Identification of technology spillover among airport alliance from the perspective of efficiency evaluation

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Identification of technology spillover among airport alliance from the perspective of efficiency evaluation: The case of China

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ABSTRACT

The development of airport alliances has undergone hardships, although airport alliances have emerged simultaneously with other airline alliances in an attempt to improve competitiveness. Technology spillover is a major benefit of airport alliances, but the effects of such spillover are not as obvious as might be expected. This paper proposes a three-stage DEA-based methodological framework to uncover the existence and characteristics of technology spillover among allied airports, and identify whether the technology spillover of airport alliances outperforms the self-development of airports. A case study that concerns multi-airport companies and non-allied airports in China, where airports and airlines are rapidly expanding, is included. The results show that the technology spillover of airport alliances does not become wide spread among all of the allied airports, which is most likely because civil aviation in China is still in a stage of rapid development. However, such spillover does appear among small- and mid-sized allied airports in cities with fast urban economic development. Finally, the related implications of our methodological framework are discussed along with our findings.

1. Introduction

The civil aviation transport industry has developed rapidly worldwide since the airline deregulation of the 1980s. Prosperity in civil aviation has created fierce competition and rising operational costs among airline companies, leading to the formation of airline alliances through which member companies pursue win-win cooperation. Since 1996, there have been three giant airline alliances, namely, Star Alliance, One World, and Sky Team. Meanwhile, airports around the world have also started to explore synergetic development by establishing a number of airport alliances, including the Galaxy International Cargo Alliance (GICA), Aviation Handling Services (AHS) alliance, Pantares Alliance, and Aéroports de Paris (ADP)-Schiphol alliance.

Compared to the advantages of airline alliances, however, the development advantages of airport alliances are less clear and airport alliances are not as stable as airline alliances. For example, Schiphol International Airport and Fraport (Frankfurt Airport) formed and reformed the Pantares Alliance in 2001 and 2008 respectively and in so doing, expected to reduce their operational costs, increase the market shares of the two hub airports, and become a powerful logistics developer providing value-added products. Similarly, since the foundation of multi-airport companies in China, the scale of airport alliances continues to vary, which reflects the unstable organization of airport alliances. As argued by Forsyth et al. (2009, 2011), the motivations behind airport integration have been to gain economies by know-how transfer. Airport know-how (technical efficiency) includes expertise in operating, investing in and marketing of airports. Know-how transfer is a type of knowledge transmission (Koo, 2005) from innovative airports to other members of an airport alliance, and improves the technical efficiency of the allied airports. Thus, the technology spillover within an airport alliance means that the technical efficiency of each allied airport should be significantly improved and thus higher than that of its paired airport (an independent airport has similar operational conditions).

In view of the above, two important policy-related questions arise. First, compared with independent airports, do allied airports gain more economies by know-how transfer (technical efficiency improvement)? Second, how does know-how diffuses among allied airports? The answers to these two questions contribute to the literature on the development of airport alliances. Second, the findings have implications for decision-makers of independent airports to judge whether or not to join an airport alliance.

Considering the improvement in airport technical efficiency with technology spillover within an airport alliance, a three-stage data

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envelopment analysis (DEA)-based methodology is proposed in this paper to assess technical efficiency of allied airports. Recently, the civil aviation industry in China has been enjoying a continuous boom, and airports have gradually attached more importance to their operational efficiency. Thus, airports from the three multi-airport companies in China are used as subjects to uncover the existence of technology spillover.

The remainder of this paper is organized as follows. Section 2 reviews the previous studies on airport operational efficiency analysis. Section 3 describes the methodological framework of the three-stage DEA. Section 4 explores the technology spillover among allied airports in China. Finally, section 5 presents our conclusions and a plan for future work.

2. Literature review

Existing studies on operational efficiency of airports have focused on two aspects: the development of airport alliances and the evaluation of airport operational efficiency. Although new airport alliances have appeared in the past few decades, research on the development of airport alliances has not attracted much attention. Doganis (1999, 2001) predicted that in 10 years the global aviation market would be controlled by only a few giant airline alliances or airport alliances in a parallel process. In contrast, Graham (2001) doubted Doganis (1999, 2001) and other similar predictions. In Graham's opinion, there would be a series of airport alliances that would improve airport operational efficiency. Tretheway (2001) found that the goal of a worldwide federation for international freight was based on cooperation and thus the alliance did not benefit its members. Mountford and McNamee (2007) summarized the ownership structures and the market competition among the multi-airport group corporations across the world. It was found that most of the corporations had major interests in more than one airport and strategic holdings in various airports. Forsyth et al. (2011) analyzed three drivers of airport alliances (i.e., non-aviation business, ground handling, and infrastructure) and noted that airports could benefit from both the management systems and technology spillover of airport alliances. Compared to the advantages of airline alliances (e.g., improving technical efficiency and reducing transaction costs to customers), however, the development advantages of airport alliances are less clear and airport alliances are not as stable as airline alliances.

