

Article

# Optimal Emission Reduction and Pricing in the Tourism Supply Chain Considering Different Market Structures and Word-of-Mouth Effect

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**Abstract:** In the context of carbon tax policy and word-of-mouth, local operators and tour operators in the tourism supply chain need to determine optimal wholesale price, carbon reduction level, and retail price of tour packages strategies. To address these decision-making issues, while considering the word-of-mouth effect, our paper considers a local operator determining wholesale price and carbon reduction level of the tour package and a tour operator determining retail price of the tour package. According to different bargaining powers, we study three scenarios: the local operator leading Stackelberg (LL), the tour operator leading Stackelberg (TL), and the static Nash game (NG). We develop three theoretical models and present some insights. We find that tourist's sensitivity to word-of-mouth has positive (negative) impacts on optimal wholesale price, carbon reduction level, retail price, demand, and profits if the impact of word-of-mouth is positive (negative), while the impact of word-of-mouth is always having positive impacts on optimal decisions, demand, and profits. Interestingly, the NG market structure contributes the most environmentally-friendly products but mostly hurts the environment. The local operator under LL can obtain the largest profit, which is even larger than the profit of the tour operator, while the tour operator under NG and TL can obtain more profit than the local operator.

**Keywords:** tourism supply chain; carbon reduction; pricing; Stackelberg game; Nash game



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## 1. Introduction

To promote green and sustainable development, many governments have issued a carbon tax policy, such as Finland, Britain, Germany, Canada, America, Norway, and Australia [1,2]. For the tourism industry, when responding to carbon tax policy, many firms in the tourism supply chain reduce carbon emissions through carbon reduction technology to control carbon emission cost and produce greener tour packages [3,4]. Moreover, with the development of e-commerce, the word-of-mouth effect has become more important for consumers to purchase products [5]. Thus, word-of-mouth is an important factor influencing tourists to purchase tourism packages. In the contexts of carbon tax policy and the impact of word-of-mouth, firms in the tourism supply chain face challenges for determining the wholesale price, carbon reduction level, and retail price of tour packages. Hence, it is particularly important to study the pricing, carbon reduction, and other operational strategies of firms in the tourism supply chain in these contexts.

For the tourism supply chain, there are always local operators and tour operators, in which local operators' wholesale tour packages for tour operators and then tour operators sell these tour packages to tourists. For instance, tourist attractions often build supplier-buyer relationships with travel agencies to form a tourism supply chain in which tourist attractions are a local operator while travel agencies are tour operators. With the

development of the Internet, some online travel giants are emerging, such as Expedia, Travelocity, Airbnb, Ctrip, Fliggy, and Meituan et al. [6]. These online travel giants as a tour operator are bound to enhance the influences of word-of-mouth, which may affect the operations of local operators and tour operators in tourism supply chains. Hence, it is necessary to explore the impacts of word-of-mouth on optimal operations of members in the tourism supply chain.

In practice, firms in the supply chain always have different bargaining powers. For instance, Choi [7] studied the optimal decisions of two manufacturers and one retailer in two Stackelberg and one Nash game contexts. Similar to the traditional supply chain, firms in the tourism supply chain always have different bargaining powers. For instance, Ctrip.com as a tour operator compared with a small and medium local operator such as Dragon Place Cave in Jiangxi has more bargaining power [8], and Mount Huang in China compared with a small and medium tour operator has more bargaining power. That's to say, it is a normal phenomenon that local operators and tour operators in the tourism supply chain have different bargaining powers. Thus, firms in the tourism supply chain determine optimal decisions also need to consider the impacts of different market structures.

Based on the previously mentioned background, the practical problems faced by firms in the tourism supply chain while considering the impacts of carbon tax policy, word-of-mouth, and different market structures can be presented as follows: (i) How should local operators determine the carbon reduction level in the context of carbon tax policy? (ii) How does word-of-mouth affect the optimal wholesale price, carbon reduction level, retail price, demand, and profits of local operators and tour operators? (iii) How do different market structures affect the optimal wholesale price, carbon reduction level, retail price, demand, and profits of local operators and tour operators? (iii) Which market structure is the most conducive to the environment? (iv) Are local operators and tour operators in the tourism supply chain more profitable?

