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Assessing the performance of tourism supply chains by using the hybrid network data envelopment analysis model

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HIGHLIGHTS

- Proposing the hybrid network DEA model, which evaluates the overall and divisional efficiency in a single DEA implementation.
- Variable and semifixed inputs are respectively measured using radial and nonradial assumptions in mathematical plan programming.
- Providing an integrated efficiency index to measure the overall efficiency of a tourism supply chain.
- Providing the measurement that reveals inefficiency sources by resolving the slacks and radial ratios.

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ABSTRACT

Although the importance of cooperation and coordination in tourism supply chains has been emphasized in previous research, studies continue to focus purely on the performance of a particular division within a given tourism supply chain. The primary aim of this study was to establish a hybrid network data envelopment analysis (DEA) model for measuring integrated and divisional performance within the supply chain. The main factor distinguishing the DEA model from previous network models is the assumption of input types; variable and semifixed inputs are respectively measured using radial and nonradial assumptions in mathematical plan programming. Another significant difference between the hybrid network DEA model and previous supply chain efficiency models is that the hybrid model contains a measurement defining the overall efficiency of tourism supply chains. To test the proposed model, the performance of the tourism supply chain across 30 regions in China was evaluated. The empirical results provide several practical insights for tourism supply chain management.

1. Introduction

In competitive market environments, network cooperation between manufacturers and service providers characterizes an advantageous partnership that can increase revenues while reducing costs (Ferguson, 2000). Supply chains represent a network structure that includes suppliers, producers, and distributors. Raw materials can be processed into final goods and services and be delivered to customers through supply chain processing (Tavana, Mirzagoltabar, Mirhedayatian, Saen, & Azadi, 2013). According to Bowersox, Closs, and Helferich (1996), supply chain management includes all activities involving the transformation and flow of goods and services. Attendant information flows from sources of materials to end users are also considered in supply chain processing. Creating seamless coordination across the functions of sourcing, production, and distribution is the primary objective of supply chain management (Li, Rao, Ragu-Nathan, & Ragu-Nathan, 2005). Moreover, supply chain processing also generates various advantages in the manufacturing industry, such as reduced cycle times, inventory costs, and logistics costs (Prasad & Selven, 2010).

The main components of a tourism supply chain are products, distributors, and resources. Examples include accommodation, which is a primary tourism service product, and travel agencies, which can be regarded as a mode of delivery or distributor of a service product (Huang, Song, & Zhang, 2010; Sigala, 2008; Yilmaz & Bititci, 2006). Tourism education, which can be regarded as a producer (or supplier) of a trained workforce (Chang, Chung, & Hsu, 2012), is an example of a resource in the supply chain. Regarding the performance of tourism supply chains, Page (2011) stated that tourist destinations, as the final component in the supply chain, are the most representative indicator of the effectiveness of tourism service flow.

Tourism supply chain management can be defined as a set of

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approaches used to more efficiently manage the operators in a chain to ensure that they meet tourist needs (Zhang, Song, & Huang, 2009). The primary concern in tourism supply chain management pertains not only to the performance of individual sections but also that of the integrated system of tourism operators (Ţigu and Calareţu, 2013). The importance of integration between different components in a tourism supply chain has been discussed in many studies (e.g., Guo, Ling, Dong, & Liang, 2013; Huang et al., 2010; Yang, Huang, Song, & Liang, 2009; Zhang et al., 2009). Enterprises could cooperate or coordinate in information sharing, marketing, decision synchronization, and incentive alignment to enhance the overall competitiveness of each component in the supply chain (Sigala, 2008). Most findings indicate that the effective integration of components in a tourism supply chain can benefit the tourism industry as a whole by lowering costs, and it can enhance tourism sustainability (Carey, Gountas, & Gilbert, 1997; Hilletofth, 2011; Theuvsen, 2004; Tseng, Chiu, & Vo, 2011; Zhang & Murphy, 2009). Furthermore, appropriate integration in tourism supply chains is advantageous for promoting innovations in business reconstruction, strategic union, and value-added services (Chen, 2009).

Despite emphasis on the importance of cooperation and coordination in tourism supply chains, studies remain mainly focused on the performance of a particular division within tourism supply chains, such as tourist hotels (Assaf, 2012; Huang, Ting, Lin, & Lin, 2013; Ting & Huang, 2012), travel agencies (Assaf, 2012; Fuentes, 2011; Koksal & Aksu, 2007; Qi & Junhai, 2011), and tourist destination efficiency (Perez, Guerrero, González, Pérez, & Caballero, 2013; Tsionas & Assaf, 2014; Wu, Lan, & Lee, 2012). Shafiee, Lotfi, and Saleh (2014) suggested that an integral indicator, which is used to measure the overall performance, should consider all components of a tourism supply chain, but studies assessing the efficiency of the entire frame of tourism supply chains remain scant. Because integration is vital to tourism supply chain management, providing a measure for assessing overall performance should be considered imperative.

The main aim of this study was to develop a hybrid network data envelopment analysis (DEA) model for measuring the integrated and divisional performance of tourism supply chains. The main difference between previous network models and the present model is the assumptions of input types; variable and semifixed inputs are respectively measured using radial and nonradial assumptions in mathematical plan programming. In previous network DEA models, many studies (e.g., Huang, Ho, & Chiu, 2014; Kao & Hwang, 2008; Kwon & Lee, 2015; Ma, 2015; Yu & Lin, 2008) have assumed all inputs and outputs as radial factors, which can change proportionally. Other studies (e.g., Liu, Zhou, Ma, Liu, & Shen, 2015; Tone & Tsutsui, 2009; Wang, Huang, Wu, & Liu, 2014; Yu, 2010) have assumed inputs and outputs to be entirely nonradial factors, which can change nonproportionally. However, conventional network DEA models do not consider the difference of changeability between variable and semifixed factors. Few researchers have attempted to incorporate this difference into DEA models and apply a mixed approach involving radial and nonradial (i.e., hybrid measure) factors. For instance, automatic banking facilities and marketing inputs have been defined as nonradial inputs by Huang, Chiu, Lin, and Liu (2012) and Huang, Chiu, Ting, and Lin (2012). In the present study, we also adopted the mixed approach and developed a hybrid network DEA, in which variable inputs, such as labor, which can be rapidly changed with variations in scale, are assumed to be radial factors; and semifixed inputs, such as assets, which cannot be adjusted rapidly or do not need to change proportionally with variation in scale, can be considered nonradial factors.

The other notable difference between the hybrid network DEA model and previous supply chain efficiency models is the measurement that defines the overall efficiency of a tourism supply chain. Various calculation approaches are reported in the literature as to how this measurement can be calculated. For instance, overall efficiency has been calculated by summing the scores of divisional efficiency (Azadi, Jafarian, Saen, & Mirhedayatian, 2015), averaging the scores of divisional efficiency (Khodakarami, Shabani, Saen, & Azadi, 2015; Saranga & Moser, 2010), or by using a convex linear combination of divisional efficiencies to define the overall efficiency (Cook, Zhu, Bi, & Yang, 2010; Shafiee et al., 2014). However, because the aforementioned modes have computed overall efficiency mostly by using a sum or weighted average rather than structuring an index for all excess input utilizations and all output deficits in every division, the sum of divisional scores cannot represent the overall efficiency though a ratio. Furthermore, using weighted averages is liable to have inconsistent benchmarking targets because of multiple independent DEA implementations (Chiu & Huang, 2011; Huang, Chiu, Fang, & Shen, 2014). Chen and Yan (2011) developed a supply chain efficiency model that measures overall efficiency as a ratio through a single DEA process, but their approach does not specifically measure the efficiency of individual divisions The model developed in the current study simultaneously evaluates the overall and divisional efficiency in a single DEA implementation, and the efficiency scores are calculated on the basis of the slacks of nonradial variables and the radial ratios of benchmarks to actual values. Furthermore, the efficiency measurement can reveal inefficiency sources by resolving the slacks and radial ratios.

The remaining sections are organized as follows: Section 2 reviews the literature on tourism supply chains, and Section 3 describes the hybrid network DEA model. Empirical results are reported in Section 4, and the conclusions of the present study and recommendations for future research are given in Section 5.

2. Literature

Tourism supply chain management is a developing academic topic in the tourism industry, primarily because of the rising popularity of package tours and trends in globalized tourism. The components of a typical package tour are transportation, accommodation, dining, and tourist attractions. Furthermore, a package tour involves various service providers including hoteliers, travel agencies, transportation companies, and restaurants. Therefore, coordination and cooperation between tourism service providers within the supply chain is a crucial element in creating a seamless experience (Lambert & Cooper, 2000). Effective supply chain management is a strategic area of focus for deriving and enhancing competitive advantages (Zhang et al., 2009). For the firms in a supply chain, collaboration between service suppliers and product channels is essential for reducing marketing costs and increasing sales (Huang et al., 2010).

Researchers have mostly focused on defining the structure of tourism supply chains, defining them as including accommodation suppliers, tour operators, travel agencies, and customers (Kaukal, Hopken, & Werthner, 2000); theme parks, accommodation providers, and tour operators (Huang et al., 2010); goods and service suppliers and delivery firms (Tapper & Font, 2004); and food and lodging suppliers, tour operators, and travel agencies that specialize in the resale of package tours (Ţigu and Calareţu, 2013).

