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A Game Theory–Based Model for Dental Centers in a Competitive Market of Dental Tourism under Government Intervention

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Abstract

The aim of this paper is to propose a mathematical model for two dental centers in a competitive market of dental tourism. Dental tourists are looking for cheaper treatment with proper quality, and dental centers are looking to maximize their profits by providing services to tourists. Government also monitors dental centers by setting tariffs (subsidies or taxes). This problem is modeled and solved in the form of Stackelberg (or Leader-Follower) game. The government as the leader determines the amount of tariffs and then the dental centers as the followers simultaneously determine the price and quality level of their services. To solve the game, first the equilibrium values related to the price and quality level of the services of the dental centers have been calculated by Nash equilibrium. Then, according to the equilibrium values obtained for dental centers, the optimal amount of tariffs are calculated. Finally, to clarify the proposed model a numerical example is provided and sensitivity analysis is performed on some parameters. In this paper, for the first time a mathematical model is developed for pricing and determining the quality of services in a competitive market of dental tourism. The obtained results indicate that increasing the amount of subsidy will lead to a decrease in the prices of service provided by the dental centers. Moreover, by increasing the amount of subsidies allocated to the dental centers, the government can expand the dental tourism industry.

Keywords: Mathematical modeling, Stackelberg game, Leader-follower strategy, Pricing.

1 | Introduction

The tourism industry is the largest and most diverse industry in the world. Many countries consider this dynamic industry as the main source of income, job creation, private sector growth, and infrastructure development. This industry has become so important in the economic and social development of countries that economists have called it invisible exports. Medical tourism is a type of tourism in which patients travel abroad to receive services such as dental treatment, cosmetic treatment, cardiovascular treatment, orthopedic treatment, neurological treatment, cancer treatment, fertility treatment, etc.

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Medical tourism has a long history, and destinations such as Harley Street in London are famous for their international health centers [1]. In the past, patients traveled from developing countries to developed countries due to the unavailability of medical services; but in recent years, there has been a kind of reverse globalization in which patients travel from developed countries to less developed countries for treatment due to low cost, service and quality, and the implicit change in the concept of health care.

Although the outbreak of COVID-19 has a negative impact on the medical tourism market, especially elective treatments (such as dental treatment, cosmetic treatment, etc.), the size of the global medical tourism market is expanding rapidly. The size of this market is projected to increase from $ 104.68 billion in 2019 to $ 273.72 billion in 2027 [2]. The size of the global medical tourism market in 2016 was $ 61 billion [3] and [4]. In terms of volume, the number of medical tourists in 2019 was 23,042.90 thousand patients, which is expected to reach 70,358.61 thousand patients in 2027 [2].

One of the most important points in medical tourism is choosing the destination country. Today, many countries are known as medical tourism destinations. The top destinations in terms of medical tourist attraction are ranked as follows: Canada, Singapore, Japan, Spain, United Kingdom, Dubai, Costa Rica, Israel, Abu Dhabi, India, France, Germany, Oman, South Korea and the Czech Republic. Influential factors in this ranking are destination attractiveness, safety, and quality of care [5]. After choosing the destination country, a medical tourist is in the stage of choosing a medical center. Several factors such as cost, quality of services, medical staff specialization, and international certifications such as the approval of the Joint Commission International (JCI) play a role in this choice. A number of famous hospitals and medical centers in terms of attracting medical tourists are shown in *Fig. 1*.

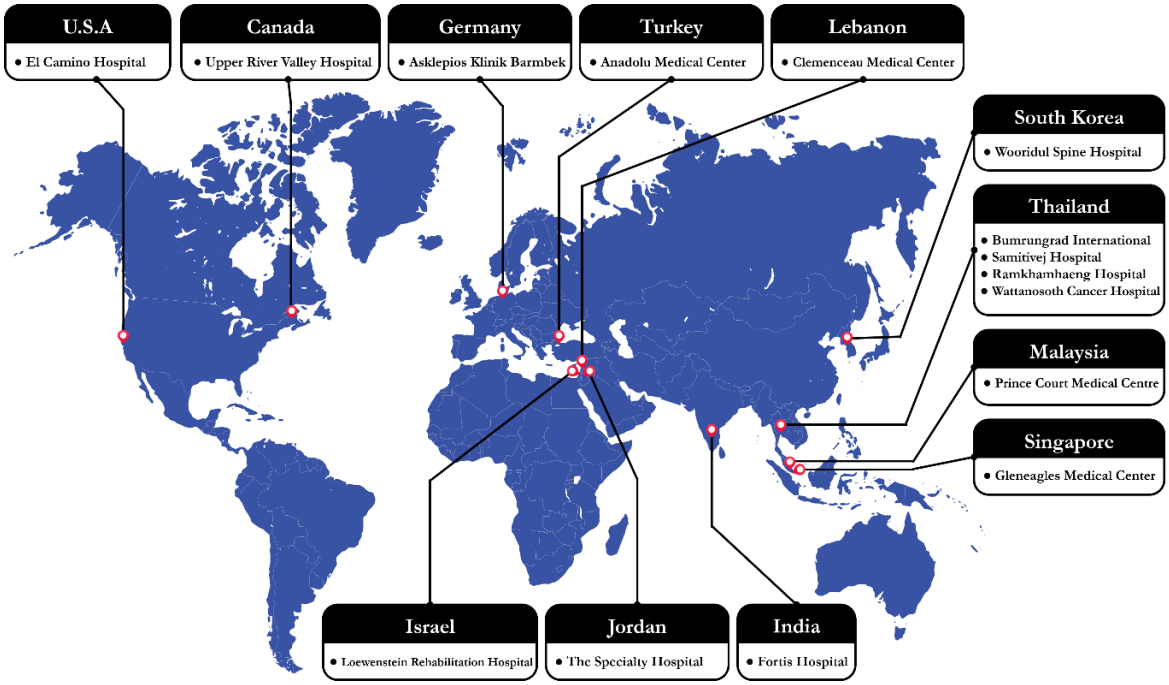

Fig. 1. Some of the famous hospitals and medical centers in terms of attracting medical tourists.