Although the previously mentioned questions are the practical problems faced by local operators and tour operators of the tourism supply chain, the existing literature does not study them. Thus, our paper fills these gaps. Specifically, our paper considers a local operator and a tour operator. The local operator determines the wholesale price and carbon reduction level of tour packages, and the tour operator determines the retail price of tour packages. According to different market structures, we consider three scenarios: the local operator compared with the tour operator has more bargaining power (LL), the tour operator compared with the local operator has more bargaining power (TL), or the local operator and tour operator have similar bargaining power (NG). Additionally, when we develop three theoretical models and optimize the models, some insights are refined. The results imply that, when the impact of word-of-mouth is positive (negative), the tourist's sensitivity to word-of-mouth has a positive (negative) effect on the optimal wholesale price, retail price, carbon reduction level, demands, and profits. The impact of word-of-mouth has a positive effect on the optimal decisions, demands, and profits. Although the reduction level under the local operator leading Stackelberg (LL) is the lowest, the total carbon emission under LL is the lowest. Similarly, although the reduction level under the Nash game (NG) is the largest, NG is most harmful to the environment. Moreover, the local operator under LL can obtain the largest profit while the tour operator under tour operator leading Stackelberg (TL) can obtain the largest profit. Our theoretical models and main insights could serve members in the tourism supply chain to determine optimal wholesale price, carbon reduction level, and retail price of tour packages in practice.

The rest of the paper can be arranged as follows. Section 2 reviews the related literature. In Section 3, we introduction the parameter, utility functions, demand function, and our research questions. The model is developed in Section 4. In Section 5, some main results are analyzed. The conclusion is presented in Section 6.

## 2. Literature Review

This paper investigates the optimal wholesale price, carbon reduction level, and retail price in the tourism supply chain, and explores the impacts of a different market structure. Thus, the related literature mainly focuses on the research of the tourism supply chain and word-of-mouth.

In 1975, the concept of the tourism supply chain was explained by the United Nations World Tourism Organization [9]. After then, the tourism supply chain has attracted the attention of scholars.

Most scholars study the tourism supply chain through empirical methods [10–17]. For instance, Arifin et al. [18] investigate the relationship between supply chain management and the hotel industry in Indonesia, and present some implications for tourists and key policymakers integrating supply chain management and tourism.

Different from empirical research in the tourism supply chain, some scholars investigate the tourism supply chain by developing theoretical models. Guo et al. [19] explore the predesigned tours and optional tours' pricing competition and channel coordination in a tourism supply chain with one local operator and one tour operator, and find that the local operator in some situations may reduce commission. Similar cooperation in the tourism supply chains have been studied by Guo and He [20] and Guo et al. [21]. Jena and Jog [22] investigate the price competition in a tourism supply chain consisting of one local operator and two tour operators, and find that tour operators leading the Stackelberg game compared with a local operator leading the Stackelberg game is more beneficial to the tourism supply chain. Ahmadimanesh et al. [23] design a mathematical model for a dental tourism supply chain with medical centers, accommodation centers, and tourists, and present the optimal number of medical and accommodation and final medical center capacity. He et al. [6] consider an O2O tourism supply chain with a tourism servicer and an online travel agency in three selling modes while considering social responsibility, and propose the conditions for all modes to be the optimal mode for members of the tourism supply chain. Jena and Meena [24] explore the price and service competition in a tourism supply chain with one local operator and two tour operators, and consider the impacts of different bargaining powers among these members, and find that competition benefits the tourism supply chain and the surplus sharing contract can coordinate the tourism supply chain. Noori-daryan et al. [25] investigate the Stackelberg game among an airline, a hotel, and a travel agency in a tourism supply chain with in which both the airline and the hotel adopt O2O selling modes, and find that O2O modes advance booking policy benefit members and the whole supply chain.

Previous studies related to the tourism supply chain have explored optimal decisions of the tourism supply chain in different market structures, but none of them has studied the impacts of carbon tax and word-of-mouth on optimal wholesale price, carbon reduction level, and retail price in a tourism supply chain, which is our novel contribution.

Moreover, word-of-mouth play an important role in tourism management [26], and Confente [26] has reviewed the tourism research regarding word-of-mouth. Many scholars investigate the impact of word-of-mouth on operations and profits of firms from the perspective of empirical studies, such as Matzler et al. [27], Chen [28], Sweeney et al. [29], and Meilatinova [30]. Specifically, for the tourism industry, many scholars explore tourism management in the word-of-mouth context through empirical studies, such as Phillips et al. [31], Wang et al. [32], and Taheri et al. [33]. With the advent of e-commerce, electronic word-of-mouth in tourism management is concerned by some scholars such as Sotiriadis and Van Zyl [34], Chen and Law [35], Pourfakhimi et al. [36], and Ran et al. [37].

These scholars have studied the various impacts of word-of-mouth on tourism management via empirical studies, but none of them has explored the impact of word-of-mouth on pricing and reduction level strategies of firms in the tourism supply chain. Thus, our paper investigates optimal pricing and reduction level in the tourism supply chain in the word-of-mouth context via theoretical models, which is new contribution for both tourism management and word-of-mouth research areas.