Research investigating supply chain performance in the tourism industry is limited. In assessing the performance of supply chain operations, most related studies have observed manufacturers such as petrochemical firms (Azadi et al., 2015); automobile, energy, high-tech, and construction companies (Saranga & Moser, 2010); food manufacturers (Shafiee et al., 2014); the semiconductor manufacturers (Tavana et al., 2013); and chemical firms (Khodakarami et al., 2015); and studies have established new efficiency measures for investigating the performance of manufacturers in supply chains (Chen & Yan, 2011; Cook et al., 2010; Halkos, Tzeremes, & Kourtzidis, 2014). However, tourism businesses are inherently different from industries that produce physical goods. By contrast, consumers of tourism services often belong to a mobile population who visit destinations to consume services and experiences, whereas a typical service supplier is geographically confined (Lee & Fernando, 2015). Furthermore, McLachlan, Clark, and Monday (2002) considered that tourism service products have certain properties (e.g., intangibility, heterogeneity, nonstorability, and nontransferability) that differ from those of conventional physical products.

Despite the main focus on manufacturers, some studies have investigated various aspects of tourism supply chain management, such as government concerns regarding unethical practices (Keating, 2009), collaboration between marketing and tourism supply chains (Guo et al., 2013; Tseng et al., 2011), models for estimating outcomes in a medical tourism supply chain (Lee & Fernando, 2015), and the influences of tour operators (Sigala, 2008). Lu (2006) constructed an alternative supply chain pattern in which destinations (instead of travel agencies) were considered the core of the chain. Font, Tapper, Schwartz, and Kornilaki (2008) discussed tourism supply chain sustainability in the implementation of policies.

Issues involving the performance of tourism supply chains are also discussed in the literature. To enable more efficient processes, Alford (2005) proposed a framework on the basis of information and communication technology to evaluate business process costs in a tourism industry supply chain. Guo and He (2012) developed a game model to evaluate the performance of cooperation between tourist hotels and travel agencies and found that hotel revenues were increased by adopting a tour package model. Harewood (2008) used a bid price control method to investigate improvements of the hotel and retailer of tourism services in their revenues. Zhang and Murphy (2009) analyzed the effect of strategic inconsistency between travel agencies and destinations and further suggested reforming travel agencies' reward system. Yang et al. (2009) investigated the performance of cooperation and competition in a tourism supply chain and found that destinations would benefit from integration with accommodation providers. Guo et al. (2013) focused on determining the optimal pricing strategy for tourist hotels to cooperate with online distribution channels.

In summary, most previous studies have used costs or revenues as indicators for evaluating the performance of firms in tourism supply chains. Although subjects relevant to tourism supply chain performance are addressed in literature, studies proposing approaches for measuring the divisional and overall efficiency of tourism supply chains remain rare in the field.

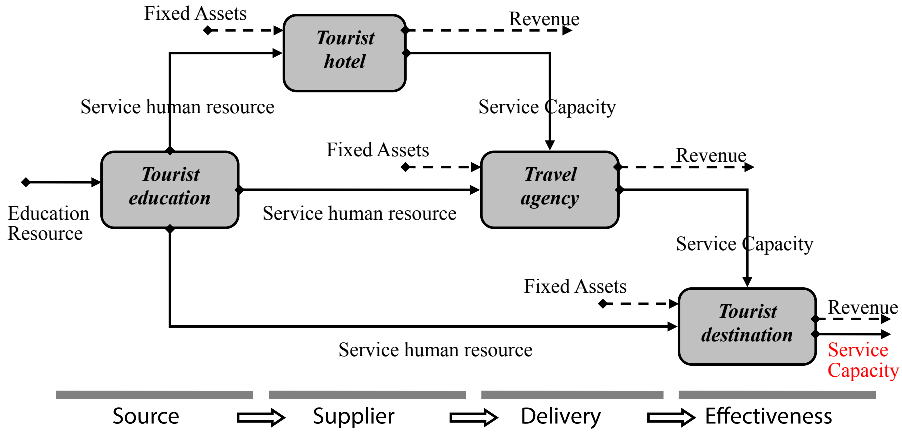
3. Empirical methodology

Since Charnes, Cooper, and Rhodes (1978) and Banker, Charnes, and Cooper (1984) proposed the DEA model, the efficiency measurement approach has been extensively developed in subsequent research. Researchers have established a network framework for the DEA model in order to evaluate multiple performance indicators (Chen & Zhu, 2004; Kao & Hwang, 2008; Seiford & Zhu, 1999). Other researches have subsequently modified the network DEA model and applied it to evaluate various businesses (Hsieh & Lin, 2010; Huang, Ho et al., 2014; Wang, Lu, Huang, & Lee, 2013; Yu, 2010). Tone and Tsutsui (2014) further extended the network DEA model as a dynamic efficiency measure. Previous network DEA models can be categorized as radial measures (e.g., Huang, Ho et al., 2014; Kwon & Lee, 2015; Ma, 2015; Yu & Lin, 2008) and nonradial measures (e.g., Liu et al., 2015; Tone & Tsutsui, 2009; Wang et al., 2014).

Radial measures assume that factors are subject to proportional change, whereas nonradial measures assume that factors nonproportional change. The present study combined the two types of measure to develop a hybrid network DEA model. Referring to the assumptions regarding the tourism supply chain models made in previous studies (e.g., Huang et al., 2010; Sigala, 2008; Zhang et al., 2009; Ţigu and Calareţu, 2013), the proposed hybrid network DEA model defines the tourism supply chain to consist of multiple stages: sourcing, supply, delivery, and efficiency. The framework of this supply chain is illustrated in Fig. 1. The sourcing stage represents the education of human resources for tourism services. Resources involving tourism education are defined as inputs, and trained workers are the outputs. The supply stage is operated by tourist hotels, which are assumed to be the supplier within the chain. For this stage, labor and fixed assets are defined as inputs, and revenue and service capacity are defined as outputs. The delivery stage refers to the delivery of tourism services and is represented by the travel agency. The inputs for this stage include labor, fixed assets, and service capacity (generated from the tourist hotels), and the outputs include revenues and the number of received travelers. The efficiency stage is represented by the performance of tourist destinations. For this stage, the number of travelers and scenic spots are defined as inputs, and tourist income from a region is defined as the final output.

According to the proposed structure, an empirical methodology can be established. Suppose the data set is an N-dimensional decision making unit (DMU) set. Each unit is denoted as DMU_n, $n = 1, \cdots, N$. The particular DMU under evaluation is represented as DMU_O, which is subject to $DMU_O \in N$. In the tourism education division, the inputs consist of radial and nonradial parts, which are labeled $x_{b_1}^{E(R)} \in R_+^{B_1}$ and $x_{b_2}^{E(NR)} \in R_+^{B_2}$, respectively, and subject to $B = B_1 + B_2$. The intermediates are defined as radial factors and are classified into three types. The factor $z_{c_1}^{E(R)(H)} \in R_+^{C_1}$ is used as the input for the tourist hotel division, $z_{c_2}^{E(R)(A)} \in R_+^{C_2}$ is used as the input for the travel agency, and $z_{c_3}^{E(R)(D)} \in R_+^{C_3}$ is used as the input for the tourist destination. To solve the linear programming problem in the DEA, the model assumes an unknown intensity variable, λ_n^E ($n = 1, \cdots, N$), which acts as a benchmark for DMU_O by taking the weight of the reference units. The technology set of the division of tourism education can be expressed as follows:

$$
\begin{aligned}
T^E\Bigg\{ & \left(x^{E(\bullet)}, z^{E(\bullet)}\right) : \sum_{n=1}^{N} \lambda_n^E x_{b_1 n}^{E(R)} \le x_{b_1}^{E(R)} (\forall b_1), \sum_{n=1}^{N} \lambda_n^E x_{b_2 n}^{E(NR)} \le x_{b_2}^{E(NR)} (\forall b_2), \\
& \sum_{n=1}^{N} \lambda_n^E z_{c_1 n}^{E(R)(H)} \ge z_{c_1}^{E(R)(H)} (\forall c_1), \sum_{n=1}^{N} \lambda_n^E z_{c_2 n}^{E(R)(A)} \ge z_{c_2}^{E(R)(A)} (\forall c_2), \\
& \sum_{n=1}^{N} \lambda_n^E z_{c_3 n}^{E(R)(D)} \ge z_{c_3}^{E(R)(D)} (\forall c_3), \sum_{n=1}^{N} \lambda_n^E = 1, \lambda_n^E \ge 0 (\forall n).
\end{aligned}
\tag{1}
$$



Note: solid line means the flow of tourist services; dotted line means the flow of associated factors.

Fig. 1. Framework of tourism service supply chain.

