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STRATEGY CHOICE IN TOURISM SUPPLY CHAINS FOR PACKAGE HOLIDAYS: A GAME-THEORETIC APPROACH

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ABSTRACT

Enterprises in a tourism supply chain usually adopt and operate two business strategies: maximizing their profits or their revenues. This paper investigates the conditions on which these strategies allow enterprises to achieve the maximum benefits in the context of entire supply chain. Several managerial implications have been derived from this theoretical research. Firstly, theme park operator, tour operators and hotel & accommodation providers obtain larger market shares and profits if they select the revenue maximization (R) strategy. Secondly, the profit maximization (P) strategy is a better strategy for both sectors when all the tour operators and all hotel & accommodation providers choose the same strategy. Finally, if both sectors could freely choose their strategies, there is market equilibrium where P-strategy and R-strategy could coexist.

INTRODUCTION

Tourism and hospitality industries have enjoyed rapid developments in recent years. This is particularly true in emerging economies in the greater China region, including Hong Kong. A number of tourism and shopping destinations have been upgraded and launched in Hong Kong. These features are particularly attractive to tourists from the mainland China, in addition to those from the rest of the region and those from the West. Tour operators are providing package holiday products consisting of core components such as theme park (e.g. DisneylandHK or OceanPark), and shopping experiences in Time Square, Pacific Places, etc. As a result, a complex supply chain has already developed in Hong Kong tourism and hospitality industry.

Package holidays are tourist programs that are purposefully configured out of a variety of tourist activities. Tourist attractions (man-made, natural, cultural or social), accommodation, transportation, and dining and shopping experiences are typical core tourist components of the package holiday products. Different types of tourist components (activities) in package holidays are provided by specialist agents and enterprises that form tourism supply chain. A typical tourism supply chain (TSC) comprises the suppliers of all the goods and services that go into the delivery of tourism products to consumers (Richard and Xavier).

There has been a rich literature on the behavioral view of enterprises on the periphery of mainstream economic thought. Perhaps the most important assumption is that enterprise is to maximize profits strategically according to the classical formulation (Hirshleifer 1980). However, this pure profit maximizing strategy behavior has been criticized by many economists, such as

Baumol (1967) and Nicholson (1995). They argued that the enterprise try to maximize sales may be reasonable for assuring their long-term survival.

Enterprises in Tourism and Hospitality industry have also practiced the different strategies of maximizing profits or revenues (Collins and Parsa 2006). The profit maximizing tourism enterprise may compete in mature tourism market, have certain market share, and gain high reputation for tourists. Moreover, it could be controlled by owners who expect continuously profit and steady growth. Contrastively, the revenue maximizing enterprise may be in its fast growth period or enjoin rapid development of tourist market. More tourists come forth, enterprise-size be rapidly expanded. Managers eager to introduce new products, gain market share, build up reputation, and achieve return to scale. Furthermore, the management is more interest its own income and prestige which depend, sometimes, on its sales rather than profit (Yakov and Jacob, 1979). Generally, both profit maximization and revenue maximization could be the strategic goals of tourism enterprises, but only one dominates, such as maximizing its revenues subject to a minimum profit constraint. Moreover, enterprises may or may not change their strategies along with protean internal or external environment.

This paper aims to investigate strategy choices of enterprises in Hong Kong TSC for package holidays. The TSC has two layers or echelons structure. In the upstream layer, there are multiple hotel & accommodation providers and a theme park. They provide serves and experiences for the downstream for configuration. A number of tour operators in the downstream layer are responsible for configuring and packing the holidays, then sale them to target tourists as a whole. The price of package holidays charged by tourists contains the payment for accommodation and the ticket of the theme park.

In this paper, two strategies of enterprises are considered: profit maximizing strategy and revenues maximizing strategy. In TSC, each tour operator or hotel & accommodation provider freely makes its own strategy decision. Because there is only one theme park operator, we assume it is a profit-maximizer. We are interested in the following questions:

(1) What impacts the strategies of maximizing profits and revenues would have on the tour operators, hotel & accommodation providers and theme pack operator respectively?

(2) Which strategy is most beneficial to individual enterprises, the sectors, and the entire TSC and what are the conditions?

(3) Could individual enterprises practice different strategies in the supply chain and what are the conditions for such co-existence?