### 3. Problem Description

Our paper considers a tourism supply chain with a local operator (L) and a tour operator (T). The tour operator sells tour packages and the local operator provides a corresponding tour service to tourists at the destination. To promote the development of green tourism, the government enacts carbon tax policy in which the local operator needs to pay a carbon tax for each unit of product. Moreover, our paper takes word-of-mouth into account. According to different powerful structures of the local operator and the tour operator, we consider three scenarios: the Stackelberg game led by the local operator (LL), the Stackelberg game led by the tour operator (TL), and the Nash game between the local operator and the tour operator (NG). To clarify the model, we present the notations in Table 1.

**Table 1.** The notations.

Notation	Explanation
$w$	Tour package wholesale price
$p$	Tour package price
$e$	The carbon reduction level
$v$	Tourist's willingness to pay for the tour package
$b$	Tourist's sensitivity to the reduction level
$v_{WOM}$	The impact of word-of-mouth
$\lambda$	Tourist's sensitivity to word-of-mouth
$e_I$	Initial unit carbon emission
$t$	Unit carbon tax
$c$	Unit tour package cost
$m$	Cost coefficient of the carbon reduction level
$\Pi_i$	Tour package wholesale price
$w$	Profit of the local operator ( $i = L$ ) or the tour operator ( $i = T$ )

The local operator determines the tour package wholesale price  $w$  and the carbon reduction level  $e$ , while the tour operator determines the tour package price  $p$ .

The tour package market size is assumed to equal to 1. Tourists' willingness-to-pay for the tour package is heterogeneous, which is assumed to be uniformly distributed between 0 and 1 [38]. Moreover, following Cao et al. [39], we assume that tourists are environmentally conscious and sensitive to the reduction level. Given that tourists' purchasing behavior is affected by word-of-mouth, our paper assumes that the impact of word-of-mouth is the parameter  $v_{WOM}$  ( $v_{WOM} \in [-1, 1]$ ), and tourist's sensitivity to word-of-mouth is the parameter  $\lambda$ , in which  $v_{WOM} < 0$  represents that word-of-mouth has a negative impact while  $v_{WOM} > 0$  implies that word-of-mouth has a positive impact [40,41].

Thus, a tourist can obtain utility  $u = v - p + be + \lambda v_{WOM}$  from purchasing a tour package. If  $u \geq 0$ , the tourist will buy the tour package. It is easy to present the demand of the tour package as follows.

$$D = 1 - p + be + \lambda v_{WOM} \quad (1)$$

Following Cao et al. [1], the government charges the local operator unit carbon tax.  $t$  for per unit carbon emission. The unit cost of the tour package is assumed to be the parameter  $c$ . Similar to Cao et al. [39], the carbon reduction cost is concave of the carbon reduction level, i.e.,  $me^2/2$ , in which the parameter  $m$  represents the cost coefficient of the carbon reduction level.

The total carbon emission can be presented as follows:  $E = D(e_I - e)$ .

### 4. Model

According to the three scenarios, we develop three theoretical models, i.e., model LL, model TL, and model NG. To clarify our model, we use superscripts LL, TL, and NG to represent the scenarios LL, TL, and NG, respectively.

#### 4.1. Model LL

In model LL, when compared with the tour operator, the local operator has more bargaining power, i.e., the local operator is the leader while the tour operator is the follower. The local operator determines the wholesale price of the tour package and the carbon reduction level first, and then the tour operator sets the retail price of the tour package.

The profit of the local operator under LL is given as follows:

$$\prod_L^{LL} = D[w - c - t(e_I - e)] - me^2/2 \quad (2)$$

The profit of the tour operator under LL is presented as follows:

$$\prod_T^{LL} = D(p - w) \quad (3)$$

Through backward induction, we make the first-order of Equation (3) equal to 0, and have the reaction function as follows:

$$p(w, e)^{LL} = (1 + w + be + \lambda v_{WOM})/2 \quad (4)$$

Putting Equation (4) into Equation (2), we have the profit of the local operator as follows:

$$\prod_L^{LL} = (1 - p(w, e)^{LL} + be + \lambda v_{WOM})[w - c - t(e_I - e)] - me^2/2 \quad (5)$$

The Hessian matrix of Equation (5) can be presented as follows:

$$\begin{bmatrix} \partial^2 \prod_L^{LL} / \partial w^2 & \partial^2 \prod_L^{LL} / (\partial w \partial e) \\ \partial^2 \prod_L^{LL} / (\partial e \partial w) & \partial^2 \prod_L^{LL} / \partial e^2 \end{bmatrix} = \begin{bmatrix} -1 & (b - t)/2 \\ (b - t)/2 & bt - m \end{bmatrix}$$