For the hybrid measurement, we define the slack variable, $s_{b_2}^{E-}(b_2 = 1, \cdots, B_2)$, for the excess input utilization in the nonradial measurements. The technology set can be rewritten as follows:

$$T^E\left\{\left(x^{E(\bullet)}, z^{E(\bullet)}\right) : \sum_{n=1}^{N} \lambda_n^E x_{b_1 n}^{E(R)} \le x_{b_1}^{E(R)} (\forall b_1), \sum_{n=1}^{N} \lambda_n^E x_{b_2 n}^{E(NR)} = x_{b_2}^{E(NR)} - s_{b_2}^{E-} (\forall b_2), \right.$$
$$\sum_{n=1}^{N} \lambda_n^E z_{c_1 n}^{E(R)(H)} \ge z_{c_1}^{E(R)(H)} (\forall c_1), \sum_{n=1}^{N} \lambda_n^E z_{c_2 n}^{E(R)(A)} \ge z_{c_2}^{E(R)(A)} (\forall c_2),$$
$$\sum_{n=1}^{N} \lambda_n^E z_{c_3 n}^{E(R)(D)} \ge z_{c_3}^{E(R)(D)} (\forall c_3),$$
$$\left. \sum_{n=1}^{N} \lambda_n^E = 1, s_{b_2}^{E-} \ge 0, \lambda_n^E \ge 0 (\forall n) \right\} \tag{2}$$

We define the slack variable, $s_g^{H-}(g = 1, \cdots, G)$, for the nonradial factors. The technology set can be rewritten as follows:

$$T^H\left\{\left(x^{H(\bullet)}, z^{E(\bullet)}, z^{H(\bullet)}, y^{H(\bullet)}\right) : \sum_{n=1}^{N} \lambda_n^H z_{c_1 n}^{E(R)(H)} \le z_{c_1}^{E(R)(H)} (\forall c_1), \right.$$
$$\sum_{n=1}^{N} \lambda_n^H x_{gn}^{H(NR)} = x_g^{H(NR)} - s_g^{H-} (\forall g),$$
$$\sum_{n=1}^{N} \lambda_n^H z_{i_1 n}^{H(R)} \ge z_{i_1}^{H(R)} (\forall i_1), \sum_{n=1}^{N} \lambda_n^H y_{i_2 n}^{H(R)} \ge y_{i_2}^{H(R)} (\forall i_2),$$
$$\left. s_g^{H-} \ge 0 \sum_{n=1}^{N} \lambda_n^H = 1, \lambda_n^H \ge 0, (\forall n). \right\} \tag{4}$$

In the second part, the model assumes the nonradial input, $x_g^{H(NR)} \in R_+^G$, for the tourist hotel division in addition to the radial factor, $z_{c_1}^{E(R)(H)}$, generated from the tourism education division. The intermediate factor, which is generated from the tourist hotel division and is used as an input for the travel agency division, is assumed to be a radial factor and is labeled $z_{i_1}^{H(R)} \in R_+^{I_1}$. The output is defined as a radial factor, $y_{i_2}^{H(R)} \in R_+^{I_2}$. An unknown intensity variable, λ_n^H $(n = 1, \cdots, N)$, is also defined. Thus, the technology set of the division of tourist hotel can be described as follows:

$$T^H\left\{\left(x^{H(\bullet)}, z^{E(\bullet)}, z^{H(\bullet)}, y^{H(\bullet)}\right) : \sum_{n=1}^{N} \lambda_n^H z_{c_1 n}^{E(R)(H)} \le z_{c_1}^{E(R)(H)} (\forall c_1), \right.$$
$$\sum_{n=1}^{N} \lambda_n^H x_{gn}^{H(NR)} \le x_g^{H(NR)} (\forall g),$$
$$\sum_{n=1}^{N} \lambda_n^H z_{i_1 n}^{H(R)} \ge z_{i_1}^{H(R)} (\forall i_1), \sum_{n=1}^{N} \lambda_n^H y_{i_2 n}^{H(R)} \ge y_{i_2}^{H(R)} (\forall i_2),$$
$$\left. \sum_{n=1}^{N} \lambda_n^H = 1, \lambda_n^H \ge 0, (\forall n) \right. \tag{3}$$

In the travel agency division, two intermediates, $z_{c_2}^{E(R)(A)}$ and $z_{i_1}^{H(R)}$, are generated from the tourism education and tourist hotel divisions, respectively. We also define the nonradial input, $x_k^{A(NR)} \in R_+^K$. The intermediate factor, which is generated from the travel agency division and used as an input for the tourist destination, is assumed to be a radial factor and is labeled $z_{l_1}^{A(R)} \in R_+^{L_1}$. The output is defined as a radial factor and is labeled $y_{l_2}^{A(R)} \in R_+^{L_2}$. An unknown intensity variable, $\lambda_n^A(n = 1, \cdots, N)$, is also defined. Thus, the technology set of the division of travel agency can be described as follows:

$$T^A\left\{\left(x^{A(\bullet)}, z^{E(\bullet)}, z^{H(\bullet)}, z^{A(\bullet)}, y^{A(\bullet)}\right) : \sum_{n=1}^{N} \lambda_n^A z_{i_1 n}^{H(R)} \le z_{i_1}^{H(R)} (\forall i_1), \right.$$
$$\sum_{n=1}^{N} \lambda_n^A z_{c_2 n}^{E(R)(A)} \le z_{c_2}^{E(R)(A)} (\forall c_2), \sum_{n=1}^{N} \lambda_n^A x_{kn}^{A(NR)} \le x_k^{A(NR)} (\forall k),$$
$$\sum_{n=1}^{N} \lambda_n^A z_{l_1 n}^{A(R)} \ge z_{l_1}^{A(R)} (\forall l_1), \sum_{n=1}^{N} \lambda_n^A y_{l_2 n}^{A(R)} \ge y_{l_2}^{A(R)} (\forall l_2)$$
$$\sum_{n=1}^{N} \lambda_n^A = 1, \lambda_n^A \ge 0 (\forall n). \tag{5}$$

We define the slack variable, $s_k^{A-} (k = 1, \cdots, K)$, for the nonradial variables. Thus, the technology set can be rewritten as follows:

$$T^A\left\{\left(x^{A(\bullet)}, z^{E(\bullet)}, z^{H(\bullet)}, z^{A(\bullet)}, y^{A(\bullet)}\right) : \sum_{n=1}^{N} \lambda_n^A z_{i_1 n}^{H(R)} \le z_{i_1}^{H(R)} (\forall i_1), \right.$$
$$\sum_{n=1}^{N} \lambda_n^A z_{c_2 n}^{E(R)(A)} \le z_{c_2}^{E(R)(A)} (\forall c_2),$$
$$\sum_{n=1}^{N} \lambda_n^A x_{kn}^{A(NR)} = x_k^{A(NR)} - s_k^{A-} (\forall k), \sum_{n=1}^{N} \lambda_n^A z_{l_1 n}^{A(R)} \ge z_{l_1}^{A(R)} (\forall l_1),$$
$$\sum_{n=1}^{N} \lambda_n^A y_{l_2 n}^{A(R)} \ge y_{l_2}^{A(R)} (\forall l_2),$$
$$\left. s_k^{A-} \ge 0, \sum_{n=1}^{N} \lambda_n^A = 1, \lambda_n^A \ge 0 (\forall n) \right\}. \tag{6}$$

In the tourist destination division, the two intermediates, $z_{c_3}^{E(R)(D)}$ and $z_{l_1}^{A(R)}$, are generated from the education and travel agency divisions, respectively. We also define the nonradial input, which is labeled $x_p^{D(NR)} \in R_+^P$. The final output is defined as a radial factor and is labeled $y_q^{D(R)} \in R_+^Q$. An unknown intensity variable, λ_n^D $(n = 1, \cdots, N)$, is also defined. Thus, the technology set of the division of tourism destination can be expressed as follows:

$$T^D\left\{\left(x^{D(\bullet)}, z^{E(\bullet)}, z^{A(\bullet)}, y^{D(\bullet)}\right) : \sum_{n=1}^{N} \lambda_n^D z_{l_1 n}^{A(R)} \le z_{l_1}^{A(R)} (\forall l_1), \right.$$
$$\sum_{n=1}^{N} \lambda_n^D z_{c_3 n}^{E(R)(D)} \le z_{c_3}^{E(R)(D)} (\forall c_3), \tag{7}$$
$$\sum_{n=1}^{N} \lambda_n^D x_{pn}^{D(NR)} \le x_p^{D(NR)} (\forall p), \cdots \sum_{n=1}^{N} \lambda_n^D y_{qn}^{D(R)} \ge y_q^{D(R)} (\forall q),$$
$$\sum_{n=1}^{N} \lambda_n^D = 1, \lambda_n^D \ge 0 (\forall n)$$

We define the slack variable, $s_p^{D-} (p = 1, \cdots, P)$, for the nonradial variables. The technology set can be rewritten as follows:

$$T^D\left\{\left(x^{D(\bullet)}, z^{E(\bullet)}, z^{A(\bullet)}, y^{D(\bullet)}\right) : \sum_{n=1}^{N} \lambda_n^D z_{l_1 n}^{A(R)} \le z_{l_1}^{A(R)} (\forall l_1), \right.$$
$$\sum_{n=1}^{N} \lambda_n^D z_{c_3 n}^{E(R)(D)} \le z_{c_3}^{E(R)(D)} (\forall c_3),$$
$$\sum_{n=1}^{N} \lambda_n^D x_{pn}^{D(NR)} = x_p^{D(NR)} - s_p^{D-} (\forall p), \cdots \sum_{n=1}^{N} \lambda_n^D y_{qn}^{D(R)} \ge y_q^{D(R)} (\forall q),$$
$$s_p^{D-} \ge 0, \sum_{n=1}^{N} \lambda_n^D = 1, \lambda_n^D \ge 0 (\forall n) \tag{8}$$