So far, a lot of researches has been done on identifying and ranking effective factors in medical tourism, and many qualitative and conceptual models have been presented in this field. However, little research has been done on the presentation of the mathematical model by considering the factors affecting medical tourism industry and the interests of the medical service providers.

Today, the dental tourism market has emerged as one of the most lucrative and competitive industries in the world and has become one of the new areas of advanced tourism. In the market of dental services, we always see interaction and confrontation between service providers and patients. This interaction, which is applied to achieve more profit and ensure a higher quality of service, provides a good platform to model these relations by game theory. According to the best of our knowledge, in this paper, for the first time a

mathematical model is developed for pricing and determining the quality of services in a competitive market of dental tourism under government intervention. The main contributions of this research can be summarized as follows:

- *A chain including dental tourists, two dental centers and government is considered.*
- *A model based on game theory is proposed to determine the optimal pricing policy and quality of dental services with price and quality dependent demand.*
- *The government oversees the dental centers by setting tariffs (subsidies or taxes) and as the leader determines the amount of the tariffs.*
- *The dental centers as the followers simultaneously set the price and quality level of their services according to the tariffs.*

The rest of this paper is organized as follows. A review of the literature is provided in Section 2. In Section 3, the problem statement and modeling are presented. In Section 4, the optimal policies of dental centers and the government are obtained. In Section 5, numerical example and sensitivity analysis are reviewed. Finally, results and suggestions for future research are provided in Section 6.

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2 | Literature Review

Today, medical tourism has received more attention with the increase of travel freedoms among countries, easier transportation facilities, and the quality improvement of services in different countries [6]. So far, several definitions have been proposed for medical tourism. Medical tourism can be defined as the effort of tourism destinations and facilities (such as hotels) to attract tourists through the promotion of medical facilities and services [7]. According to a study by Milstein and Smith [8], medical tourism is patients traveling outside their own country to access health services with lower costs, higher quality, faster treatment, and receiving services that are not available in their own country. Medical tourism as a common culture refers to the travel of patients abroad, which aims to access medical services and facilities such as dentistry, surgery, and visiting tourist sites [9]. Sarwar et al. [10] defined medical tourism as a way to achieve high-quality treatment in a foreign country at a reasonable price so that patients could also enjoy their vacation. According to a study by Musa et al. [11], medical tourism is all those activities related to the travel and hospitality of a tourist who stays in a destination country for at least one night with the aim of achieving, promoting, or restoring health using medical methods.

Dental tourism is a thriving subset of medical tourism described by the American Dental Association as "traveling to another country to obtain dental treatment". This concept includes people who seek dental care outside of their local health systems, and this may be done during holidays [12]. Service quality and perceived satisfaction play an important role in developmenting the medical tourism industry [13]. In addition, human and technological factors are recognized as important conditions for developing the medical tourism industry in developing countries [14]. In the following, some studies on the factors affecting the choice of medical tourism destination and the factors affecting the satisfaction of medical tourists are reviewed.

2.1 | Factors Affecting Destination Choice

Several reasons can affect medical tourism. Some researchers have classified these reasons as pushing and pulling factors. The most important pushing factors are the quality, efficiency and reputation of the hospital. The most important pulling factors are high treatment costs, long waiting lines, and lack of access to treatments [15]. Lunt et al. [16] categorized the factors influencing the choice of medical tourism destination into three groups. The first group includes factors related to the country's environment. The second group focuses on medical and tourism industry factors, and the third group refers to factors related to the quality of facilities and services.

Bies and Zacharia [17] assessed incentives in the growing medical tourism industry. They prioritized four options using ANP. These options include: 1) Encouraging the employer to medical tourism, 2) Self-selected medical tourism, 3) Encouraging the government to medical tourism, and 4) Status quo. The results indicate that self-selected medical tourism is more preferable to government or employer-sponsored programs because it has the highest benefits, relatively fewer opportunities, lower costs, and similar risks than the other two alternatives.

Smith and Forgione [18] examined the factors influencing the choice of medical tourism destination for American patients. They presented a two-stage model in which patients choose the destination country and the destination treatment center, respectively. They also stated that the factors influencing the choice of the destination country (including economic conditions, political climate, and regulatory policies) and the factors influencing the choice of the medical center (including costs, hospital reputation, quality of care, and physician training) shall be considered by policy makers. Bagga et al. [19] considered factors such as the low cost of medical services, advanced medical equipment, and the medical ecosystem of the host country to be effective in choosing a destination. Many factors influence the choice of a medical tourist as a destination, especially easy access to health services, high level of hygiene, high-quality of health services, safety and security, cost efficiency, and tourism opportunities [20].

Ghasemi et al. [21] stated that identifying sustainability criteria for medical tourism destinations and prioritizing them can help patients choose destinations that meet their needs. Sustainability criteria cover all economic, social and environmental dimensions. Lack of available services or dissatisfaction with the dental services received in the origin country encourages patients to choose dental tourism. Advances in technology, lower travel costs, the availability of better-quality materials, trained dental professionals, and the attractiveness of tourism destinations all have a significant impact on the decision of dental tourists in choosing a dental tourism destination [22] and [23]. Nexhipi [24] examined the factors influencing the attraction of dental tourists in Albania. Factors analyzed include price, quality, hygiene, customer care, customer behavior, environment, and places to visit. Akbar et al. [25] cited factors such as insurance, reliability, and physical condition as influential factors in medical tourism in Indonesia. Another important factor in choosing a medical tourism destination is the waiting time. In India, with more than millions of dentists, there is almost no waiting time for patients.

2.2 | Factors Affecting Tourists' Satisfaction

Tourists' satisfaction is their feelings and attitudes towards the services received in the long term. Tourists who are satisfied with the quality of the services provided for treatment, return there again or introduce this country to others. Key criteria in medical tourism that motivate revisiting include the expertise and reputation of physicians, physicians and staff with international certification, safety and quality of medicine, quality of medical treatment, high-quality of health care, advanced medical treatments, availability of medicines, easy access to the pharmacy and short waiting time [26]. Uğurluoğlu et al. [27] cited factors such as the timing of appointments, the cost of examinations and medications, a sufficient number of staff and physicians, proper queuing, cleanliness and the behavior of physicians and staff as factors influencing medical tourists' satisfaction. Aljumah et al. [28] examine quality as one of the factors affecting tourist satisfaction and point to the relationship between customer satisfaction and customer loyalty. Other studies have examined the quality of services as one of the main factors affecting the satisfaction of health tourists [29] and [30]. By collecting data from major hospitals in South Korea, Park et al. [31] examined the relationship between health care workers' satisfaction with management, and its impact on health tourists' satisfaction.