The existing studies reveal that airports benefit from technology spillover, which is closely related to airport operational efficiency. The evaluation of airport operational efficiency is a popular subject for airport studies. A number of studies have focused on evaluating airport operational efficiency, and they have had two main features. First, some researchers have focused on evaluating operational efficiency in different areas or under different circumstances (Martín and Román, 2001; Fernandes and Pacheco, 2002; Barros and Dieke, 2007; Fung et al., 2008; Ablanedo-Rosas and Gemoets, 2010; Tsekeris, 2011; Assaf and Gillen, 2012; Perelman and Serebrisky, 2012; Choo and Oum, 2013; Fan et al., 2014; Tsui et al., 2014a, b; Ülkü, 2015; Örkcü et al., 2016; Liu, 2016; Coto-Millan et al., 2016). Second, other researchers have attempted to establish a complete index system or more advanced methods to evaluate airport operational efficiency (Lee et al., 2014; Lai et al., 2015; Merkert and Assaf, 2015; Olfat et al., 2016; Sun et al., 2017). Most of them have proposed a series of extended DEA models to accurately evaluate the airport operational efficiency.

It is clear that while there have been many studies on the evaluation of airport operational efficiency, few have paid attention to the advantages and development trends of airport alliances, particularly the influences of airport alliances on the technical efficiency of allied airports. To validate whether allied airports have a significant advantage in operational efficiency, and to investigate the effects of technology spillover, this paper proposes a methodological framework to identify and analyze the more obvious technology spillover among allied airport.

3. Methodology

3.1. Methodological framework

It is known that propensity score matching (PSM) method is popular in observational studies for uncovering the true association between treatments and outcomes (Raghunathan et al., 2016). However, due to of sample size constraints (especially the scale of allied airports), the PSM method is not suitable for small-sized samples. To determine whether allied airports have technology spillover, and whether the spillover effect outperforms self-development, we propose a research framework (Fig. 1) based on a three-stage DEA model instead.

First, to determine the presence of technology spillover in allied airports, a method is suggested to assess airport operational efficiency. The operational efficiency of an airport is not only related to its inputs (e.g., infrastructures, investments and staffs) and outputs (e.g., passenger traffic and freight cargo) but is also influenced by external environmental factors such as urban economic development. External environmental factors may alter the evaluation of operational efficiency, which is known as the environmental effect. These negative effects are removed in the suggested three-stage DEA model.

Second, to validate the significant difference between allied airports (treatment group) and non-allied airports (control group) in terms of operational efficiency, the control group was built according to the previous operational efficiency of the allied airports before they joined their alliances. That is, before the allied airports joined their alliances, contemporary non-allied airports whose operational efficiencies were similar to those of the potential allied airports were selected for the control group.

Next, we collected the input/output index values of the treatment group and the control group and the environmental variables. Based on the three-stage DEA model below, the pure technical efficiency of the two groups was calculated. Pure technical efficiency is considered as the know-how of airports. If the pure technical efficiency of an allied airport is significantly more improved than that of its paired airport in the control group, it means the allied airport has benefited from the technology spillover, though the value of pure technical efficiency may be revealed to be inefficient. Furthermore, the technology spillover of the allied airport outperforms its self-improvement of technical efficiency if the airport remains unallied.

Finally, with the pure technical efficiency of the two groups, a paired sample T test and difference comparison were adopted to validate whether allied airports enjoying technology spillover outperformed what their self-improvement would have been.

3.2. Three-stage DEA model

The three-stage DEA model, proposed by Fried (2002), is a non-parameter evaluation method used to better assess the efficiency of a decision-making unit (DMU). In Fried's opinion, the redundancy (inefficient part) in the inputs and outputs of the evaluation model resulted from management inefficiency, environmental effects and random disturbance. Therefore, the environmental effects and the influence of random disturbance should be removed so that the adjusted inputs and outputs can be obtained. Using the adjusted DEA model, the evaluation of operational efficiency is more accurate. The process of the three-stage DEA model is as follows.

> Stage I: The DEA-BCC (Banker, Charnes and Cooper) model for a normal efficiency evaluation is applied based on given input and output indexes.