Thus, an overall network operational technology set in terms of radial and nonradial factors can be defined as follows:

$$T^{overall}\left\{\left(x^{E(\bullet)}, z^{E(\bullet)}, x^{H(\bullet)}, z^{H(\bullet)}, y^{H(\bullet)}, x^{A(\bullet)}, z^{A(\bullet)}, y^{A(\bullet)}, x^{D(\bullet)}, y^{D(\bullet)}\right) : \right.$$
$$\sum_{n=1}^{N} \lambda_n^E x_{b_1 n}^{E(R)} \le x_{b_1}^{E(R)} (\forall b_1), \sum_{n=1}^{N} \lambda_n^E x_{b_2 n}^{E(NR)} = x_{b_2}^{E(NR)} - s_{b_2}^{E-} (\forall b_2),$$
$$\sum_{n=1}^{N} \lambda_n^E z_{c_1 n}^{E(R)(H)} \ge z_{c_1}^{E(R)(H)} (\forall c_1), \sum_{n=1}^{N} \lambda_n^E z_{c_2 n}^{E(R)(A)} \ge z_{c_2}^{E(R)(A)} (\forall c_2),$$
$$\sum_{n=1}^{N} \lambda_n^E z_{c_3 n}^{E(R)(D)} \ge z_{c_3}^{E(R)(D)} (\forall c_3),$$
$$\sum_{n=1}^{N} \lambda_n^H z_{C_1 n}^{E(R)(H)} \le z_{c_1}^{E(R)(H)} (\forall c_1), \sum_{n=1}^{N} \lambda_n^H x_{gn}^{H(NR)} = x_g^{H(NR)} - s_g^{H-} (\forall g),$$
$$\sum_{n=1}^{N} \lambda_n^H z_{i_1 n}^{H(R)} \ge z_{i_1}^{H(R)} (\forall i_1) \sum_{n=1}^{N} \lambda_n^H y_{i_2 n}^{H(R)} \ge y_{i_2}^{H(R)} (\forall i_2),$$
$$\sum_{n=1}^{N} \lambda_n^A z_{i_1 n}^{H(R)} \le z_{i_1}^{H(R)} (\forall i_1), \sum_{n=1}^{N} \lambda_n^A z_{c_2 n}^{E(R)(A)} \le z_{c_2}^{E(R)(A)} (\forall c_2),$$
$$\sum_{n=1}^{N} \lambda_n^A x_{kn}^{A(NR)} = x_k^{A(NR)} - s_k^{A-} (\forall k),$$
$$\sum_{n=1}^{N} \lambda_n^A z_{l_1 n}^{A(R)} \ge z_{l_1}^{A(R)} (\forall l_1), \sum_{n=1}^{N} \lambda_n^A y_{l_2 n}^{A(R)} \ge y_{l_2}^{A(R)} (\forall l_2),$$
$$\sum_{n=1}^{N} \lambda_n^D z_{l_1 n}^{A(R)} \le z_{l_1}^{A(R)} (\forall l_1), \sum_{n=1}^{N} \lambda_n^D z_{c_3 n}^{E(R)(D)} \le z_{c_3}^{E(R)(D)} (\forall c_3),$$
$$\sum_{n=1}^{N} \lambda_n^D x_{pn}^{D(NR)} = x_p^{D(NR)} - s_p^{D-} (\forall p),$$
$$\sum_{n=1}^{N} \lambda_n^D y_{qn}^{D(R)} \ge y_q^{D(R)} (\forall q),$$
$$\sum_{n=1}^{N} \lambda_n^E = 1, \sum_{n=1}^{N} \lambda_n^H = 1, \sum_{n=1}^{N} \lambda_n^A = 1, \sum_{n=1}^{N} \lambda_n^D = 1,$$
$$\left. \lambda_n^E \ge 0, \lambda_n^H \ge 0, \lambda_n^H \ge 0, \lambda_n^D \ge 0, s_{b_2}^{E-}, s_g^{H-}, s_k^{A-}, s_p^{D-} \ge 0 (\forall n) \right\}. \tag{9}$$

Suppose that the under evaluation, DMU_O, has a data set of variables as follows:

$$\left\{ x_{b_1 o}^{E(R)}, x_{b_2 o}^{E(NR)}, z_{c_1 o}^{E(R)(H)}, z_{c_2 o}^{E(R)(A)}, z_{c_3 o}^{E(R)(D)}, x_{go}^{H(NR)}, z_{i_1 o}^{H(R)}, y_{i_2 o}^{H(NR)}, x_{ko}^{A(NR)}, z_{l_1 o}^{A(R)}, y_{l_2 o}^{A(NR)}, x_{po}^{D(NR)}, y_{qo}^{D(R)} \right\}. \tag{10}$$

Then, the hybrid network model based on the framework of Fig. 1 can be expressed as follows:

Min θ

(Tourism education)

$$\text{s.t.} \sum_{n=1}^{N}\lambda_n^E x_{b_1 n}^{E(R)} \le \varphi^I x_{b_1 o}^{E(R)}(\forall b_1); \sum_{n=1}^{N}\lambda_n^E x_{b_2 n}^{E(NR)} = x_{b_2 o}^{E(NR)} - s_{b_2}^{E-}(\forall b_2);$$
$$\sum_{n=1}^{N}\lambda_n^E z_{c_1 n}^{E(R)(H)} \ge \varphi^O z_{c_1 o}^{E(R)(H)}(\forall c_1); \sum_{n=1}^{N}\lambda_n^E z_{c_2 n}^{E(R)(A)} \ge \varphi^O z_{c_2 o}^{E(R)(A)}(\forall c_2);$$
$$\sum_{n=1}^{N}\lambda_n^E z_{c_3 n}^{E(R)(D)} \ge \phi^O z_{c_3 o}^{E(R)(D)}(\forall c_3);$$

(Tourist hotel)

$$\sum_{n=1}^{N}\lambda_n^H z_{c_1 n}^{E(R)(H)} \le \eta^I z_{c_1 o}^{E(R)(H)}(\forall c_1); \sum_{n=1}^{N}\lambda_n^H x_{g\,n}^{H(NR)} = x_{go}^{H(NR)} - s_g^{H-}(\forall g);$$
$$\sum_{n=1}^{N}\lambda_n^H z_{i_1 n}^{H(R)} \ge \eta^O z_{i_1 o}^{H(R)}(\forall i_1); \sum_{n=1}^{N}\lambda_n^H y_{i_2 n}^{H(R)} \ge \eta^O y_{i_2 o}^{H(R)}(\forall i_2)$$

(Travel agency)

$$\sum_{n=1}^{N}\lambda_n^A z_{i_1 n}^{H(R)} \le \delta^I z_{i_1 o}^{H(R)}(\forall i_1); \sum_{n=1}^{N}\lambda_n^A z_{c_2 n}^{E(R)(A)} \le \delta^I z_{c_2 o}^{E(R)(A)}(\forall c_2);$$
$$\sum_{n=1}^{N}\lambda_n^A x_{kn}^{A(NR)} = x_{ko}^{A(NR)} - s_k^{A-}(\forall k);$$
$$\sum_{n=1}^{N}\lambda_n^A z_{l_1 n}^{A(R)} \ge \delta^O z_{l_1 o}^{A(R)}(\forall l_1); \sum_{n=1}^{N}\lambda_n^A y_{l_2 n}^{A(R)} \ge \delta^O y_{l_2 o}^{A(R)}(\forall l_2);$$

(Tourist destination)

$$\sum_{n=1}^{N}\lambda_n^D z_{l_1 n}^{A(R)} \le \rho^I z_{l_1 o}^{A(R)}(\forall l_1); \sum_{n=1}^{N}\lambda_n^D z_{c_3 n}^{E(R)(D)} \le \rho^I z_{c_3 o}^{E(R)(D)}(\forall c_3);$$
$$\sum_{n=1}^{N}\lambda_n^D x_{pn}^{D(NR)} = x_{po}^{D(NR)} - s_p^{D-}(\forall p);$$
$$\sum_{n=1}^{N}\lambda_n^D y_{qn}^{D(R)} \ge \rho^O y_{qo}^{D(R)}(\forall q);$$
$$\sum_{n=1}^{N}\lambda_n^E = 1, \sum_{n=1}^{N}\lambda_n^H = 1, \sum_{n=1}^{N}\lambda_n^A = 1, \sum_{n=1}^{N}\lambda_n^D = 1;$$
$$0 \le \lambda_n^E, \lambda_n^H, \lambda_n^A, \lambda_n^D \le 1(\forall n);$$
$$0 \le \varphi^I, \eta^I, \delta^I, \rho^I \le 1;$$
$$1 \le \varphi^O, \eta^O, \delta^O, \rho^O;$$
$$s_{b_2}^{E-}, s_g^{H-}, s_k^{A-}, s_p^{D-} \ge 0. \tag{11}$$

In Formula (11), the objective value, θ, is defined as follows:

$$\theta = \frac{1 - \frac{B_1}{B}\left(1-\varphi^I\right) - \frac{1}{B}\sum_{b_2=1}^{B_2}\frac{s_{b_2 o}^{E-}}{x_{b_2 o}^{E(NR)}}}{\varphi^O} + \frac{1 - \frac{C_1}{C_1+G}\left(1-\eta^I\right) - \frac{1}{C_1+G}\sum_{g=1}^{G}\frac{s_g^{H-}}{x_{go}^{H(NR)}}}{\eta^O} + \frac{1 - \frac{I_1+C_2}{I_1+C_2+K}\left(1-\delta^I\right) - \frac{1}{I_1+C_2+K}\sum_{k=1}^{K}\frac{s_k^{A-}}{x_{ko}^{A(NR)}}}{\delta^O} + \frac{1 - \frac{L_1+C_3}{L_1+C_3+P}\left(1-\rho^I\right) - \frac{1}{L_1+C_3+P}\sum_{p=1}^{P}\frac{s_p^{D-}}{x_{po}^{D(NR)}}}{\rho^O} \tag{12}$$

The radial variables, namely $\varphi^I\eta^I\delta^I\rho^I\varphi^O\eta^O\delta^O$, and$\rho^O$, are assumed to be unknown variables and can be solved through an optimization process. The slacks, namely $s_{b_2}^{E-}$,s_g^{H-},s_k^{A-}, and s_p^{D-}, which indicate excess nonradial input utilization, can also be evaluated. The objective value (θ) consists of radial variables and slacks.