According to the findings of Mahmud et al. [32], the cost of medical tourism has a direct impact on the satisfaction of medical tourists and the level of tourist loyalty. Also, the attractions of the destination and the culture of the host country are among the factors affecting the satisfaction of tourists. The results of Asgarnezhad Nouri et al. [33] showed that the quality of perceived services and medical quality, enjoyment, costs, and risk affect the perceived value of medical tourists. The perceived value affects the destination

image of medical tourists, and the destination image also affects the satisfaction and loyalty of medical tourists. Finally, satisfaction can lead to the loyalty of medical tourists.

Furthermore, some articles have examined the factors affecting the satisfaction of dental tourists. Akbar et al. [34] examined the relationship between quality and patient loyalty. They stated that patients' loyalty and satisfaction with the medical center has a direct relationship with the quality of dental services provided by that center. According to Luo et al. [35], the factors affecting the satisfaction of dental tourists based on importance include: attitude, cost, convenience, pain management, quality, and perceived need of patients to prevent oral disease. Another factor affecting the satisfaction of dental tourists is convenient transportation in the destination country [36]. Some programs, such as free and convenient transportation, increase the loyalty of dental tourists [37]. In a study, Lwin et al. [4] examined the satisfaction of dental tourists in Bangkok. They stated that the quality of dental treatment, access to the medical destinations, and the attractiveness of the destination have a positive and significant effect on the satisfaction of dental tourists.

Literature reviews on dental tourism studies are presented in this section to ensure the developed model is unique in terms of novelty. Most of the previous works focus on identifying and ranking effective factors in dental tourism. The main novelties of this paper are listed as follows:

- *Developing a mathematical model for pricing and determining the quality of services in a competitive market of dental tourism.*
- *Considering the impact of the governments (subsidies or taxes) on dental centers and determining the optimal amount of tariffs.*
- *Proposing a solution method based on game theory approach for the developed model.*
- *Generalizing the developed model's performance using sensitivity analysis.*

3 | Problem Statement and Modeling

3.1 | Problem Statement

Today, the dental tourism industry as a source of profitable income has been considered by policymakers and businesses. In this study, as shown in *Fig. 2*, a chain including the government, two dental centers, and dental tourists are considered. The government as the leader oversees dental centers by setting tariffs (subsidies or taxes). The negative tariffs decrease the cost of a dental center and act as subsidies. The positive tariffs increase the cost of a dental center and behave as taxes. Dental centers as the followers simultaneously set the price and quality level of their services (such as orthodontics, prosthodontics/cosmetic, periodontics, endodontics, oral and maxillofacial surgery, and teeth whitening) according to the tariffs set by the government. Pricing is the most important component of business models, and the decision in this regard has a significant impact on profitability. Dental tourists are looking for cheaper and better-quality treatment and choose one of dental centers according to the utility obtained from choosing dental centers. The research flowchart of this study is presented in *Fig. 3*.

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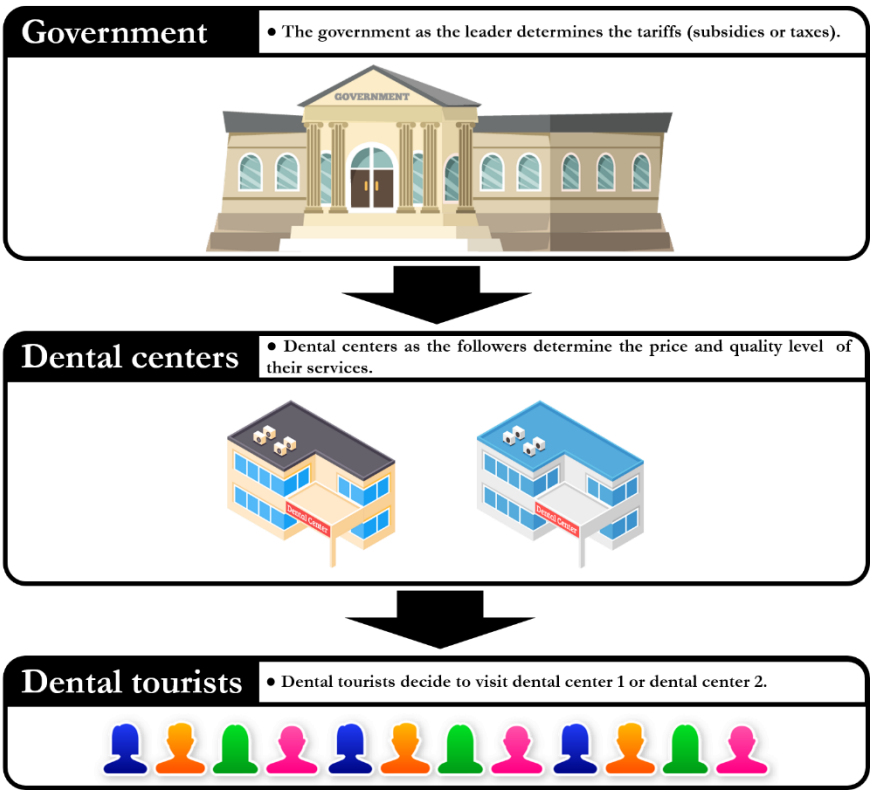

Fig. 2. Schematic of the problem.

