchase standard services due to the fact that it needs to increase it's affordability to public.

Stackelberg Competition Model can most accurately illustrate this competing condition. The Stackelberg Competition Model involves a scenario where one firm acts as a leader, setting its strategy first, and the other firm acts as a follower, setting its strategy after observing the leader's choice. Due to the fact that public institution are more strictly restricted by the government, it can change relevant pricing policy more freely, so one may assume private institution as the leader. To explain this game, one can draw Table 2.

Table 2. Stackelberg Competition Model.

	Private(low, Q=30)	Private(high, Q=50)
Public(low, Q=30)	(900, 900)	(1000, 300)
Public(high, Q=50)	(300, 1000)	(600, 200)

Seen from Table 2, one can observe that private institution, as the leader, has a dominant strategy of choosing higher quantity supplied. In order to avoid lower payoff, public institution will choose to cut its quantity supplied. So the Nash equilibrium will be private institution provide high quantity supplied and public institution provide low quantity supplied, which benefits the leader a lot more in this game. This model can help private institution set efficient quantity output in order to maximize its profit which can furthermore improve market efficiency, improve resource allocation and pricing stability, aiming to balance market dynamics in medical aesthetic industry.

4. Limitations and Prospects

While game theory can have a significant impact on the medical aesthetic industry, it's crucial to note several limitations that may affect its applicability and effectiveness. First, the model assumes that the roles of leader and follower are fixed, which is somewhat inaccurate due to the dynamic nature of the market. In real-life situations, these roles may shift based on consumer preferences and the introduction of new competitors. For instance, a public institution that traditionally acts as a follower might develop a groundbreaking treatment, allowing it to take the lead in the market. Conversely, a private institution that leads due to its premium services might lose its position if a more cost-effective competitor enters the market. This fluidity in roles changes the static nature of the Stackelberg model.

Second, new technological advancements can significantly impact the model. When more effective and affordable devices or treatments are introduced, the model may become invalid. For example, if a new non-invasive procedure is developed that provides similar or better results than existing invasive surgeries at a lower cost, it could disrupt the existing strategies of both public and private institutions. Such technological shifts can alter the competitive landscape overnight, making previous models and predictions invalid. This rapid pace of innovation in the medical aesthetic

industry requires a flexible and adaptable approach, which traditional game theory models may not always accommodate.

Third, it's impossible to achieve perfect information in real-world scenarios. Both patients and institutions have incomplete information about each other's payoffs, making it difficult to create an accurate payoff matrix. Patients might not fully understand the potential outcomes and costs of different treatment options, while institutions might lack precise knowledge of patients' willingness to pay or their preferences. Decisions are often made based on inaccurate or incomplete data, so the outcomes are unlikely to reach the optimal situation predicted by the model. For example, a patient might choose a lower-priced treatment due to budget constraints, even if a slightly more expensive option would provide better results, or an institution might misjudge the market demand for a new treatment, leading to suboptimal pricing strategies.

Last but not least, the Stackelberg competition model requires time for followers to respond after the leader poses an action. During this reaction process, market conditions may fluctuate and become unstable, causing price levels to be unstable, which breaches macroeconomic goals such as price stability. For instance, if a leading private institution sets a high price for a new treatment, public institutions might initially struggle to respond due to budget constraints or regulatory approvals. By the time they adjust their strategies, changes in patient preferences, economic conditions, or further technological advancements might have already altered the market dynamics. This time lag between action and reaction can result in periods of volatility, undermining the predictability and stability that game theory models aim to provide.

5. Conclusion

In conclusion, the application of game theory provides valuable insights to both the consultation process and the competition between public and private sectors. Game theory reveals the importance of giving appropriate extent of increment in quoting process and can help predicting the best level of output to maximize the market efficiency. In the rapidly evolving medical aesthetics industry, understanding the mechanisms of decision-making and competitive behavior is increasingly important. By applying game theory, stakeholders can better navigate the complexities of the market, improve resource allocation, and achieve more stable pricing, ultimately enhancing the industry's overall efficiency and equity. Future research should strive to refine these models to better capture the intricate realities of the medical aesthetics market.

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