Based on the solved values, $s^{(\bullet)*}$, $\varphi^{(\bullet)*}$,$\eta^{(\bullet)*}$,$\delta^{(\bullet)*}$, and$\rho^{(\bullet)*}$, the efficiencies of various divisions are defined as follows:

Efficiency of tourism education:

$$Eff^E = \frac{1 - \frac{B_1}{B}\left(1-\varphi^{I*}\right) - \frac{1}{B}\sum_{b_2=1}^{B_2}\frac{s_{b_2 o}^{E-*}}{x_{b_2 o}^{E(NR)}}}{\varphi^{O*}} \tag{13}$$

Efficiency of tourist hotels:

$$Eff^H = \frac{1 - \frac{C_1}{C_1+G}\left(1-\eta^{I*}\right) - \frac{1}{C_1+G}\sum_{g=1}^{G}\frac{s_g^{H-*}}{x_{go}^{H(NR)}}}{\eta^{O*}} \tag{14}$$

Efficiency of travel agencies:

$$Eff^A = \frac{1 - \frac{I_1+C_2}{I_1+C_2+K}\left(1-\delta^{I*}\right) - \frac{1}{I_1+C_2+K}\sum_{k=1}^{K}\frac{s_k^{A-*}}{x_{ko}^{A(NR)}}}{\delta^{O*}} \quad (15)$$

Efficiency of tourist destinations:

$$Eff^D = \frac{1 - \frac{L_1+C_3}{L_1+C_3+P}\left(1-\rho^{I*}\right) - \frac{1}{L_1+C_3+P}\sum_{p=1}^{P}\frac{s_p^{D-*}}{x_{po}^{D(NR)}}}{\rho^{O*}} \quad (16)$$

The statuses of the four efficiencies for the DMU_O under evaluation are defined as follows:

Definition 1. DMU_O performs efficiently in the division of tourism education if and only if $Eff^E = 1$.

Proof: If $\sum_{n=1}^{N}\lambda_n^E x_{b_1n}^{E(R)} = x_{b_1}^{E(R)}$, $\sum_{n=1}^{N}\lambda_n^E x_{b_2n}^{E(NR)} = x_{b_2}^{E(NR)}$, $\sum_{n=1}^{N}\lambda_n^E z_{c_1n}^{E(R)(H)} = z_{c_1}^{E(R)(H)}$, $\sum_{n=1}^{N}\lambda_n^E z_{c_2n}^{E(R)(A)} = z_{c_2}^{E(R)(A)}$, and $\sum_{n=1}^{N}\lambda_n^E z_{c_3n}^{E(R)(D)} = z_{c_3}^{E(R)(D)}$ have been identified, then solve $\varphi^{I*} = \varphi^{O*} = 1$ and $s_{b_2o}^{E-*} = 0$ can be solved. The efficiency index of tourism education, $Eff^E = 1$, can also be determined. If radial slacks exist, for instance as $\sum_{n=1}^{N}\lambda_n^E x_{b_1n}^{E(R)} = \varphi^I \cdot x_{b_1o}^{E(R)} - s^-$, they do not need to be accounted for in the efficiency index. Therefore, radial slacks are assumed to be freely disposable and do not affect the efficiency evaluation (Tone, 2004). If $Eff^E = 1$, $\rho^{O*}$and $1 - \frac{B_1}{B}(1-\varphi^{I*}) - \frac{1}{B}\sum_{b_1=1}^{B_1}\frac{s_{b_2o}^{E-*}}{x_{b_2o}^{E(NR)}}$ must both be equal to 1. We can consequently obtain $\varphi^{O*} = \varphi^{I*} = 1$ and $s_{b_2o}^{E-*} = 0$.

Definition 2. DMU_O performs efficiently in the division of tourist hotel if and only if $Eff^H = 1$.

Proof: If $\sum_{n=1}^{N}\lambda_n^H z_{c_1n}^{E(R)(H)} = z_{c_1o}^{E(R)(H)}$, $\sum_{n=1}^{N}\lambda_n^H x_{gn}^{H(NR)} = x_{go}^{H(NR)}$, $\sum_{n=1}^{N}\lambda_n^H z_{i_1n}^{H(R)} = z_{i_1o}^{H(R)}$, and $\sum_{n=1}^{N}\lambda_n^H y_{i_2n}^{H(R)} = y_{i_2o}^{H(R)}$ have been identified, then $\eta^{I*} = \eta^{O*} = 1$ and $s_g^{H-*} = 0$ can be solved. The efficiency index of tourist hotel, $Eff^H = 1$, can also be evaluated. If $Eff^H = 1$, η^{O*} and $1 - \frac{C_1}{C_1+G}(1-\eta^{I*}) - \frac{1}{C_1+G}\sum_{g=1}^{G}\frac{s_g^{H-*}}{x_{go}^{H(NR)}}$ must be both equal to one. We can consequently obtain $\eta^{O*} = \eta^{I*} = 1$ and $s_g^{H-*} = 0$.

Definition 3. The DMU_O performs efficiently in the travel agency division if and only if $Eff^A = 1$.

Proof: If $\sum_{n=1}^{N}\lambda_n^A z_{i_1n}^{H(R)} = z_{i_1o}^{H(R)}$, $\sum_{n=1}^{N}\lambda_n^A z_{c_2n}^{E(R)(A)} = z_{c_2o}^{E(R)(A)}$, $\sum_{n=1}^{N}\lambda_n^A x_{kn}^{A(NR)} = x_{ko}^{A(NR)}$, $\sum_{n=1}^{N}\lambda_n^A z_{l_1n}^{A(R)} = z_{l_1o}^{A(R)}$, and $\sum_{n=1}^{N}\lambda_n^A y_{l_2n}^{A(R)} = y_{l_2o}^{A(R)}$ have been identified, then $\delta^{I*} = \delta^{O*} = 1$ and $s_k^{A-*} = 0$ can be solved. The efficiency index of travel agency, $Eff^A = 1$, can be identified as well. If $Eff^A = 1$, δ^{O*} and $1 - \frac{I_1+C_2}{I_1+C_2+K}(1-\delta^{I*}) - \frac{1}{I_1+C_2+K}\sum_{k=1}^{K}\frac{s_k^{A-*}}{x_{ko}^{A(NR)}}$ must be both equal to one. We can consequently obtain $\delta^{O*} = \delta^{I*} = 1$ and $s_k^{A-*} = 0$.

Definition 4. The DMU_O performs efficiently in the tourist destination division if and only if $Eff^D = 1$.

Proof: If $\sum_{n=1}^{N}\lambda_n^D z_{l_1n}^{A(R)} = \rho^I \cdot z_{l_1o}^{A(R)}$, $\sum_{n=1}^{N}\lambda_n z_{c_3n}^{E(R)(D)} = \rho^I \cdot z_{c_3o}^{E(R)(D)}$, $\sum_{n=1}^{N}\lambda_n^D x_{pn}^{D(NR)} = x_{po}^{D(NR)}$, and $\sum_{n=1}^{N}\lambda_n^D y_{qn}^{D(R)} = \rho^O \cdot y_{qo}^{D(R)}$ have been identified, then $\rho^{I*} = \rho^{O*} = 1$ and $s_p^{D-*} = 0$ can be solved. The efficiency index of tourist destination, $Eff^D = 1$, can be evaluated as well. If $Eff^D = 1$, ρ^{O*} and $1 - \frac{L_1+C_3}{L_1+C_3+P}(1-\rho^{I*}) - \frac{1}{L_1+C_3+P}\sum_{p=1}^{P}\frac{s_p^{D-*}}{x_{po}^{D(NR)}}$ must be both equal to one. We can consequently obtain $\rho^{O*} = \rho^{I*} = 1$ and $s_p^{D-*} = 0$.

Through the solved values, $s^{(\bullet)*}$, $\varphi^{(\bullet)*}$,$\eta^{(\bullet)*}$,$\delta^{(\bullet)*}$, and$\rho^{(\bullet)*}$, we define the inefficiency indicators for tourism education division as follows:

$$\text{Inefficiency from the radial input: } \frac{B_1}{B}\left(1-\varphi^{I*}\right) \quad (17)$$

$$\text{Inefficiency from the nonradial input: } \frac{1}{B}\sum_{b_2=1}^{B_2}\frac{s_{b_2o}^{E-*}}{x_{b_2o}^{E(NR)}} \quad (18)$$

$$\text{Inefficiency from the radial intermediate (output): } \varphi^{O*} - 1 \quad (19)$$

The inefficiency indicators of the tourist hotel division are defined as follows:

$$\text{Inefficiency from the radial intermediate (input): } \frac{C_1}{C_1+G}\left(1-\eta^{I*}\right) \quad (21)$$

$$\text{Inefficiency from the nonradial input: } \frac{1}{C_1+G}\sum_{g=1}^{G}\frac{s_g^{H-*}}{x_{go}^{H(NR)}} \quad (22)$$

$$\text{Inefficiency from the radial intermediate (output): } \left(\eta^{O*} - 1\right) \quad (23)$$

The inefficiency indicators of the travel agency division are defined as follows:

$$\text{Inefficiency from the radial intermediate (input): } \frac{I_1+C_2}{I_1+C_2+K}\left(1-\delta^{I*}\right) \quad (24)$$

$$\text{Inefficiency from the nonradial input: } \frac{1}{I_1+C_2+K}\sum_{k=1}^{K}\frac{s_k^{A-*}}{x_{ko}^{A(NR)}} \quad (25)$$

$$\text{Inefficiency from the radial intermediate (output): } \left(\delta^{O*} - 1\right) \quad (26)$$