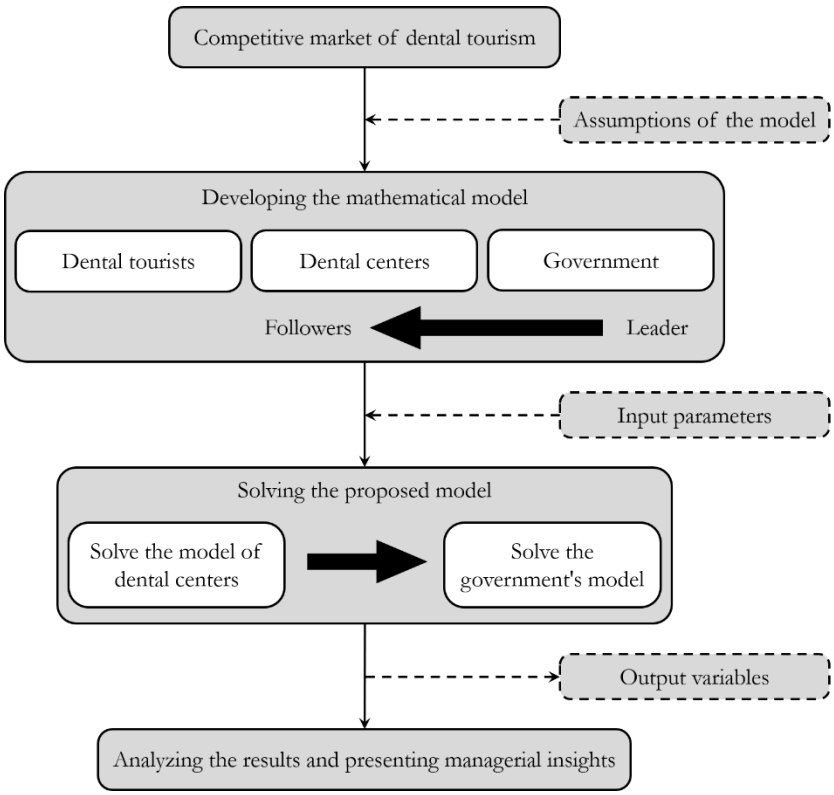

Fig. 3. The research flowchart of this study.

3.2 | Model Assumptions

The main assumptions of the problem are listed as follows:

- *Two dental centers are competing to attract dental tourists.*
- *The government oversees dental centers by setting tariffs.*
- *The quality of services provided in dental centers is different and it is possible to increase the quality by spending more money.*
- *All parameters, price and demand functions have non-negative values.*
- *The utility of a dental tourist is a linear function of the price and quality of service provided by the dental center.*
- *Similar to research [38], the demand for dental centers is based on the Multinomial Logit (MNL) model.*
- *Similar to the studies [39] and [40], the cost of dental centers is considered as a nonlinear function of service quality and price.*

3.3 | Notation

The indices, parameters, and variables used in the mathematical formulation are listed as follows.

Indices:

i,j: Index of the dental centers. i=1,2

Parameters:

α: The sensitivity coefficient of the price in the dental tourist's utility function.

β: The sensitivity coefficient of the quality in the dental tourist's utility function.

λ: The relative weight (importance) factor between the government's profit and the profits of dental centers.

γ_i: The sensitivity coefficient of the multiplicative term of price and quality in the cost function for the dental center i.

κ_i: The sensitivity coefficient of the quadratic term of quality in the cost function for the dental center i.

T_{min}: The coefficient related to the minimum amount of the tariff allocated to the dental centers

T_{max}: The coefficient related to the maximum amount of the tariff allocated to the dental centers.

μ: The total expected number of dental tourists.

Decision variables:

P_i: Price of service provided by the dental center i.

Q_i: Quality of service provided by the dental center i.

T_i: Tariff (tax or subsidy) set by the government for the dental center i.

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Dependent variables:

D_i: Expected demand for the dental center i.
C_i: Cost function for the dental center i.
U_i: Dental tourist's utility function from receiving service in the dental center i.
π_i: Profit function for the dental center i.
G: Government's utility function.

3.4 | Mathematical Modeling of the Problem

In this section, dental tourist's utility function, demand and profit functions for dental centers and, the government's utility function are modeled. Cost is one of the most important factors in dental tourism. In the growing dental tourism industry, quality is also an important factor. Without quality services, no business will survive. Therefore, low price and high-quality of dental services are the most important motivating factors in patients traveling to receive dental services outside their borders. Dental tourist's utility function from receiving service in the dental center *i* (U_i) is expressed as *Eq. (1)*. As can be seen, increasing the quality of dental services has a positive and linear effect on the utility of the medical tourist, and with increasing price, the utility decreases linearly.

$$U_i(Q_i,P_i)=\beta Q_i-\alpha P_i. \tag{1}$$

Medical tourists are faced with two options for choosing a dental center. They can choose one of the options according to the utility obtained from them. The medical tourists choose the dental center that is most desirable for them. For this purpose, MNL model has been used. The popularity and fame of this model is for its simplicity. In fact, the resulting formula for the probabilities of choice in this model has a closed-form and can be easily interpreted. Many researchers have been involved in shaping the Logit model, but this model is known as McFadden, an American economist. The expected demand for dental centers is calculated as *Eq. (2)*.

$$D_i=\mu\left(\frac{e^{(\beta Q_i-\alpha P_i)}}{e^{(\beta Q_i-\alpha P_i)}+e^{(\beta Q_j-\alpha P_j)}}\right). \qquad i=1,2 \quad j=3-i \tag{2}$$

Then, the expected demand for dental centers is written in *Eq. (3)* using the first-order Taylor series expansion of *Eq. (2)*. According to *Eq. (3)*, the total expected demand for dental centers 1 and 2 equals to μ.

$$D_i=\frac{\mu}{2}+\frac{\mu}{4}\left(\beta Q_i-\alpha P_i-\beta Q_j+\alpha P_j\right). \qquad i=1,2 \quad j=3-i \tag{3}$$

The cost of a dental center increases as the quality of services or demand increases. The cost function for dental centers is in the form of *Eq. (4)*.

$$C_i=T_iD_i+\gamma_iQ_iD_i+\frac{\kappa_i}{2}Q_i^2. \qquad i=1,2 \tag{4}$$

Given that the profit is derived from the difference between income and expenses, the profit of dental centers will be in the form of *Eq. (5)*.