It is easy to verify the Hessian matrix is a negative definite. Hence, the optimal decisions can be obtained by setting the first-order conditions equal to 0, i.e.,  $\partial \prod_L^{LL} / \partial w = 0$  and  $\partial \prod_L^{LL} / \partial e = 0$ . The optimal wholesale price and carbon reduction level in model LL are given as follows:

$$w^{LL*} = \frac{2m(1+c+\lambda v_{WOM})-b^2c-(1+be_I+\lambda v_{WOM})t^2+t[2me_I-b^2e_I-(1+c+\lambda v_{WOM})b]}{4m-(b+t)^2},$$

$$e^{LL*} = \frac{(b+t)(1-c-te_I+\lambda v_{WOM})}{4m-(b+t)^2}$$

Putting these optimal decisions into Equation (4), we have the optimal retail price of the tour package in model LL, as follows.

$$p^{LL*} = \frac{m(3+c+3\lambda v_{WOM})-b^2c-(1+be_I+\lambda v_{WOM})t^2+t[me_I-b^2e_I-(1+c+\lambda v_{WOM})b]}{4m-(b+t)^2}$$

#### 4.2. Model TL

In model TL, when compared with the local operator, the tour operator has more bargaining power, i.e., the tour operator is the leader while the local operator is the follower. The tour operator sets the retail price of the tour package first, and then the local operator determines the wholesale price and the carbon reduction level of the tour package.

To solve this Stackelberg game, we set  $p = w + \sigma$ , where  $\sigma$  is the unit margin. Thus, the demand function can be written as follows.

$$D_\sigma = 1 - w - \sigma + be + \lambda v_{WOM} \quad (6)$$

The profit of the tour operator under TL is presented as follows.

$$\prod_T^{TL} = D_\sigma \sigma \quad (7)$$

The profit of the local operator under TL is given as follows.

$$\prod_L^{TL} = D_\sigma [w - c - t(e_I - e)] - me^2/2 \quad (8)$$

Through backward induction, we present the Hessian matrix of Equation (8) can be presented as follows:

$$\begin{bmatrix} \partial^2 \prod_L^{TL} / \partial w^2 & \partial^2 \prod_L^{TL} / (\partial w \partial e) \\ \partial^2 \prod_L^{TL} / (\partial e \partial w) & \partial^2 \prod_L^{TL} / \partial e^2 \end{bmatrix} = \begin{bmatrix} -2 & b - t \\ b - t & 2bt - m \end{bmatrix}$$

It is easy to verify this Hessian matrix is a negative definite. Thus, we make the first-orders of Equation (8) equal 0, and have the reaction functions as follows:

$$w(\sigma)^{TL} = \frac{m(1 + c + \lambda v_{WOM} - \sigma) - b^2c - (1 + be_I + \lambda v_{WOM} - \sigma)t^2 + t[me_I - b^2e_I - (1 + c + \lambda v_{WOM} - \sigma)b]}{2m - (b + t)^2} \quad (9)$$

$$e(\sigma)^{TL} = \frac{(b + t)(1 - c - te_I + \lambda v_{WOM} - \sigma)}{2m - (b + t)^2} \quad (10)$$

Putting Equations (9) and (10) into Equation (7), we have the profit of the tour operator as follows:

$$\prod_T^{TL} = [1 - w(\sigma)^{TL} - \sigma + be(\sigma)^{TL} + \lambda v_{WOM}] \sigma \quad (11)$$

Solving the second-order of Equation (11), we have  $\partial^2 \prod_T^{TL} / \partial \sigma^2 = -2m / [2m - (b + t)^2] < 0$ . Thus, by setting the first-order of Equation (11) equal to 0, we can present the optimal unit margin as follows:

$$\sigma^{TL*} = (1 - c - e_I t + \lambda v_{WOM}) / 2$$

Putting this optimal unit margin into Equations (9) and (10), we present optimal decisions under TL as follows:

$$w^{TL*} = \frac{m(1 + 3c + \lambda v_{WOM}) - 2b^2c - e_I t^3 - (1 + c + 3be_I + \lambda v_{WOM})t^2 + t[3me_I - 2b^2e_I - (1 + 3c + \lambda v_{WOM})b]}{4m - 2(b + t)^2};$$

$$e^{TL*} = \frac{(b + t)(1 - c - te_I + \lambda v_{WOM})}{4m - 2(b + t)^2}; p^{TL*} = \frac{m(3 + c + e_I t + 3\lambda v_{WOM}) - b^2(1 + c + e_I t + \lambda v_{WOM}) - t(3 + c + e_I t + 3\lambda v_{WOM})b - 2(1 + \lambda v_{WOM})t^2}{4m - 2(b + t)^2}$$

#### 4.3. Model NG

In model NG, the local operator and the tour operator have similar bargaining power, and we assume that there is a static Nash game between the local operator and the tour operator. The tour operator sets the retail price of the tour package, and the local operator determines the wholesale price and the carbon reduction level of the tour package at the same time.