In order to address these research questions, this paper proposes a multi-stage game framework. The theme park operator determines its ticket price. After choosing their strategies, hotel & accommodation providers compete with each other, and the quantity competition determines a market equilibrium price. After learning the prices from the upstream, tour operators decide their strategies, then the equilibrium price for package holidays are reached through quantity competition. The multi-stage game is solved in bottom-up fashion. Given the demand faced by the tour operators, each of them simultaneously determines the number of tourists they served so as to maximize profits or revenues. Aggregating the equilibrium quantities of tourists for all the tour operators gives the best response function for hotel & accommodation providers and the theme park operator as demand curves. Using the same logic for the hotel & accommodation providers, and combining the result from the theme park, the final equilibriums have been obtained.

Game theory has not been widely used in tourism and hospitality literature. Only very limited pioneering efforts can be found in this area. Taylor (1998) introduced a game matrix analyzed tour operator's mixed price strategy. Chung (2000) examined pricing strategies and business performances of super deluxe hotels in Seoul by modified prisoner's dilemma game model. Wie (2003) formulated a dynamic game model of strategic capacity investment in cruise line industry. Bastakis, Buhalis, and Butler (2004) presented a bargaining game with asymmetric information to analyze relationships between tour operator and small and medium sized tourism accommodation enterprises. Recently, Garcia and Tugores (2006) proposed a two-stage duopoly game model in which hotels competed in both quality and price. The most of above literatures focus on single tourism enterprise or sector. This differs from our scenario which is in TSC for package holidays.

The rest of the paper is organized as follows. Section 2 presents the model and the equilibrium solution. Section 3 discusses the strategy choices of enterprises in TSC in different situations. Section 4 presents a number of useful managerial implications derived from theoretical results, and identifies the directions for future work. It should be noted that proofs of theorems with more mathematical background are omitted in order to save space.

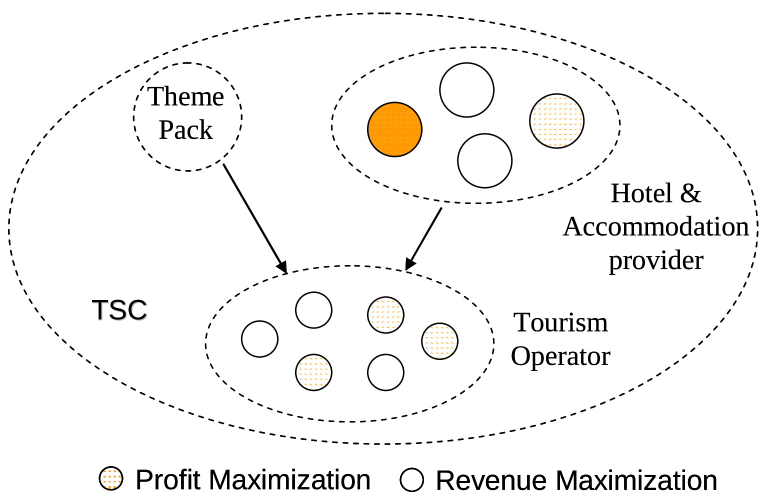

Figure 1. Tourism Supply Chain under study.

METHOD

The TSC for package holidays includes three sectors, namely tour operator (TO), hotel & accommodation provider (HA), and theme park operator (TP). There is only one TP while multiple TOs and HAs in the TSC. TP provides key activity for tourists to visit, and HAs supply accommodation for tourists. TOs are responsible for packaging the holidays to tourists including the options from the TP and HAs. For the sake of simplicity, we assume that all the tourists join the package holidays. This means that tourists do not obtain tickets directly from the TP operator. Those who obtain tickets directly from the TP operator do not require HA and therefore are not included for consideration in our model. TOs and HAs are grouped into sectors and entities within a sector are homogeneous. The two-echelon structure can be represented as a tree with each sector represented as a node (see figure 1).

Each TO/HA in TSC has two strategies: profit maximizing strategy (P-strategy) and revenue maximizing strategy (R-strategy). Enterprises in TSC play a two-stage game:

Stage 1: TP chooses the ticket price, and each HA determines his marketing strategy and optimal service quantities according to his strategy through competition.

Stage 2: Each TO obtains the decision made by TP and HAs and then determines his marketing strategy and quantity of package holidays sold simultaneously through competition.