$$\pi_i=(P_i-T_i-\gamma_iQ_i)D_i-\frac{\kappa_i}{2}Q_i^2. \qquad i=1,2 \tag{5}$$

As a result, the model of dental centers 1 and 2 will be in the form of *Eqs. (6)* and *(7)*, respectively.

$$\max \pi_1=\left(P_1-T_1-\gamma_1 Q_1\right)\left(\frac{\mu}{2}+\frac{\mu}{4}\left(\beta Q_1-\alpha P_1-\beta Q_2+\alpha P_2\right)\right)-\frac{\varkappa_1}{2}Q_1^{\,2}. \tag{6}$$

$$\text{s.t.}\begin{cases}P_1\geq 0\\ Q_1\geq 0\end{cases}$$

$$\max \pi_2=(P_2-T_2-\gamma_2 Q_2)\left(\frac{\mu}{2}+\frac{\mu}{4}(\beta Q_2-\alpha P_2-\beta Q_1+\alpha P_1)\right)-\frac{\varkappa_2}{2}Q_2^{\,2}. \tag{7}$$

$$\text{s.t.}\begin{cases}P_2\geq 0\\ Q_2\geq 0\end{cases}$$

The government monitors dental centers by setting tariffs. The Government's utility function is presented in *Eq. (8)*. The government pursues the development of dental tourism and earning for itself by attracting tourists and increasing the income of dental centers. λ is the relative importance factor of the government's profit compared to the profit of dental centers, which can have a value in a closed range [0,1]. λ = 1 means the government focuses on its own profit and λ = 0 means the government focuses on the profits of dental centers and the development of dental tourism.

$$G=\lambda(T_1D_1+T_2D_2)+(1-\lambda)(\pi_1+\pi_2). \tag{8}$$

$$\max_{T_1,T_2} G=\lambda(T_1D_1+T_2D_2)+(1-\lambda)(\pi_1+\pi_2).$$

$$\text{s.t.}\begin{cases}\max\limits_{P_i} \pi_i=(P_i-T_i-\gamma_i Q_i)D_i-\frac{\varkappa_i}{2}Q_i^{\,2},\ i=1,2\\ \quad \text{s.t.}\begin{cases}D_i=\frac{\mu}{2}+\frac{\mu}{4}\left(\beta Q_i-\alpha P_i-\beta Q_j+\alpha P_j\right),\ i=1,2\quad j=3-i\\ P_i\geq 0,\ i=1,2\\ Q_i\geq 0,\ i=1,2\end{cases}\\ -T_{min}P_i\leq T_i\leq T_{max}P_i,\ i=1,2\end{cases} \tag{9}$$

Finally, the Stackelberg game model between government and dental centers is presented as follows:

4 | Solution Method

In this section, the game theory approach is used to solve the model and determine the best decisions for the government and the dental centers. In this structure, dental centers make their own decisions about pricing and determining the quality of services and seek to maximize their profits. The government also monitors dental centers by setting tariffs (subsidies or taxes). The government as the leader in the Stackelberg game determines the amount of tariff, and the dental centers as the followers in the Stackelberg game determine the price and quality of their services simultaneously. To solve the game using the backward approach, dental centers first determine the equilibrium values of their decision variables, among which there is a Nash competition. The government then determines the tariffs based on the equilibrium values obtained for dental centers. Finally, dental centers determine the price and quality of their services by placing tariffs in their profit function.

Proposition. The equilibrium price and quality level for dental centers are obtained in the form of *Eqs. (10)-(13)*.

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$$P_1=\frac{\left(\begin{array}{c}\mu\alpha^3\left(T_1\gamma_2{}^2\kappa_1+T_2\gamma_1{}^2\kappa_2-\mu\gamma_1{}^2\gamma_2{}^2\right)\\+\alpha^2\left(\beta\mu^2\gamma_1\gamma_2(2\gamma_1+\gamma_2)-\mu\left(\beta(\gamma_1\kappa_2(T_1+T_2)+2\gamma_2\kappa_1T_1)-6\gamma_1{}^2\kappa_2-4\gamma_2{}^2\kappa_1\right)-4\kappa_1\kappa_2(2T_1+T_2)\right)\\-\alpha\left(\beta^2\mu^2\gamma_1(\gamma_1+2\gamma_2)-\beta\mu(\beta T_1(\kappa_1+\kappa_2)-6\gamma_1\kappa_2-8\gamma_2\kappa_1)+24\kappa_1\kappa_2\right)+\beta^2\mu(\beta\mu\gamma_1+4\kappa_1)\end{array}\right)}{\left(\alpha^3\mu(\gamma_1{}^2\kappa_2+\gamma_2{}^2\kappa_1)-2\alpha^2\beta\mu(\gamma_1\kappa_2+\gamma_2\kappa_1)-12\alpha^2\kappa_1\kappa_2+\alpha\beta^2\mu(\kappa_1+\kappa_2)\right)}. \tag{10}$$

$$P_1=\frac{\left(\begin{array}{c}\mu\alpha^3\left(T_1\gamma_2{}^2\kappa_1+T_2\gamma_1{}^2\kappa_2-\mu\gamma_1{}^2\gamma_2{}^2\right)\\+\alpha^2\left(\beta\mu^2\gamma_1\gamma_2(2\gamma_1+\gamma_2)-\mu\left(\beta(\gamma_1\kappa_2(T_1+T_2)+2\gamma_2\kappa_1T_1)-6\gamma_1{}^2\kappa_2-4\gamma_2{}^2\kappa_1\right)-4\kappa_1\kappa_2(2T_1+T_2)\right)\\-\alpha\left(\beta^2\mu^2\gamma_1(\gamma_1+2\gamma_2)-\beta\mu(\beta T_1(\kappa_1+\kappa_2)-6\gamma_1\kappa_2-8\gamma_2\kappa_1)+24\kappa_1\kappa_2\right)+\beta^2\mu(\beta\mu\gamma_1+4\kappa_1)\end{array}\right)}{\left(\alpha^3\mu(\gamma_1{}^2\kappa_2+\gamma_2{}^2\kappa_1)-2\alpha^2\beta\mu(\gamma_1\kappa_2+\gamma_2\kappa_1)-12\alpha^2\kappa_1\kappa_2+\alpha\beta^2\mu(\kappa_1+\kappa_2)\right)}. \tag{11}$$