The profit of the tour operator under NG is presented as follows:

$$\prod_T^{NG} = D_\sigma \sigma \quad (12)$$

The profit of the local operator under NG is given as follows:

$$\prod_L^{NG} = D_\sigma[w - c - t(e_I - e)] - me^2/2 \quad (13)$$

The Hessian matrix of Equation (13) can be presented as follows:

$$\begin{bmatrix} \partial^2 \prod_L^{NG} / \partial w^2 & \partial^2 \prod_L^{NG} / (\partial w \partial e) \\ \partial^2 \prod_L^{NG} / (\partial e \partial w) & \partial^2 \prod_L^{NG} / \partial e^2 \end{bmatrix} = \begin{bmatrix} -2 & b - t \\ b - t & 2bt - m \end{bmatrix}$$

It is easy to verify that the Hessian matrix is a negative definite. Moreover, the second-order of Equation (12) can be proposed as follows:  $\partial^2 \prod_T^{NG} / \partial \sigma^2 = -2 < 0$ .

Thus, when we set the first-order of Equations (12) and (13) equal to 0, we have the optimal decisions under NG as follows.

$$\begin{aligned} w^{NG*} &= \frac{m(1+2c+\lambda v_{WOM})-b^2c-(1+be_I+\lambda v_{WOM})t^2+t[2me_I-b^2e_I-(1+c+\lambda v_{WOM})b]}{3m-(b+t)^2}, \\ e^{NG*} &= \frac{(b+t)(1-c-te_I+\lambda v_{WOM})}{3m-(b+t)^2}; \sigma^{NG*} = \frac{m(1-c-e_I t+\lambda v_{WOM})}{3m-(b+t)^2}, \\ p^{NG*} &= \frac{m(2+c+2\lambda v_{WOM})-b^2c+t[me_I-b^2e_I-b(1+c+\lambda v_{WOM})]-(1+be_I+\lambda v_{WOM})t^2}{3m-(b+t)^2} \end{aligned}$$

## 5. Result Analysis

First, we analyze the monotonicity of some parameters on optimal decisions and profits.

**Proposition 1.** *The monotonicity of tourist's sensitivity to word-of-mouth on optimal decisions can be given as follows:*

- (a) If  $v_{WOM} \geq 0$ ,  $w^*$  increases with  $\lambda$ ; and if  $v_{WOM} < 0$ ,  $w^*$  decreases with  $\lambda$ ;
- (b) If  $v_{WOM} \geq 0$ ,  $e^*$  increases with  $\lambda$ ; and if  $v_{WOM} < 0$ ,  $e^*$  decreases with  $\lambda$ ;
- (c) If  $v_{WOM} \geq 0$ ,  $p^*$  increases with  $\lambda$ ; and if  $v_{WOM} < 0$ ,  $p^*$  decreases with  $\lambda$ .

Proposition 1 shows that, if the impact of word-of-mouth is positive, as tourist's sensitivity to word-of-mouth increases, the wholesale price, the retail price, and carbon reduction level of the tour package increase. If the impact of word-of-mouth is negative, as tourist's sensitivity to word-of-mouth increases, the wholesale price, the retail price, and the carbon reduction level of the tour package decrease.

In the case of a positive impact of word-of-mouth, as tourist's sensitivity to word-of-mouth increases, tourists' willingness to pay for tour packages has increased. Thus, the tour operator will improve its retail price to pursue more profit. Correspondingly, wholesale price will increase, which encourages the local operator to improve the carbon reduction level to match a relatively high sales price.

In the case of a negative impact of word-of-mouth, as tourist's sensitivity to word-of-mouth increases, tourists' willingness to pay for tour packages has decreased. The tour operator will reduce its retail price to attract tourists. Meanwhile, the local operator will reduce its wholesale price, and its carbon reduction level due to a negative word-of-mouth impact.