In the mathematical formulation, there are N TOs and M HAs in the TSC, indexed by $i = 1...N$ and $j = 1...M$. The subscript (P and R) is used to distinguish the entities in TSC using different marketing strategies. For example, TO_R is a set of TOs who take R-strategy, N_R is the number of TO_R and $n_R = \frac{N_R}{N}$ is market ratio in TO sector. The strategy sets of TOs and HAs are denoted by $X = (X_i, X_{-i})$ and $Y = (Y_j, Y_{-j})$ in space $\{P, R\}^N$ and $\{P, R\}^M$ respectively, where $i = 1...N$, $j = 1...M$. X_{-i} and Y_{-j} represent strategy sets of TOs and HAs excluding TO_i and HA_j. Unit cost of TH, HA, and TO are c, c_2 and c_1, while price of TH, HA, and TO are p, p_2 and p_1. Without loss of generality, we assume a linear inverse price function for TO_j is $p_1^j = \alpha - \beta Q$. Linear price function is broadly used in manufacture supply chain (Carr and Karmarkar 2005; Xiao and Yu 2006), also applied in tourism and hospitality literatures (Zheng 1997; Wie 2005). The parameter α presents the market scale and $\alpha > c + c_1 + c_2$. β is quantity-sensitivity that means increment of quantities tourists leads to decrement of price for competition.

Tourism Operator's Model

The profit function of TO_j is $\pi_1^j = q_1^j (p_1^j - p - p_2 - c_1^j)$, and the revenue function of TO_j is $R_1^j = q_1^j (p_1^j - p - p_2)$, where c_1^j is unit cost of TO_j. Take the first and second derivations respective to q_1^j, we get the optimal quantities:

$$q_1^j = \begin{cases} \dfrac{\alpha - p - p_2 - c_1^j}{2\beta} - \dfrac{1}{2}\sum_{i \neq j} q_1^i, & j \in TO_P \\ \dfrac{\alpha - p - p_2}{2\beta} - \dfrac{1}{2}\sum_{i \neq j} q_1^i, & j \in TO_R \end{cases}$$

Sum up quantities for all the TOs, the total number of tourists is:

$$Q = \frac{(\alpha - p - p_2 - n_P c_{1P})N}{\beta(N+1)}, \text{ where } c_{1P} = \frac{\sum_{j \in TO_P} c_1^j}{N_P} \tag{1}$$

Hotel & Accommodation Provider's Model

From equation (1), a demand curve for HAs is $p_2 = \alpha - p - n_2 c_{1P} - \dfrac{Q\beta(N+1)}{N}$. Applying the same logic as that for TOs, the profit function and the revenue function for HA_j are $\pi_2^j = q_2^j (p_2 - c_2^j)$ and $\pi_2^j = q_2^j p_2$ respectively, where c_2^j is unit cost of HA_j. If following quantities are decided, HAs have no incentive to deviate those selections.

$$q_2^j = \begin{cases} \dfrac{\alpha - p - n_P c_{1P} - c_2^j}{2\beta(N+1)} N - \dfrac{1}{2}\sum_{i \neq j} q_2^i, & j \in HA_P \\ \dfrac{\alpha - p - n_P c_{1P}}{2\beta(N+1)} N - \dfrac{1}{2}\sum_{i \neq j} q_2^i, & j \in HA_R \end{cases}$$

Sum up quantities for all the HAs, the total number of tourists is

$$Q = \frac{MN(\alpha - p - n_P c_{1P} - m_P c_{2P})}{\beta(M+1)(N+1)}, \text{ where } c_{2P} = \frac{\sum_{j \in HA_P} c_2^j}{M_p} \tag{2}$$

Theme Park Operator's Model

From equation (1), TP ticket price is $p = \alpha - p_2 - n_P c_{1P} - \dfrac{Q\beta(N+1)}{N}$. TP maximizes its profit $\pi_3 = Q(p - c)$, and get the optimal tourists quantity:

$$Q = \frac{N(\alpha - p_2 - n_P c_{1P} - c)}{2\beta(N+1)} \tag{3}$$

Model Equilibriums

Combining (2) and (3), following equilibriums are obtained:

for TP: $$Q=\frac{NM(\alpha-c-n_Pc_{1P}-m_Pc_{2P})}{\beta(2M+1)(N+1)};\pi_3=\frac{M^2N(\alpha-c-n_Pc_{1P}-m_Pc_{2P})^2}{\beta(2M+1)^2(N+1)}.$$