$$P_2=\frac{\left(\begin{array}{c}\mu\alpha^3\left(T_1\gamma_2{}^2\kappa_1+T_2\gamma_1{}^2\kappa_2-\mu\gamma_1{}^2\gamma_2{}^2\right)\\+\alpha^2\left(\beta\mu^2\gamma_1\gamma_2(\gamma_1+2\gamma_2)-\mu\left(\beta(\gamma_2\kappa_1(T_1+T_2)+2\gamma_1\kappa_2T_2)-6\gamma_2{}^2\kappa_1-4\gamma_1{}^2\kappa_2\right)-4\kappa_1\kappa_2(T_1+2T_2)\right)\\-\alpha\left(\beta^2\mu^2\gamma_2(2\gamma_1+\gamma_2)-\beta\mu(\beta T_2(\kappa_1+\kappa_2)-6\gamma_2\kappa_1-8\gamma_1\kappa_2)+24\kappa_1\kappa_2\right)+\beta^2\mu(\beta\mu\gamma_2+4\kappa_2)\end{array}\right)}{\left(\alpha^3\mu(\gamma_1{}^2\kappa_2+\gamma_2{}^2\kappa_1)-2\alpha^2\beta\mu(\gamma_1\kappa_2+\gamma_2\kappa_1)-12\alpha^2\kappa_1\kappa_2+\alpha\beta^2\mu(\kappa_1+\kappa_2)\right)}. \tag{12}$$

$$Q_2=\frac{\mu(-\alpha\gamma_2+\beta)\left(\alpha^2\left(\mu\gamma_1{}^2+\kappa_1(T_2-T_1)\right)-\alpha(2\beta\mu\gamma_1+6\kappa_1)+\mu\beta^2\right)}{\alpha^3\mu(\gamma_1{}^2\kappa_2+\gamma_2{}^2\kappa_1)-2\alpha^2\beta\mu(\gamma_1\kappa_2+\gamma_2\kappa_1)-12\alpha^2\kappa_1\kappa_2+\alpha\beta^2\mu(\kappa_1+\kappa_2)}. \tag{13}$$

Proof. In order to obtain equilibrium values, the first partial derivatives of the profit functions of dental centers 1 and 2 are taken with respect to their decision variables; thus, equilibrium values are obtained by solving *Eq. (14)*. These values correspond to *Eqs. (10)-(13)*.

$$\begin{cases}\frac{\partial\pi_1}{\partial P_1}=0\Longrightarrow\frac{\mu}{2}+\frac{\mu}{4}(-\alpha P_1+\alpha P_2+\beta Q_1-\beta Q_2)-\frac{\mu\alpha}{4}(-\gamma_1Q_1+P_1-T_1)=0\\\frac{\partial\pi_1}{\partial Q_1}=0\Longrightarrow-\gamma_1\left(\frac{\mu}{2}+\frac{\mu}{4}(-\alpha P_1+\alpha P_2+\beta Q_1-\beta Q_2)\right)+\frac{\mu\beta}{4}(-\gamma_1Q_1+P_1-T_1)-\kappa_1Q_1=0\\\frac{\partial\pi_2}{\partial P_2}=0\Longrightarrow\frac{\mu}{2}+\frac{\mu}{4}(\alpha P_1-\alpha P_2-\beta Q_1+\beta Q_2)-\frac{\mu\alpha}{4}(-\gamma_1Q_2+P_2-T_2)=0\\\frac{\partial\pi_2}{\partial Q_2}=0\Longrightarrow-\gamma_2\left(\frac{\mu}{2}+\frac{\mu}{4}(\alpha P_1-\alpha P_2-\beta Q_1+\beta Q_2)\right)+\frac{\mu\beta}{4}(-\gamma_2Q_2+P_2-T_2)-\kappa_2Q_2=0\end{cases}. \tag{14}$$

In order to evaluate the optimality of the obtained solutions, Hessian matrix related to the profit functions of dental centers must be negative definite. Hessian matrix is written as *Eq. (15)*.

$$H_{\pi_i}=\begin{bmatrix}\frac{\partial^2\pi_i}{\partial P_i^2} & \frac{\partial^2\pi_i}{\partial P_i\partial Q_i}\\\frac{\partial^2\pi_i}{\partial Q_i\partial P_i} & \frac{\partial^2\pi_i}{\partial Q_i^2}\end{bmatrix}=\begin{bmatrix}-\frac{1}{2}\mu\alpha & \frac{1}{4}\mu(\gamma_i\alpha+\beta)\\\frac{1}{4}\mu(\gamma_i\alpha+\beta) & -\frac{1}{2}\gamma_i\mu\beta-\kappa_i\end{bmatrix}. \qquad i=1,2 \tag{15}$$

If the following two requirements are met, the Hessian matrix is negative definite.

$$\begin{cases}-\frac{1}{2}\mu\alpha<0\\\left(-\frac{1}{2}\mu\alpha\right)\left(-\frac{1}{2}\gamma_i\mu\beta-\kappa_i\right)-\left(\frac{1}{4}\mu(\gamma_i\alpha+\beta)\right)^2>0. \qquad i=1,2\end{cases} \tag{16}$$

Given that the values of μ and α are positive, the first requirement is always met. Therefore, if *Eq. (17)* is established, the Hessian matrix is negative definite and the equilibrium values are obtained from *Eqs. (10)-(13)* will be optimal values.

$$\frac{1}{8}\alpha\beta\gamma_i\mu^2+\frac{1}{2}\alpha\mu\kappa_i-\frac{1}{16}\alpha^2\gamma_i^2\mu^2-\frac{1}{16}\beta^2\mu^2>0. \qquad i=1,2 \tag{17}$$

This completes the proof of Proposition.