Suppose that there are I DMUs and N inputs and M outputs, and $\boldsymbol{X}$ is an $N \times I$ matrix. X_n is the n-th row in $\boldsymbol{X}$, and λ is a column vector. By solving the following model, the technical efficiency (θ) of the ith DMU can be obtained:

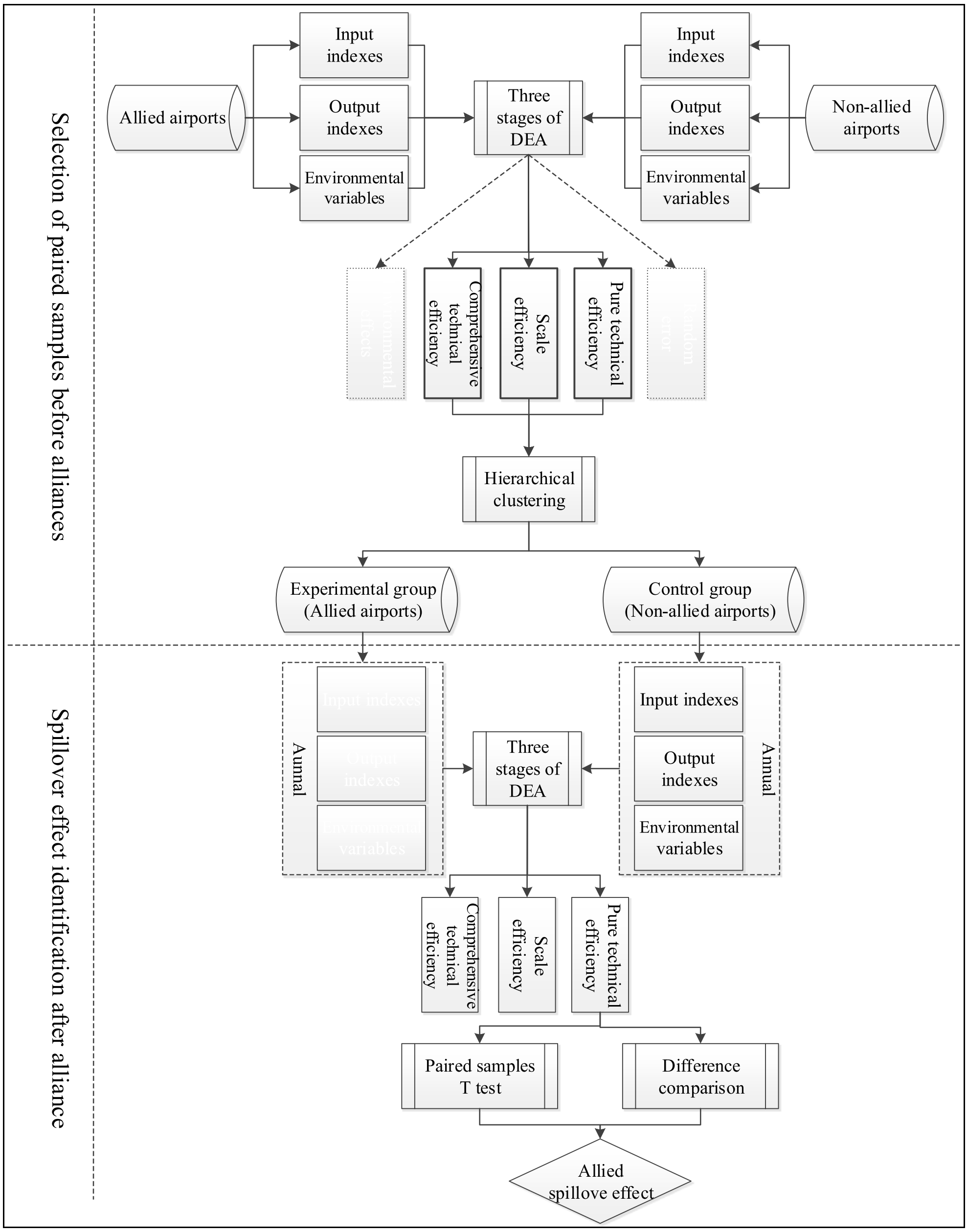

Fig. 1. The process of the methodological framework.

$$
\min \theta \quad s.t. \begin{cases} \sum_j^t \lambda_j x_j \le \theta x_0 \\ \sum_j^t \lambda_j y_j \ge y_0 \\ I\lambda = 1 \\ \lambda_j \ge 0,\ j = 1,2,\ldots,t \end{cases} \tag{1}
$$

Stage II: The stochastic frontier approach (SFA) model is employed to remove the environmental effect and the random error from the input slacks (input redundancy, which should be reduced).