for $j\in TO_P$: $$q_1^{jP}=\frac{Q}{N}+\frac{n_Pc_{1P}-c_1^j}{\beta},\pi_1^{jP}=\beta(\frac{Q}{N})^2+\frac{2Q}{N}(n_Pc_{1P}-c_1^j)+\frac{(n_Pc_{1P}-c_1^j)^2}{\beta}.$$

for $j\in TO_R$: $$q_1^{jR}=\frac{Q}{N}+\frac{n_Pc_{1P}}{\beta},\pi_1^{jR}=\beta(\frac{Q}{N})^2+\frac{Q}{N}(2n_Pc_{1P}-c_1^j)+\frac{n_Pc_{1P}}{\beta}(n_Pc_{1P}-c_1^j).$$

for $j\in HA_P$: $$q_2^{jP}=\frac{Q}{M}+\frac{N(m_Pc_{2P}-c_2^j)}{\beta(N+1)},$$

$$\pi_2^{jP}=\frac{\beta(N+1)}{N}(\frac{Q}{M})^2+\frac{2Q}{M}(m_Pc_{2P}-c_2^j)+\frac{N(m_Pc_{2P}-c_2^j)^2}{\beta(N+1)}.$$

for $j\in HA_R$: $$q_2^{jR}=\frac{Q}{M}+\frac{Nm_Pc_{2P}}{\beta(N+1)},$$

$$\pi_2^{jR}=\frac{\beta(N+1)}{N}(\frac{Q}{M})^2+\frac{Q}{M}(2m_Pc_{2P}-c_2^j)+\frac{Nm_Pc_{2P}}{\beta(N+1)}(m_Pc_{2P}-c_2^j).$$

Following definition is used throughout the rest of paper.

DEFINITION 1. Given other HAs' (TOs') strategies, if $\pi_{1i}(X_i,X_{-i}^*)\le\pi_{1i}(X_i^*,X_{-i}^*)$ ($\pi_{2j}(Y_j,Y_{-j}^*)\le\pi_{2j}(Y_j^*,Y_{-j}^*)$) for $\forall i=1...N$ ($\forall j=1...M$), then (X_i^*,X_{-i}^*) ((Y_j^*,Y_{-j}^*)) is the TO (HA) Nash Equilibrium, and n_P^* (m_P^*) is Equilibrium Market Ratio.

The definition means that if a TO or a HA is in the Nash equilibrium he has no incentive to unilaterally change his strategy. In other words, equilibrium strategy is his optimal choice given others' strategies, so that any change would lead he to earn less than if he remained with his current strategy. For simplicity, we assume that all TOs or HAs are identical.

FINDINGS

Based on the above equilibriums, we first identify the impact of different strategy choices on TOs, HAs and TP's performances. The results are presented as follows:

PROPOSITION 1. (1) Output shares and profits of TOs or HAs who choose R-strategy is greater than those choose P-strategy; (2) TP is benefit from the R-strategy taken by TOs and HAs.

Then a simple scenario is discussed in which all the enterprises in the same sector using the same strategy. This is considered as all the TOs and HAs join their sector associations, so that they keep their decisions consistently through coordination. Four instances are considered, which are (1) all the TOs and HAs choose the P-strategy; (2) all the TOs choose the P-strategy and all the HAs choose the R-strategy; (3) all the TOs choose the R-strategy and all the HAs choose the P-strategy; (4) all the TOs and HAs choose the R-strategy. The profits of TOs or HAs in different instances are easily extended from the result of previous section and listed as follows, as well as the game matrix structure shown in Table 1.

Table 1. Game Matrix.