Proposition 1 implies that, in the case of a positive (negative) impact of word-of-mouth, as tourist's sensitivity to word-of-mouth increases, the local operator should improve (reduce) its wholesale price and carbon reduction level while the tour operator should improve (reduce) its retail price. Proposition 1 also means that the impacts of tourist's sensitivity to word-of-mouth on optimal decisions in the tourism supply chain depends on the positive or negative impact of word-of-mouth.

**Proposition 2.** *The monotonicity of tourist's sensitivity to word-of-mouth on optimal demand and profits can be given as follows.*

- (a) If  $v_{WOM} \geq 0$ ,  $D^*$  increases with  $\lambda$ ; otherwise,  $D^*$  decreases with  $\lambda$ ;

- (b) If  $v_{WOM} \geq 0$ ,  $\Pi_L^*$  increases with  $\lambda$ ; otherwise,  $\Pi_L^*$  decreases with  $\lambda$ ;  
 (c) If  $v_{WOM} \geq 0$ ,  $\Pi_T^*$  increases with  $\lambda$ ; otherwise,  $\Pi_T^*$  decreases with  $\lambda$ ;

Proposition 2a shows that the optimal demand increases (decreases) with the tourist's sensitivity to word-of-mouth if the impact of word-of-mouth is positive (negative). In the case of a positive impact of word-of-mouth, as tourist's sensitivity to word-of-mouth increases, though the retail price will increase, the carbon reduction level will increase and the consumer will obtain more utility from word-of-mouth, which will increase the demand. In the case of a negative impact of word-of-mouth, as tourist's sensitivity to word-of-mouth increases, though the retail price will decrease, the carbon reduction level will decrease and the consumer will undertake utility loss from word-of-mouth, which will reduce the demand.

Proposition 2b,c show that, if the impact of word-of-mouth is positive, as tourist's sensitivity to word-of-mouth increases, both the local operator and the tour operator will obtain more profit. Otherwise, as tourist's sensitivity to word-of-mouth increases, both the local operator and the tour operator will suffer losses. In the case of a positive (negative) impact of word-of-mouth, as tourist's sensitivity to word-of-mouth increases, the retail price and the demand increase (decrease), which benefit (hurt) the tour operator. Moreover, the increased (decreased) wholesale price and the demand benefit (hurt) the local operator.

Proposition 2 implies that, in the case of a positive (negative) impact of word-of-mouth, tourist's sensitivity to word-of-mouth has a positive (negative) effect on the optimal demand and the optimal profits of the local operator and the tour operator. Proposition 2 also means that a relatively high tourist's sensitivity to word-of-mouth may reduce the demands and hurt the members in the tourism supply chain.

**Proposition 3.** The monotonicity of tourist's sensitivity to word-of-mouth on optimal decisions, demand, and profits are given as follows:

- (a)  $w^*$ ,  $e^*$ , and  $p^*$  increase with  $v_{WOM}$ ;  
 (b)  $D^*$  increases with  $v_{WOM}$ ;  
 (c)  $\Pi_L^*$  and  $\Pi_T^*$  increases with  $v_{WOM}$ .

Proposition 3a shows that the optimal decisions increase with the impact of word-of-mouth. As the impact of word-of-mouth increases, tourists' utilities increase. Thus, the local operator will improve the wholesale price and carbon reduction level and the tour operator will improve the retail price.

Proposition 3b shows that the optimal demand increases with the impact of word-of-mouth. As the impact of word-of-mouth increases, the retail price and carbon reduction level increase, while increased retail price will reduce tourists' utilities. The increased carbon reduction level and the impact of word-of mouth will improve tourists' utilities. The increased utility is larger than the decreased utility, which contributes an increased demand.

Proposition 3c shows that the optimal profits increase with the impact of word-of-mouth. Given that the optimal retail price and demand increase with the impact of word-of-mouth, the tour operator in this context can obtain more profit. Although an increased carbon reduction level brings more cost, the local operator can obtain more profit from the increased wholesale price and demand.

Proposition 3 implies that the impact of word-of-mouth has a positive impact on optimal decisions, demand, and profits. Specifically, as the impact of word-of-mouth increases, the local operator should improve its wholesale price and reduction level and the tour operator should improve the retail price.

Secondly, we analyze the impact of market structures on the optimal decisions.

**Theorem 1.** The impact of different market structures on the optimal decisions can be given as follows.

- (a)  $w^{TL*} < w^{NG*} < w^{LL*}$ ;

- (b)  $e^{LL*} < e^{TL*} < e^{NG*}$ ;  
 (c)  $p^{NG*} < p^{TL*} < p^{LL*}$ .