The inefficiency indicators of the tourist destination division are defined as follows:

$$\text{Inefficiency from the radial intermediate (input): } \frac{L_1+C_3}{L_1+C_3+P}\left(1-\rho^{I*}\right) \quad (27)$$

$$\text{Inefficiency from the nonradial input: } \frac{1}{L_1+C_3+P}\sum_{p=1}^{P}\frac{s_p^{D-*}}{x_{po}^{D(NR)}} \quad (28)$$

$$\text{Inefficiency from the radial output: } \rho^{O*} - 1 \quad (29)$$

To confine the overall efficiency indicator within the range [0,1], we define the sums of the numbers of factors as $\Phi = B + C + I + G + K + L + P$ and $\Omega = I + L + C + Q$, in which $I = I_1 + I_2$, $L = L_1 + L_2$

and $C = C_1 + C_2 + C_3$. The overall efficiency indicator is then defined as follows:

$$Eff^{overall} = \frac{1 - \psi^R - \psi^{NR}}{1 + \mu^R} \tag{30}$$

where

$$\psi^R = \frac{B_1}{\Phi}\left(1 - \varphi^{I*}\right) + \frac{C_1}{\Phi}\left(1 - \eta^{I*}\right) + \frac{I_1 + C_2}{\Phi}\left(1 - \delta^{I*}\right) + \frac{L_1 + C_3}{\Phi}\left(1 - \rho^{I*}\right) \tag{31}$$

$$\psi^{NR} = \frac{1}{\Phi}\left(\sum_{b_2=1}^{B_2}\frac{s_{b_2o}^{E-*}}{x_{b_2o}^{E(NR)}} + \sum_{g=1}^{G}\frac{s_g^{H-*}}{x_{go}^{H(NR)}} + \sum_{k=1}^{K}\frac{s_k^{A-*}}{x_{ko}^{A(NR)}} + \sum_{p=1}^{P}\frac{s_p^{D-*}}{x_{po}^{D(NR)}}\right) \tag{32}$$

$$\mu^R = \frac{C}{\Omega}\left(\varphi^{o*} - 1\right) + \frac{I}{\Omega}\left(\eta^{o*} - 1\right) + \frac{L}{\Omega}\left(\delta^{o*} - 1\right) + \frac{Q}{\Omega}\left(\rho^{o*} - 1\right) \tag{33}$$

where ψ^R represents the weighted average of inefficiency from the radial input, ψ^{NR} represents the weighted average of inefficiency from the nonradial inputs, and μ^R represents the weighted average of inefficiency from the output.

Theorem 1. *The indicator E_n is confined to the range* [0,1].

[Proof:] Because $0 \le \varphi^{I*}, \eta^{I*}, \delta^{I*}, \rho^{I*} \le 1$, *and* $0 \le \frac{B_1}{\Phi}, \frac{C_1}{\Phi}, \frac{I_1+C_2}{\Phi}, \frac{L_1+C_3}{\Phi} \le 1$ *are known, we have* $0 \le \psi^R \le 1$. *Because* $0 \le \sum_{b_2=1}^{B_2}\frac{s_{b_2o}^{E-*}}{x_{b_2o}^{E(NR)}}, \sum_{g=1}^{G}\frac{s_g^{H-*}}{x_{go}^{H(NR)}}, \sum_{k=1}^{K}\frac{s_k^{A-*}}{x_{ko}^{A(NR)}}, \sum_{p=1}^{P}\frac{s_p^{D-*}}{x_{po}^{D(NR)}} \le 1$ *are known we have* $0 \le \psi^{NR} \le 1$. *The maximum value of* $\psi^R + \psi^{NR}$ *is equal to 1, and* $0 \le 1 - \psi^R - \psi^{NR} \le 1$ *can be identified. Therefore,* $0 \le \frac{1-\psi^R-\psi^{NR}}{1+\mu^R} \le 1$ *can be proved.*

Definition 5. *DMU_O is efficient overall if* $Eff^{overall} = 1$.

[Proof:] If $\varphi^{I*} = \eta^{I*} = \delta^{I*} = \rho^{I*} = 1$ *and* $s_{b_2o}^{E-*} = s_g^{H-*} = s_k^{A-*} = s_p^{D-*} = 0$, *then* $1 - \psi^R - \psi^{NR} = 1$ *can be identified. If* $\varphi^{o*} = \eta^{o*} = \delta^{o*} = \rho^{o*} = 1$, *then* $1 + \mu^R = 1$. *Therefore,* $Eff^{overall} = 1$ *can be proved.*

We also define the inefficiency indicators for the overall chain as follows:

$$\text{Inefficiency of the radial (initial) input: } \frac{B}{\Phi}\left(1 - \varphi^{I*}\right) \tag{34}$$

$$\text{Inefficiency of the final output: } \frac{Q}{\Omega}\left(\rho^{o*} - 1\right) \tag{35}$$

$$\text{Inefficiency of the intermediate: } \frac{C_1}{\Phi}\left(1 - \eta^{I*}\right) + \frac{I_1 + C_2}{\Phi}\left(1 - \delta^{I*}\right) + \frac{L_1 + C_3}{\Phi}\left(1 - \rho^{I*}\right) \tag{36}$$

$$\text{Inefficiency of the radial output: } \frac{C}{\Omega}\left(\varphi^{o*} - 1\right) + \frac{I}{\Omega}\left(\eta^{o*} - 1\right) + \frac{L}{\Omega}\left(\delta^{o*} - 1\right) \tag{37}$$

$$\text{Inefficiency of the nonradial input: } \frac{1}{\Phi}\left(\sum_{b_2=1}^{B_2}\frac{s_{b_2o}^{E-*}}{x_{b_2o}^{E(NR)}} + \sum_{g=1}^{G}\frac{s_g^{H-*}}{x_{go}^{H(NR)}} + \sum_{k=1}^{K}\frac{s_k^{A-*}}{x_{ko}^{A(NR)}} + \sum_{p=1}^{P}\frac{s_p^{D-*}}{x_{po}^{D(NR)}}\right) \tag{38}$$

4. Empirical results

For the empirical evaluation, 30 regions across China were used as observations to analyze the performance of the tourism supply chain. The empirical data were obtained from the *Year Book of China*

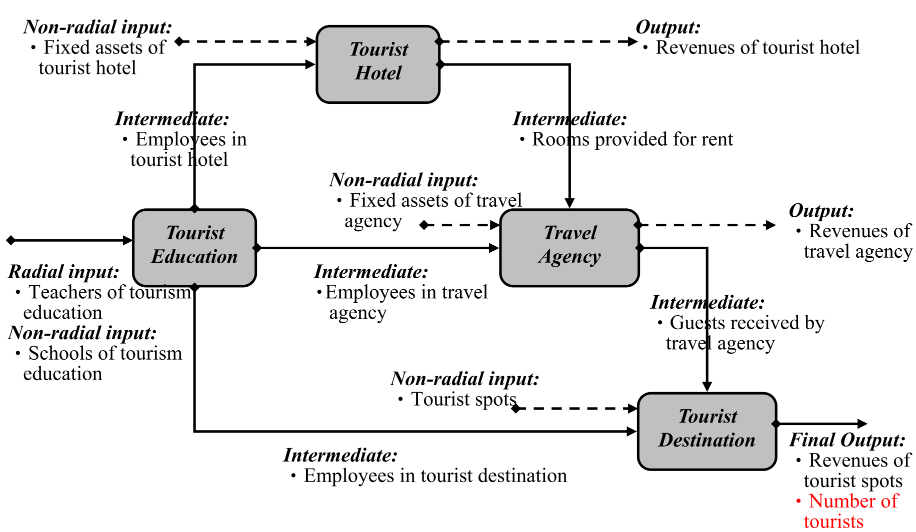


Fig. 2. Graphical illustration of factors within the tourism service supply chain.

Tourism Statistics 2013 and *the Year Book of China Education Statistics 2013*. The relations between the variables are illustrated in Fig. 2, in which the fixed asset and laborers are assumed to be nonradial and radial inputs, respectively, and service capacity is assumed to be an intermediate input. Revenues in the hotel and travel agency divisions are defined as the intermediate outputs in the supply chain. The revenue of tourist spots and the number of tourists are defined as the final outputs. The descriptive statistics of the empirical data are listed in Table 1, and the specific definitions of variables are described as follows:

> "Teachers of tourism education" refers to the total number of full-time educators teaching in a department of tourism or hospitality at a university or vocational school.

Table 1
Descriptive statistics for empirical data.

	Average	Std. Dev.	Max	Min
Radial (initial) input:				
Teachers of tourism education	1877.3	1055.2	4284.4	156.7
Non-radial input:				
Schools of tourism education	73.5	65.2	285.0	6.0
Fixed assets of tourist hotel	15,221.1	13,736.2	59,680.2	1853.9
Fixed assets of travel agency	2703.4	3221.7	13,853.0	426.5
Tourist spots	184.4	111.3	496.0	35.0
Intermediate:				
Employees in tourist hotel	51,267.8	35,904.8	164,812.0	7245.0
Employees in travel agency	9948.3	7889.2	35,408.0	900.0
Employees in tourism destination	6716.5	5722.6	26,319.0	141.0
Rooms provided for rent	85,724.1	52,208.3	228,244.0	13,111.0
Guests received by travel agency	6380.7	6662.0	24,173.7	416.1
Output:				
Revenues of tourist hotel	7702.3	7264.4	26,293.9	777.0
Revenues of travel agency	9559.5	12,024.4	44,902.8	451.7
Final output:				
Revenues of tourist spots	127.0	213.3	912.2	4.9
Number of tourists	89.7	74.4	278.0	5.0

Table 2
Result of efficiencies for the 30 regions.