		HA	
		P-Strategy	R-Strategy
TO	P-Strategy	(π_1^{PP}, π_2^{PP})	(π_1^{PR}, π_2^{PR})
	R-Strategy	(π_1^{RP}, π_2^{RP})	(π_1^{RR}, π_2^{RR})

$$\pi_1^{PP} = \frac{M^2(\alpha - c - c_1 - c_2)^2}{\beta(2M+1)^2(N+1)^2}; \pi_2^{PP} = \frac{N(\alpha - c - c_1 - c_2)^2}{\beta(2M+1)^2(N+1)};$$

$$\pi_1^{RP} = [\frac{M(\alpha - c - c_2)}{(2M+1)(N+1)} - c_1]\frac{M(\alpha - c - c_2)}{\beta(2M+1)(N+1)}; \pi_2^{RP} = \frac{N(\alpha - c - c_2)^2}{\beta(2M+1)^2(N+1)};$$

$$\pi_1^{PR} = \frac{M^2(\alpha - c - c_1)^2}{\beta(2M+1)^2(N+1)^2}; \pi_2^{PR} = (\frac{\alpha - c - c_1}{2M+1} - c_2)\frac{N(\alpha - c - c_1)}{\beta(2M+1)(N+1)};$$

$$\pi_1^{RR} = [\frac{M(\alpha - c)}{(2M+1)(N+1)} - c_1]\frac{M(\alpha - c)}{\beta(2M+1)(N+1)}; \pi_2^{RR} = (\frac{\alpha - c}{2M+1} - c_2)\frac{N(\alpha - c)}{\beta(2M+1)(N+1)}.$$

LEMMA 1. $\pi_1^{PR} > \pi_1^{RR} > \pi_1^{RP}, \pi_1^{PR} > \pi_1^{PP} > \pi_1^{RP}, \pi_2^{RP} > \pi_2^{RR} > \pi_2^{PR}, \pi_2^{RP} > \pi_2^{PP} > \pi_2^{PR}$.

THEOREM 1. All the TOs and HAs choosing the P-strategy is the unique Nash Equilibrium of the above game matrix.

Consequently, we investigate in a common scenario where TOs and HAs freely choose their strategies. Following theorem gives the sufficient and necessary condition of Nash

Equilibrium in TO sector:

THEOREM 2. The sufficient and necessary condition for (X_i^*, X_{-i}^*) to be Nash Equilibrium in TO sector is Equilibrium Market Ratio n_P^* satisfy: $n_P^* \in [n_P^-, n_P^+] \bigcap [0,1]$, where

$$n_p^- = \frac{1}{1-k} + \frac{1-k}{N(N-2+2k)} - \frac{(\alpha - c - m_P c_{2P})k}{c_1(1-k)},$$

$$n_p^+ = \frac{1}{1-k} + \frac{(N-1+k)}{N(N-2+2k)} - \frac{(\alpha - c - m_P c_{2P})k}{c_1(1-k)}, \text{ and } k = \frac{M}{(2M+1)(N+1)}.$$

Similar to Theorem 2, theorem about HA sector is shown as follows:

THEOREM 3. The sufficient and necessary condition for (Y_j^*, Y_{-j}^*) to be Nash Equilibrium in HA sector is Equilibrium Market Ratio m_P^* satisfy: $m_P^* \in [m_P^-, m_P^+] \bigcap [0,1]$, where

$$m_p^- = 1 + \frac{1}{2M} + \frac{2}{M(2M-3)} - \frac{\alpha - c - n_P c_{1P}}{2Mc_2}$$

$$m_p^+ = 1 + \frac{1}{2M} + \frac{2M-1}{M(2M-3)} - \frac{\alpha - c - n_P c_{1P}}{2Mc_2}.$$

Sometime, the TO sector and HA sector have the large number of enterprises. For example, a great number of tour operators in Mainland China run the business with tour to Disney HK, and there are plenty of hotels serving tourists in Hong Kong. In this condition, the corollary shows our finding:

COROLLARY 1. All the TOs and HAs choose P-strategy when conditions $N \to \infty$ and $M \to \infty$ are hold.

This corollary is intuitive, as $[m_P^-, m_P^+]$ and $[n_P^-, n_P^+]$ converge to 1 when N and M become infinite. It presents the perfect competition market in which price is equal to unit cost and all the TOs and HAs are unprofitable.

Previous analyses in this sector are in behavior of tourism enterprise. However, as is common in the industrial organization literature, social planer cares about the sector welfare or total sector plus (Garcia and Tugores 2006). Welfare function or total sector surplus is defined as the sum of profits of all enterprises in the sector.

The TO sector's surplus is: $\Pi_{TO} = N_p \pi_1^P + N_R \pi_1^R$

The HA sector's surplus is: $\Pi_{HA} = M_P \pi_2^P + M_R \pi_2^R$

Maximizing the sector's surplus, one can easy get the following proposition:

PROPOSITION 2. P strategy is the optimal choice for TO sector and HA sector.