Finally, the government takes into account the equilibrium values obtained for dental centers and determines tariffs based on the following model.

$$\max_{T_1,T_2} G=\lambda(T_1D_1+T_2D_2)+(1-\lambda)(\pi_1+\pi_2).$$

$$\text{s.t.} \begin{cases} (3),(5),(10)\text{-}(13) \\ T_{min}P_i \le T_i \le T_{max}P_i, \ i=1,2. \end{cases} \tag{18}$$

5 | Numerical Example and Sensitivity Analysis

5.1 | Numerical Example

Two dental centers have been considered to review the proposed model and the resulted relations. The two centers are competing to attract dental tourists. The expected demand for these two centers is a total of 1000 tourists, which are divided between these two dental centers according to the price and quality of services. The quality levels of services of Dental Center 1 and Dental Center 2 are considered 5 and 3, respectively. Both dental centers do not intend to invest in increasing quality levels in the short term. Dental centers seek to maximize their profits through appropriate pricing of services and thus attract more dental tourists. The parameter values for each dental center are summarized in *Table 1*. Also, the results obtained from the proposed model are presented in *Table 2*.

Table 1. The values assigned to the parameters.

Dental Centers	Parameters					
	α	β	γ_i	κ_i	T_{min}	T_{max}
Dental Center 1	0.4	0.7	2	4	0.09	0.09
Dental Center 2	0.4	0.7	3	3	0.09	0.09

Table 2. Equilibrium values obtained for variables.

λ	T_1	T_2	D_1	D_2	P_1	P_2	π_1	π_2	G
0	1.22	-1.38	330	670	13.52	15.32	1076.51	4436.95	-521.89
1	1.31	1.56	575	425	17.31	14.56	1792.02	3257.24	1415.19

5.2 | Sensitivity Analysis

In this section, the effect of *a* changes on the outputs of the proposed model in two cases (a) $\lambda = 0$ and (b) $\lambda = 1$, is studied. In the first case, the government's goal is to maximize the profits of dental centers and the development of dental tourism, and in the second case, the government's goal is to maximize its profits. These changes are presented in *Figs. 4-7*. The results are as follows.

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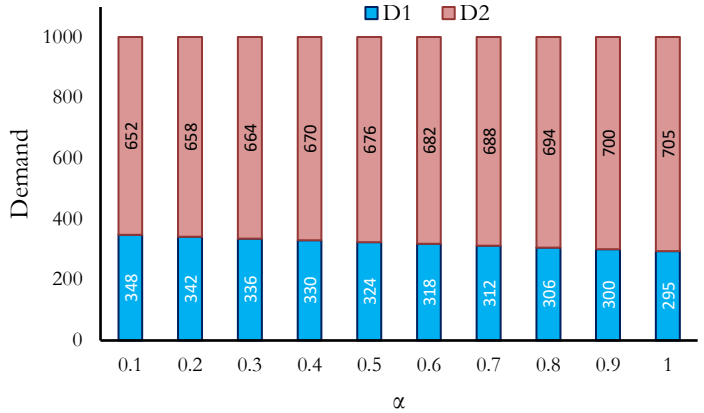
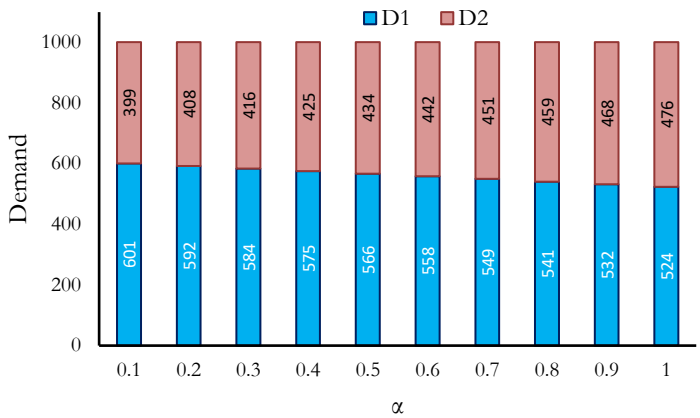
5.2.1 | Effect of α on D_i

As shown in *Fig. 4*, as *a* increases, the demand of Dental Center 1 has a descending trend and the demand of Dental Center 2 has an ascending trend. Comparing the two cases of (a) and (b), the demand of Dental Center 1 at each level of α in case (b) is higher than that in case (a), while the demand for Dental Center 2 at each level of α in case (b) is lower than that in case (a).



(a)

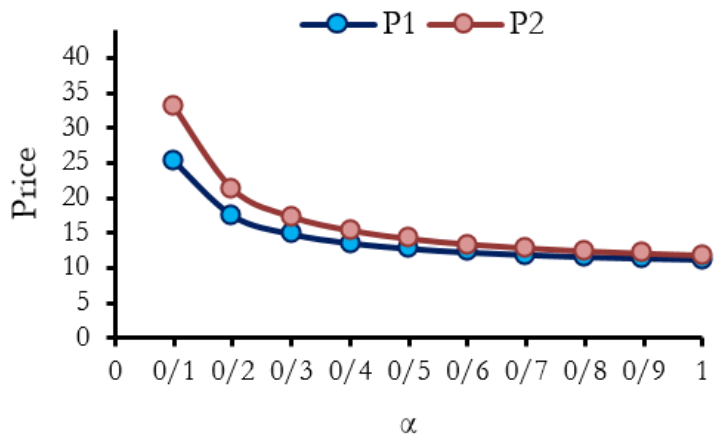


(b)

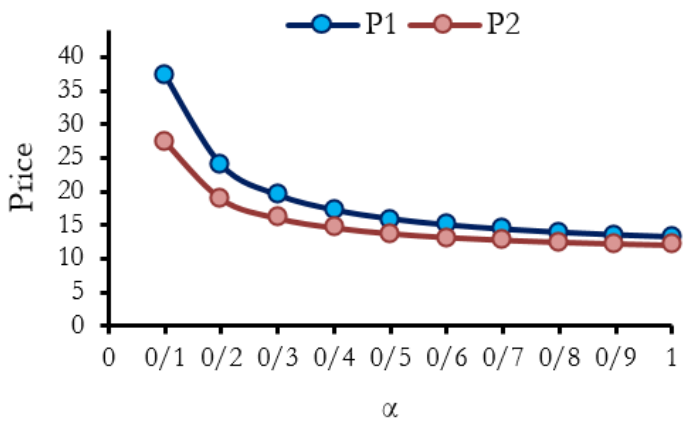
Fig. 4. The impact of α on demand for dental centers: (a). λ = 0; (b). λ = 1.