No.	Region	Divisional Efficiency				Overall Efficiency
		Education	Hotel	Travel Agency	Destination	
01	Beijing	1	1	1	1	1
02	Tianjin	0.452	0.976	0.550	1	0.636
03	Hebei	0.784	0.663	0.431	1	0.622
04	Liaoning	0.810	0.656	0.387	0.417	0.499
05	Shanghai	1	0.763	0.373	0.496	0.570
06	Jiangsu	0.509	0.630	0.791	1	0.622
07	Zhejiang	0.455	0.696	0.337	0.708	0.485
08	Fujian	0.292	1	0.387	0.445	0.318
09	Shandong	1	1	1	0.176	0.535
10	Guangdong	0.695	0.770	1	1	0.821
11	Guangxi	1	1	0.739	1	0.870
12	Hainan	0.375	0.800	0.569	0.476	0.322
13	Shanxi	0.773	1	0.704	0.307	0.382
14	Inner Mongolia	0.413	1	0.639	0.676	0.599
15	Jilin	1	0.792	0.592	1	0.737
16	Heilongjiang	0.696	0.809	0.344	0.701	0.485
17	Anhui	0.458	0.778	0.646	0.289	0.355
18	Jiangxi	0.489	0.751	1	0.480	0.418
19	Henan	1	1	1	0.430	0.719
20	Hubei	0.649	0.838	0.635	0.330	0.491
21	Hunan	1	0.764	0.610	1	0.772
22	Sichuan	0.560	0.706	1	0.457	0.521
23	Guizhou	0.340	0.712	1	0.413	0.345
24	Yunnan	0.555	1	0.696	0.846	0.649
25	Shaanxi	0.746	0.936	0.676	0.423	0.470
26	Gansu	0.563	0.755	0.702	0.393	0.388
27	Qinghai	0.608	0.839	0.272	1	0.521
28	Ningxia	1	1	0.406	1	0.751
29	Xinjiang	1	0.768	1	1	0.926
30	Chongqing	1	0.906	0.459	1	0.753
Kruskal Wallis test:						
	Mean	0.707	0.844	0.665	0.682	0.586
	Std. Dev.	0.245	0.128	0.244	0.293	0.184
	Chi-square statistic: 18.765					
	P-value: 0.001					

"Schools of tourism education" refers to the total number of schools, which have a department involved in tourism or hospitality skills training.

"Fixed assets of tourist hotels" refers to the total value of fixed asset of all hotels in the region. It is measured in units of 1 million RMB.

"Fixed assets of travel agencies" refers to the total value of fixed asset of all travel agencies in the region. It is measured in units of 1 million RMB.

"Tourist spots" refers to the total number of scenic spots in the region.

"Employees in tourist hotels" refers to the total number of hotel workers in the region.

"Employees in travel agencies" refers to the total number of travel agency workers in the region.

"Employees at tourism destinations" refers to the total number of workers serving in any scenic spots in the region.

"Rooms provided for rent" refers to total number of rooms available for rent to guests in the region.

"Guests received by travel agencies" refers to the total number of tourists whose tours are managed and guided by local travel agents. It is measured in units of 1000 people.

"Revenues from tourist hotels" refers to the total revenue of all hotels in the region. It is measured in units of 1 million RMB.

"Revenues from travel agencies" refers to the total revenue of all travel agencies in the region. It is measured in units of 1 million RMB.

"Revenues of tourist spots" refers to total incomes, including admissions and commodity sales, in all scenic spots. It is measured in units of 1000 RMB.

"Number of tourists" refers to the total number of tourists traveling to all destinations in the region. It is measured in units of 1 million person-times.

The efficiency scores evaluated using the empirical model are listed in Table 2. Under the heading "Divisional Efficiency," the efficiency of the tourism education division (i.e.,Eff^E), tourist hotel division (i.e.,Eff^H), travel agency division (i.e.Eff^A), and tourist destination division (i.e.Eff^D) are shown in Columns 1–4, respectively. In summary, 10 regions (No. 01, 05, 09, 11, 15, 19, 21, 28, 29, and 30) were found to be efficient units in the tourism education division; 9 regions (No. 01, 08, 09, 11, 13, 14, 19, 24, and 28) were efficient units in the tourist hotel division; 8 regions (No. 01, 09, 10, 18, 19, 22, 23, and 29) were efficient units in the travel agency division; and 12 regions were efficient in the tourist destination

Table 3
Result of inefficiency of divisions.

No.	Region	Education			Hotel			Agency			Destination		
		Input		Output	Intermediate	Non-radial Input	Output	Intermediate	Non-radial Input	Output	Intermediate	Non-radial Input	Output
		Radial	Non-radial										
01	Beijing	–	–	–	–	–	–	–	–	–	0	0	0
02	Tianjin	0.120	–	0.946	0.024	–	–	–	–	0.819	0	0	0
03	Hebei	0.179	0.037	–	0.172	0.089	0.115	–	–	1.318	0	0	0
04	Liaoning	0.108	0.082	–	0.208	–	0.208	–	–	1.583	0.006	0	1.383
05	Shanghai	–	–	–	0.094	–	0.187	–	–	1.679	0	0.069	0.875
06	Jiangsu	0.210	0.280	–	0.108	0.136	0.199	–	–	0.264	0	0	0
07	Zhejiang	0.275	0.155	0.254	–	0.006	0.427	–	–	1.968	0	0	0.412
08	Fujian	0.341	0.368	–	–	–	–	0.209	–	1.044	0	0.201	0.797
09	Shandong	–	–	–	–	–	–	–	–	–	0.543	0.048	1.322
10	Guangdong	0.227	0.077	–	0.105	–	0.163	–	–	–	0	0	0
11	Guangxi	–	–	–	–	–	–	0.260	–	–	0	0	0
12	Hainan	0.237	0.350	0.101	0.100	–	0.126	–	–	0.757	0.304	0.220	0
13	Shanxi	0.020	0.207	–	–	–	–	0.296	–	–	0.510	0.115	0.222
14	Inner Mongolia	0.239	0.165	0.444	–	–	–	–	–	0.566	0.039	0	0.423
15	Jilin	–	–	–	0.148	0.060	–	0.314	–	0.159	0	0	0
16	Heilongjiang	0.246	0.058	–	0.191	–	–	–	–	1.905	0	0.149	0.215
17	Anhui	0.281	0.261	–	0.109	–	0.146	0.201	–	0.238	0.205	0.028	1.655
18	Jiangxi	0.189	0.322	–	0.144	0.038	0.090	–	–	–	0.431	0.089	0
19	Henan	–	–	–	–	–	–	–	–	–	0.537	0	0.076
20	Hubei	0.059	0.292	–	0.091	–	0.085	–	–	0.576	0.11	0	1.696
21	Hunan	–	–	–	–	0.132	0.137	0.131	–	0.425	0	0	0
22	Sichuan	0.150	0.291	–	0.121	–	0.245	–	–	–	0.314	0	0.501
23	Guizhou	0.290	0.37	–	0.047	0.013	0.321	–	–	–	0.453	0.134	0
24	Yunnan	0.125	0.32	–	–	–	–	–	–	0.437	0	0.103	0.060
25	Shaanxi	–	0.254	–	0.038	0.026	–	0.014	–	0.459	0.442	0.135	0
26	Gansu	0.275	0.162	–	0.133	–	0.148	–	–	0.425	0.441	0.166	0
27	Qinghai	–	0.042	0.575	0.131	–	0.035	–	–	2.676	0	0	0
28	Ningxia	–	–	–	–	–	–	–	0.014	1.430	0	0	0
29	Xinjiang	–	–	–	–	0.052	0.234	–	–	–	0	0	0
30	Chongqing	–	–	–	0.035	0.059	–	0.068	–	1.032	0	0	0
Kruskal Wallis test:													
	Mean	0.119	0.136	0.077	0.067	0.020	0.096	0.050	0.000	0.659	0.145	0.049	0.321
	Std. Dev.	0.119	0.139	0.213	0.068	0.039	0.114	0.099	0.003	0.736	0.207	0.07	0.535
	Chi-square statistic		11.299			8.766			34.012			1.786	
	P-value		0.004			0.012			0.000			0.409	

division. Beijing (No. 01) is the only region that was efficient in all divisions.

From the overall efficiency ($Eff^{overall}$) results, Beijing (No. 01), which was identified as efficient in all divisions, was uniquely evaluated as achieving the best practice in overall efficiency. Xinjiang (No. 29) and Guangxi (No. 11) were ranked second and third, respectively. Fujian (No. 08) had the lowest score (0.318) among all regions.

To compare the divisions, the efficiency averages, which were identified as statistically significant at the 1% level through the Kruskal–Wallis test, are displayed at the bottom of Table 2. By average efficiency score, the divisions were ranked in the descending order of the tourist hotel division (0.844), tourism education division (0.707), tourist destination (0.682), and travel agency division (0.665).

The result of overall efficiency indicated that most regions had scores of <1 and were thus evaluated as inefficient. We also found that most of regions were inconsistent in various divisional efficiencies. For example, the efficiency of Shanghai (No. 05) was above average for the tourism education and tourist hotel divisions but lower than the average for the travel agency and tourist destination divisions. To compare the averages of divisional efficiency, the tourist hotel division was the most efficient among all the divisions in the supply chain, whereas the travel agency division was the least efficient.

To explore the sources of inefficiency, the inefficiency indices for the four divisions were computed; the results are listed in Table 3. A high value represents a large contribution to inefficiency from a particular factor type.