Similar to the definition of sector welfare, the supply chain welfare or supply chain plus is $\Pi_{Chian} = \Pi_{TO} + \Pi_{HA} + \pi_3$. The following proposition gives the optimal strategy choices when the supply chain welfare is maximal.

PROPOSITION 3. In the context of entire supply chain, the optimal strategy choices of TOs (n_P) and HAs (m_P) satisfy $\dfrac{\alpha - c - n_P c_1 - m_P c_2}{\alpha - c - c_1 - c_2} = \dfrac{(2M+1)(N+1)}{2MN}$.

APPLICATION OF RESULTS AND FUTURE WORK

Several managerial implications have been derived from this theoretical research. Firstly, tour operators and hotel & accommodation providers who select the revenue maximization (R) strategy get the larger market share and profit compared to the situation where the profit maximization (P) strategy is adopted. TP also prefers R-strategy to P-strategy for more tourism visitors. Secondly, if all the tour operators or hotel & accommodation providers synchronously choose the same strategy, P strategy is a better strategy for both of these sectors. Thirdly, when tour operators or hotel & accommodation providers could freely choose their strategies, there is market equilibrium where P-strategy and R-strategy could coexist. Finally, in view of individual sectors, one of the sectors, either tour operators or hotel & accommodation providers, is expected to take the P-strategy. In the context of entire supply chain, the condition in which supply chain welfare is maximal is also presented.

The further research can be extended in two possible directions. We have assumed the quantity competition between tour operators and hotel & accommodation providers, an alternative model would be to replace the quantity competition by a price competition where the enterprises choose equilibrium prices rather than quantities. Comparative analysis would yield more different and interesting results. We would investigate strategy choice in a more realistic market structure. Tour operator and hotel & accommodation sectors are dominated by few large leader enterprises. Other enterprises are small and compete as followers. It would be interesting to discuss the different impact of strategy choices between leader and follower enterprises.

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REFERENCES

Bastakis C., Buhalis D., and Butler R. (2004). The Perception of Small and Medium Sized Tourism Accommodation Providers on the Impacts of the Tour operators' power in Eastern Mediterranean. *Tourism Management*, 25, 151-170.

Baumol W. J. (1967). Business Behavior, Value and Growth, rev. ed. New York: Harcourt, Brace & World.

Carr S. M., and Karmarkar U. S. (2005). Competition in Multiechelon Assembly Supply Chains. *Management Science*, 51, 45-59.

Collins M., and Parsa H. G. (2006). Pricing Strategies to Maximize Revenues in the Lodging industry. *Hospitality Management*, 25, 91-107.

Chung K. Y. (2000). Hotel Room Rate Pricing Strategy for Market Share in Oligopolistic Competition – Eight-year Longitudinal Study of Super Deluxe Hotels in Seoul. *Tourism Management*, 21, 135-145.

Garcia D., and Tugores M. (2006). Optimal Choice of Quality in Hotel Services. *Annals of Tourism Research*, 33, 456-469.

Hirshleifer J. (1980). Price Theory and Applications. Englewood Cliffs, NJ.: Prentice-Hall.

Nicholson W. (1995). Microeconomic Theory: Basic Principles and Extensions. Fort Worth, Tex.: Dryden Press.

Richard and Xavier, Tourism Supply Chain: Report of Desk Research Project for the Travel Foundation. http://www.leedsmet.ac.uk.

Taylor P. (1998). Mixed Strategy Pricing Behaviour in the UK Package Tour Industry. *International Journal of the Economics of Business*, 5, 29-46.

Wie B. W. (2005). A Dynamic Game Model of Strategic Capacity Investment in the Cruise Line Industry. *Tourism Management*, 26, 203-217.

Xiao T., and Yu G. (2006). Supply Chain Disruption Management and Evolutionarily Stable Strategies of Retailers in the Quantity-setting Duopoly Situation with Homogeneous Goods. *European Journal of Operational Research*, 173, 648-668.

Yakov A., and Jacob K. (1979). Revenue vs. Profit Maximization: Differences in Behavior by the Type of Control and by Market Power. *Southern Economic Journal*, 45, 838-846.

Zheng G. (1997). Proposing a Room Pricing Model for Optimizing Profitability. *International Journal of Hospitality Management*, 16, 273-277.

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