Theorem 1a shows that the optimal wholesale price under LL is the largest, the optimal wholesale price under NG is medium, and the optimal wholesale price under TL is the lowest. Under LL, the local operator is the leader. Thus, the local operator will improve wholesale price to earn more profit. Under TL, the tour operator is the leader. Thus, the tour operator is reluctant to the local operator to set a relatively high wholesale price.

Theorem 2b shows that the optimal carbon reduction level under NG is the largest, the optimal carbon reduction level under TL is medium, and the optimal carbon reduction level under LL is the lowest. Under LL, the local operator as the leader is reluctant to undertake more of a carbon reduction cost. Thus, the local operator has no incentive to improve the carbon reduction level. Under TL, the tour local wishes that the local operator could improve the carbon reduction level to attract more tourists. Under NG, given that the local operator and the tour operator have a similar bargaining power, the local operator has the incentive to improve the carbon reduction level.

Theorem 1c shows that the optimal retail price under LL is the largest, the optimal retail price under TL is medium, and the optimal retail price under NG is the lowest. Under LL, given that the wholesale price is the largest, the tour operator will set the highest retail price. Under TL, the tour operator as the leader wants to earn more profit by setting a relatively high retail price.

Theorem 1 implies that the local operator as the leader should set the largest wholesale price and the lowest carbon reduction level. In addition, the tour operator as the leader should set a medium retail price. Interestingly, Theorem 1 also implies that the carbon reduction level under NG is the largest while the local operator as the leader will set the lowest carbon reduction level, and the tour operator as the follower will set the largest retail price.

**Theorem 2.** *The impact of different market structures on the optimal demands can be given as follows:  $D^{LL*} < D^{TL*} < D^{NG*}$ .*

Theorem 2 shows that the optimal demand under NG is the largest, the optimal demand under TL is medium, and the optimal demand under LL is the lowest. From Theorem 1, we find that the carbon reduction level under NG is the largest and the retail price under NG is the lowest, which contributes to the largest demand. The carbon reduction level under LL is the lowest and the retail price under LL is the largest, which causes the lowest demand.

Theorem 2 implies that the optimal demand is the largest when the local operator and the local operator has similar bargaining power while it is the lowest when the local operator dominates the market. Theorem 2 also means that the Stackelberg game compared with the Nash game in the tourism supply chain may lead to a relatively low demand.

**Theorem 3.** *The impact of different market structures on the optimal total carbon emission can be presented as follows:  $E^{LL*} < E^{TL*} < E^{NG*}$ .*

Theorem 3 shows that the optimal total carbon emission under NG is the largest, the optimal total carbon emission under TL is medium, and the optimal total carbon emission under LL is the lowest. Under NG, although the carbon reduction level is the largest, the demand is also the largest, and the carbon increment from the increased demand is larger than the carbon decrement from the increased carbon reduction level. Under LL, although the carbon reduction level is the lowest, the demand is also the lowest, and the carbon increment from a decreased carbon reduction level is less than the carbon decrement from a decreased demand.

Combined with Theorem 1, Theorem 3 implies that the NG market structure contributes the most environmentally-friendly product, but, overall, mostly harms the environment. The LL market structure leads to the least environmentally-friendly product, but, overall, is the most environmentally-friendly. As such, the case of the local operator as the leader in the tourism supply chain is most conducive to the environment.

**Theorem 4.** *The impact of different market structures on the optimal profits can be presented as follows.*

- (a)  $\Pi_L^{TL*} < \Pi_L^{NG*} < \Pi_L^{LL*}$ ;
- (b)  $\Pi_T^{LL*} < \Pi_T^{NG*} < \Pi_T^{TL*}$ .

Theorem 4a shows that the profit of the local operator under LL is the largest, the profit of the local operator under NG is medium, and the profit of the local operator under TL is the lowest. Under LL, the local operator is the leader. When compared with the tour operator, the local operator has more bargaining power, which contributes the largest profit. Under TL, the tour operator is the leader, and the local operator has less bargaining power, which causes the lowest profit.

Theorem 4b shows that the profit of the tour operator under TL is the largest, the profit of the local operator under NG is medium, and the profit of the tour operator under LL is the lowest. Under TL, the tour operator as the leader has more bargaining power, which contributes the largest profit. Under LL, the tour operator as the follower has less bargaining power, which causes the lowest profit.

Theorem 4 shows that, in different market structures, the leader obtains the largest profit while the follower obtains the lowest profit.

**Theorem 5.** *The size relationship between the local operator and the tour operator can be given as follows.*

- (a) Under Model LL, we have  $\Pi_L^{LL*} > \Pi_T^{LL*}$ ;
- (b) Under Model TL, we have  $\Pi_L^{LL*} < \Pi_T^{LL*}$ ;
- (c) Under Model NG, we have  $\Pi_L^{LL*} < \Pi_T^{LL*}$ .