5.2.2 | Effect of α on P_i

As shown in *Fig. 5*, the prices of services provided by dental centers decrease by increases in α. Comparing the two cases of (a) and (b), the price of the service provided by Dental Center 1 at each level of α in case (b) is higher than that in case (a). In comparison, the price of the service provided by Dental Center 2 at each level of α in case (b) is lower than that in case (a).



(a)

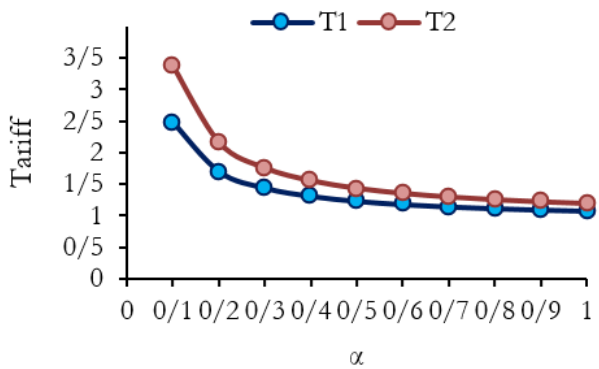


(b)

Fig. 5. The impact of α on the prices of service provided by the dental centers: (a). λ = 0; (b). λ = 1.

5.2.3 | Effect of α on T_i

As shown in *Fig. 6*, with increasing α, the tariff set by the government for Dental Center 1 has a descending trend and the tariff allocated to Dental Center 2 has an ascending trend. In case (a), this tariff is a tax for Dental Center 1 and a subsidy for Dental Center 2. With the increase of α in case (b), the tariffs of dental centers have a decreasing trend and these tariffs are in the form of taxes.



(a)

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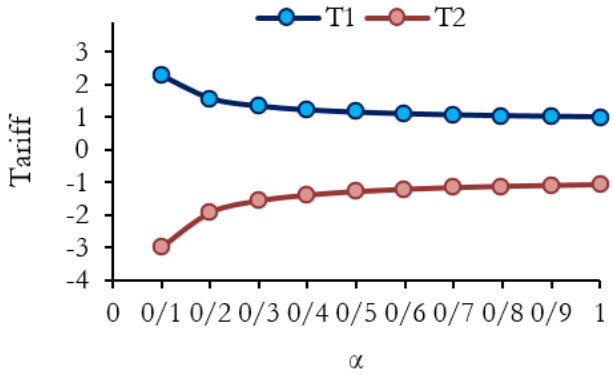
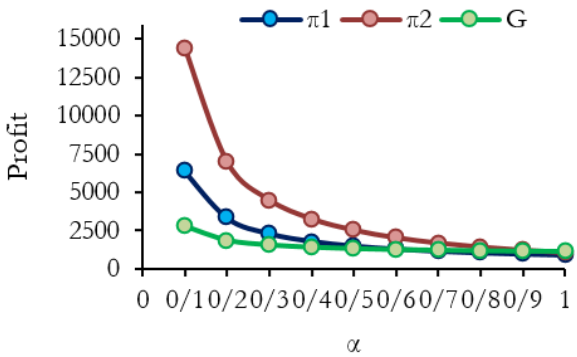


(b)

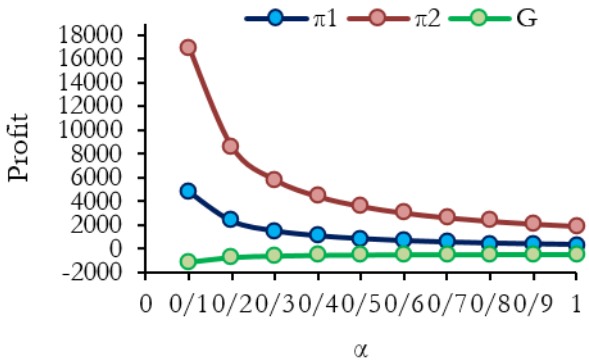
Fig. 6. The impact of α on the tariff (tax or subsidy) set by the government: (a). λ = 0; (b). λ = 1.

5.2.4 | Effect of α on π_i and G

As shown in *Fig. 7*, with increasing *a* in case (a), the profits of dental centers have a descending trend and the government's utility has an ascending trend. With increasing *a* in case (b), the profits of the dental centers and the government's utility have a decreasing trend, and as expected, the government's utility in case (b) is more than that in case (a).



(a)



(b)

Fig. 7. The impact of α on the profits of dental centers and the government's utility: (a). λ = 0; (b). λ = 1.

From the numerical example and sensitivity analysis, the main managerial insights are listed as follows:

I. The tariffs (subsidies or taxes) set by the government can have a significant impact on the prices of service provided by the dental centers and their profit.
II. The policy of expanding the dental tourism industry will lead to higher total profit for dental centers.
III. If the government tend to increase its profits, dental tourist's utility has a decreasing trend.

6 | Conclusion

In the present study, the problem of competition in the tourism industry between two dental centers was reviewed. The government has also entered to the proposed model as a key player which will have a significant impact on the tourism industry in the real world. First, the model was solved using the game theory approach and the equilibrium solutions for decision variables of the dental centers were obtained. Then, to find the equilibrium values of the tariff allocated by the government to the dental centers, the equilibrium solutions of the dental centers were placed in the government model and the equilibrium values of the tariffs were calculated. The results are as follows: 1) increasing the amount of subsidy will lead to a decrease in the prices of service provided by the dental centers. 2) By increasing the amount of subsidies allocated to the dental centers, the government can expand the dental tourism industry.

In this study, we confronted a few limitations both in academia and in real-world applications which they could be overcome for future researches. Data gathering and lack of previous similar studies working in the dental tourism were the critical limitations in this work. Also, in this study, all the parameters and the variables are assumed as deterministic values. For future research, uncertainty optimization approaches such as interval optimization [41], fuzzy optimization [42]-[46], and robust optimization [47] and [48] can be applied in order to handle data uncertainty. Furthermore, considering the role of advertising in modeling can be another research topic.

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