In the table, the inefficiency scores for the tourism education division are listed under the heading "Education." Overall the inefficiency of 17 regions was caused by both radial and nonradial inputs, and that of five regions was caused by output deficits. On average, the index of nonradial input with 0.136 was significantly higher than the other factors in the tourist education division. In the tourist hotels division, the results (under the heading of "Hotel") reveal that the inefficiency in 18 regions was caused by intermediates, and that in 10 regions was caused by nonradial inputs. Positive values for output inefficiency were observed in 16 regions. On average, the output index was significantly higher in the tourist hotel division than in the other divisions. The inefficiency indices of travel agencies are listed under the heading of "Agency." The results revealed that 20 regions had positive output inefficiency values, and the average of output (0.689) was higher than input and intermediate. The inefficiency output index in the travel agency division was also considerably higher than that in other divisions. In the tourist destination division, the average of output (0.321) was higher than the intermediate and nonradial inputs but did not reach the level of statistical significance in the Kruskal–Wallis test.

From the results of the inefficiency indices, we can conclude that the inefficiency is principally caused by an output deficit in the tourist hotel and travel agency divisions, and the inefficiency in the tourism education division mainly resulted from excess (nonradial) input utilization. In the travel agency division, inefficiency resulted from a deficit of revenue; this has been assessed as the most significant source of inefficiency in the travel agency division.

Table 4
Result of inefficiency of overall performance.

No.	Region	Initial input	Final output	intermediate	Radial output	non-radial input
01	Beijing	–	–	–	–	–
02	Tianjin	0.040	–	0.008	0.559	–
03	Hebei	0.060	–	0.057	0.358	0.063
04	Liaoning	0.036	0.173	0.072	0.448	0.041
05	Shanghai	–	0.109	0.031	0.467	0.052
06	Jiangsu	0.070	–	0.036	0.116	0.208
07	Zhejiang	0.092	0.051	–	0.694	0.080
08	Fujian	0.114	0.100	0.104	0.261	0.334
09	Shandong	–	0.165	0.271	–	0.036
10	Guangdong	0.076	–	0.035	0.041	0.039
11	Guangxi	–	–	0.130	–	–
12	Hainan	0.079	–	0.185	0.258	0.340
13	Shanxi	0.007	0.028	0.403	–	0.190
14	Inner Mongolia	0.080	0.053	0.019	0.308	0.082
15	Jilin	–	–	0.206	0.040	0.030
16	Heilongjiang	0.082	0.027	0.064	0.476	0.141
17	Anhui	0.094	0.207	0.239	0.096	0.151
18	Jiangxi	0.063	–	0.263	0.023	0.247
19	Henan	–	0.010	0.269	–	–
20	Hubei	0.020	0.212	0.086	0.165	0.146
21	Hunan	–	–	0.065	0.140	0.066
22	Sichuan	0.050	0.063	0.198	0.061	0.145
23	Guizhou	0.097	–	0.242	0.080	0.292
24	Yunnan	0.042	0.007	–	0.109	0.237
25	Shaanxi	–	–	0.241	0.115	0.241
26	Gansu	0.092	–	0.265	0.143	0.206
27	Qinghai	–	–	0.044	0.893	0.021
28	Ningxia	–	–	–	0.358	0.010
29	Xinjiang	–	–	–	0.058	0.026
30	Chongqing	–	–	0.045	0.258	0.029
	Mean	0.040	0.040	0.119	0.218	0.115
	Std. Dev.	0.040	0.067	0.113	0.228	0.106
	Kruskal Wallis test:					
	Chi-square statistic		29.475			
	P-value		0.000			

To compare the variable (radial) and semifixed (nonradial) inputs, the average of the nonradial inputs (0.136) was higher than that of the radial inputs (0.119) in the tourist education division; that of the nonradial inputs (0.020) was lower than that of the radial inputs (0.067) in the tourist hotel division; that of nonradial inputs (0.000) was lower than that of the radial inputs (0.050) in the travel agency division; and the average of the nonradial input (0.145) and was higher than that of the radial input (0.094) in the destination division. The results revealed that the radial inputs, which characterize the intermediates between divisions, contributed to inefficiency more than the nonradial inputs did. Alternatively, excess service capacity had a larger effect than excess fixed assets on the efficiencies. In the results of the initial inputs, we found that the excess utilization of nonradial inputs affected the inefficiency more than that of radial inputs. This finding indicates that the number of schools and teachers in tourist education in China is excessive and that the surplus of schools influenced the efficiency of education more than the surplus of teachers did.

To determine the inefficiency sources of the overall performance of the supply chain, the inefficiency indices are shown in Table 4. According to the average scores of inefficiency index, the factors contributing to inefficiency were ranked in the descending order of radial outputs (0.218), intermediate outputs (0.119), nonradial inputs (0.115), and initial inputs and final outputs (both 0.040).

From the perspective of integrated performance, we found that insufficient radial outputs, which consisted of the revenues of tourist hotels and travel agencies, were the main source of inefficiency for the overall supply chain. This finding reveals that in the three profit-generating divisions (tourist hotels, travel agencies, and tourist destinations), the tourist destination division had the highest revenue, whereas the tourist hotel and travel agency divisions have higher deficit in revenue. Furthermore, excess service capacity generated from hotels and travel agencies also had negative influences on the overall efficiency of the supply chain. The findings imply that, in the tourist hotel and travel agency divisions, although firms offer several services to guests, they do not derive the corresponding income for their services.

The surplus of schools of tourism education (i.e., the nonradial input) was also assessed as an obvious source of inefficiency. By comparison, the surplus of tourism education teachers (i.e. the initial input) had only a minor effect on the overall efficiency.

5. Conclusion

This study developed a hybrid network DEA model for evaluating efficiency of the tourism supply chain across 30 regions in China. The theoretical contribution provides a measure that can assess simultaneously efficiencies for various divisions within the tourism supply chain. The difference between the DEA model and conventional models for analyzing supply chains is the assumption of different input types. The proposed model considers the difference between the input types and assumes variable and semifixed factors as radial and nonradial inputs, respectively. The other merit of the model is that it defines the overall efficiency, which is measured on the basis of radial ratios and slacks in all the divisions, thus representing the integrated performance of the tourism supply chain. The overall efficiency can also be resolved into multiple inefficiency indices in order to explore the sources of inefficiency.

Empirical results derived from the proposed model provide several practical insights for tourism supply chain management in China. First, the overall efficiency indices reveal that only one region exhibited best practices in the integrated performance; most regions were evaluated with a score of <1. This finding implies that collaboration and integration between divisions in the tourism supply chain appear inadequate, and consequently, most regions have not achieved overall efficiency.

Second, among the divisions, the tourist hotel division exhibited the highest efficiency in the supply chain. In addition to tourism customers, hotels also can receive an increasing number of business customers who generate additional revenue for the industry (Hwang & Chang, 2003), as a result of rapid economic growth in recent years. The travel agency division was identified as the least efficient among the divisions, and its inefficiency principally sourced from deficits in revenue. Many travel agencies charge low service fees to attract more customers, and they collect rebates from other businesses, such as hotels, gift shops, restaurants, and entertainment businesses. Therefore, they were assessed as having a shortage of income and lower efficiency than the other sections.

Third, excess service capacity, which could not be efficiently used to generate outputs, was observed in the tourist hotel, travel agency, and tourist destination divisions, and its contribution to inefficiency was evaluated as larger than that of excess fixed assets utilization. The measure of inefficiency for the overall supply chain also showed consistent results, in which the service capacity cannot be fully utilized. Li (2001) and Chiou, Lan, and Yen (2010) have indicated that tourist services characterize nonstorable perishable goods, of which surplus will be lost throughout the transformation process from production to consumption if they are not concurrently consumed to generate revenue. Therefore, surplus service capacity, which cannot effectively be used to generate outputs, must be reduced to improve the overall performance of the tourism supply chain.

Fourth, the evaluation of tourism education revealed that a significant source of inefficiency was from the input side. Tourism education is rapidly developing in China, and the number of tourist schools has increased by 67.9% over the period of 2004–2013. To meet large potential market demand, public and private sectors have heavily invested resources into building infrastructure across many regions. However, China's economy is currently mainly based on industrial development, and the number of domestic tourists in the past 5 years has grown at a low annual growth rate of 0.6%. Consequently, China's tourism education is now exhibiting signs of overexpansion.

Overall, we can conclude that the integration of the divisions of the tourism supply chain is insufficient. Unequal revenue distributions and excess service capacity can be regarded as the main causes of problems in the integrated performance of the supply chain. The tourism industry is considered to be the next highly profitable industry in China, because of the increasing national consumption capacity. In fact, the pace of development of tourism-related industries appears to have exceeded the growth in demand in the tourism market, and excess service capacity was observed in the tourism supply chain. Although reduced pricing could mitigate the loss of service capacity for some divisions, such as travel agencies, but that would result in revenues being unevenly distributed among the elements of the supply chain. We suggest that in addition to maintaining a long-term cooperative partnership (Ling, Guo, & Liang, 2011), the optimal and fair pricing by one division for another division could be a strategy to enhance the integrated performance of the tourism supply chain and improve the revenue distribution among divisions. Because manufacturers are currently the principal generators of growth in China, accounting for the growth rate of the tourism market, we suggest that tourism service providers should focus on increasing the quality of tourism services instead of increasing the quantity through innovation (Orfila-Sintes & Mattsson, 2009). We also suggest that the quality of tourism education should be improved. Because the quality of tourism education is far from satisfactory in China (Gu, Kavanaugh, & Cong, 2007; Wang, 2010; Wu, Morrison, Yang, Zhou, & Cong, 2014), authorities must invest resources into improving teaching methods, textbooks, and faculty backgrounds rather than increase the scale of education.

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