Theorem 5 shows that the local operator can obtain a higher profit than the tour operator under LL while the tour operator can obtain a higher profit than the local operator under NG and TL. Under LL, the local operator as the leader can pursue more profit by setting a relatively large wholesale price, which reduces the profit of the tour operator. Under NG and TL, the tour operator can obtain more profit than the local operator, which is vital because the tour operator does not need to undertake the carbon reduction cost and the local operator does not have bargaining power.

Theorem 5 shows that the local operator can get more profit than the tour operator only when the local operator has more bargaining power. Otherwise, the tour operator can obtain more profit.

## 6. Conclusions

In the context of a green economy and word-of-mouth, local operators and tour operators face the challenges of determining optimal carbon reduction level, wholesale price, and retail price strategies of tour packages. To address these challenges, we consider a local operator and a tour operator. When considering the impact of word-of-mouth, we explore optimal decisions of the local operator and the tour operator under different market structures. The different market structures are divided according to different bargaining power, i.e., the local operator has more bargaining power (LL), the tour operator has more bargaining power (TL), or the local operator and the tour operator have similar bargaining powers (NG). We develop three theoretical models, and refine some insights.

The impacts of word-of-mouth are presented as follows. (i) As the impact of word-of-mouth increases, the local operator should improve wholesale price and reduction level and the tour operator should improve retail price, which benefits both of them. (ii) In the case of a positive (negative) impact of word-of-mouth, the local operator should improve (reduce) wholesale price and carbon reduction level and the tour operator should improve (reduce) retail price as tourist's sensitivity to word-of-mouth increases. (iii) Tourist's sensitivity to word-of-mouth has positive (negative) effects on the optimal demand and the optimal profits of the local operator and the tour operator in the case of a positive (negative) impact on word-of-mouth.

The impacts of market structures on optimal decisions are given as follows: (i) under LL, the local operator should set the largest wholesale price and a lowest carbon reduction level while the tour operator should set the largest retail price. (ii) Under TL, the local operator should set the lowest wholesale price and a medium carbon reduction level while the tour operator should set a medium retail price. (iii) Under NG, the local operator should set a medium wholesale price and the highest carbon reduction level while the tour operator should set the lowest retail price.

The impacts of market structures on optimal demand and total carbon emission are given as follows: (i) LL market structure causes the lowest demand and total carbon emission in the case of the local operator as the leader in the tourism supply chain that is most beneficial to the environment. (ii) TL market structure leads to a medium demand and total carbon emission. (iii) NG contributes the largest demand and total carbon emission. Essentially, NG contributes the most environmentally-friendly product but greatest harm to the environment.

In order to explore optimal decisions in the tourism supply chain in the carbon tax and word-of-mouth contexts, our paper develops three theoretical models according to market bargaining power. The theoretical frameworks are given as follows. Consumers' utilities for purchasing tour packages are described through a literature review and questionnaire surveys, and the cost structures of members in the tourism supply chain are explored through the method of enterprise research. The theoretical models are developed and solved by some methods such as the Nash game, the Stackelberg game, and the optimization theory. The main insights of paper can guide members in the tourism supply chain to determine optimal decisions in the carbon tax and word-of-mouth contexts.

The impacts of market structures on profits and the size between profits of the two members are given as follows. (i) Under LL, the local operator obtains the largest profit while the tour operator obtains the lowest profit. (ii) Under NG, both the local operator and the tour operator obtain medium profits. (iii) Under TL, the local operator obtains the lowest profit while the tour operator obtains the largest profit. (iv) The local operator can obtain more profit than the tour operator only when the local operator has more bargaining power.

There is still more space needed for future research. First, there is information symmetric between the local operator and the tour operator. It is worth studying optimal decisions in the tourism supply chain when considering information asymmetric. Secondly, our paper only considers one local operator and one tour operator. The competitions between multiple local operators and tour operators can be researched in the future. Third, considering that O2O and Omnichannel modes in reality are more prevalent, it will be interesting to explore the impact of word-of-mouth on operations of members in the tourism supply chain in these contexts. Fourth, besides a carbon tax policy, some countries implement a carbon cap-and-trade policy. Thus, how members in the tourism supply chain should make decisions in the cap-and-trade and word-of-mouth is worth studying. At last, our paper studies one-period decision-making strategies. Thus, two periods or multi-periods can be taken into consideration.

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analysis for the main results. J.W. revised the written draft and provided theoretical and technical guidance for this paper. All authors have read and agreed to the published version of the manuscript.

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