The input slack of input n at DMU i is shown in Eq. (2):

$$
s_{ni} = x_{ni} - X_n\lambda \ge 0 \tag{2}
$$

The SFA regression model is shown in Eq. (3.3):

$$
s_{ni} = f^n(z_i;\ \beta^n) + v_{ni} + u_{ni} \tag{3}
$$

where x_{ni} is the nth input of the ith DMU, $f^n(z_i;\ \beta^n)$ denotes the environmental effect on input slacks, $z_i = [z_{i1},\ldots,z_{Ki}]$ represents the K observable environmental variables of DMU i, $v_{ni} \sim N(0,\ \partial_{vn}^2)$ is a random error term, $u_{ni} \sim N^+(u^n,\ \partial_{un}^2) \ge 0$ is the management inefficiency obeying the nonnegative tail of normal distribution, and v_{ni} is independent from u_{ni}. Parameters $(\beta^n,\ u^n,\ \partial_{vn}^2,\ \partial_{un}^2)$ can be estimated by the method of maximum likelihood estimation.

To eliminate the influence of environmental variables and random error on the DMU efficiency evaluation, the DMUs should be adjusted so that they fall into the same environment. Therefore, the adjusted input of each DMU can be calculated by Eq. (4):

$$
x'_{ni} = x_{ni} + [\max_i\{z_i\hat{\beta}^n\} - z_i\hat{\beta}^n] + [\max_i\{\hat{v}_{ni}\} - \hat{v}_{ni}] \tag{4}
$$

Stage III: The initial input x_{ni} is replaced by the adjusted input x'_{ni}, while the outputs are unchanged; then, the new efficiency evaluation can be calculated by re-running the DEA-BCC model (Stage I).

3.3. Hierarchical cluster analysis

Cluster analysis (Eisen et al., 1998) is a statistical technique that is used for grouping a set of objects in such a way that objects in the same group (called a cluster) are more similar (in one sense or another) to each other than to objects in other groups (clusters). Cluster analysis was employed to select a paired airport for each allied airport. The process of hierarchical cluster analysis is as follows:

Stage I: Each sample is presumed to be a cluster;
Stage II: The between group linkage method is employed to calculate the squared Euclidean distance between every pair of samples (or clusters)
Stage III: The closest samples (or clusters) are assigned into the same cluster, and the distance between every pair of clusters is calculated
Stage IV: Stage II and III are repeated until all samples are grouped into one cluster

3.4. Paired-sample T test

According to the results of the three-stage DEA model and hierarchical cluster analysis, the impacts of the environmental factors on the technology spillover of alliances are removed, and members of both the treatment group and the control group are clustered and paired according to the value of three types of operational efficiency. Thus, the paired-sample T test (Fritz and Berger, 2015) was applied to compare the means of pure technical efficiency of any two random airport samples. The test allows us to validate whether the pure technical efficiency (technology spillover) of the allied airports (treatment group) is significantly different from that of the non-allied airports (control group). The paired-sample T test has two basic hypotheses. First, the two airport samples are random and independent of each other, and they are from populations obeying normal distributions with an identical variance. Second, the two groups are randomly sampled, which means that the two airports in a paired sample are randomly assigned to two experimental groups (the treatment and the control group). In fact, in this paper the treatment group is not randomly built because the airports from the alliance are already allied. Instead, the paired non-allied airports are randomly assigned to the control group according to hierarchical clustering, thus satisfying the second hypothesis, which can ensure the randomness of the paired sample.

3.5. Difference comparison

To validate whether the pure technical efficiency (technology spillover) of allied airports outperforms the self-development of non-allied airports, we defined difference comparison as Eq. (5) for further verification.

$$d_t^i = (vrste_t^{i,a} - vrste_t^{i,p}) - d_0^i \tag{5}$$

where d_t^i is the pure technical efficiency difference of pair i in year t, two types of *vrste* are the results of the three-stage DEA model, $vrste_t^{i,a}$ is the pure technical efficiency of the allied airport in pair i of year t, $vrste_t^{i,p}$ is the pure technical efficiency of the non-allied airport in pair i of year t, and d_0^i is the difference in the pure technical efficiency of pair i before the airport from the treatment group i joined an airport alliance. If $d_t^i > 0$, it reveals that the allied airport in pair i has a significant advantage from *pure technical efficiency* (technology spillover). Otherwise, it means that the allied airport does not benefit from the technology spillover.

4. Empirical study

According to the methodological framework, data of airport alliances in China were collected and the technical spillover among the airport alliances was identified by the three-stage DEA based model. The results were analyzed and are discussed below.

4.1. Data collection

(1) Airport alliances in China

According to the opinion of Forsyth et al. (2009), airport alliances can be classified into strategic alliances and multi-airport companies. Both types of airport alliances have appeared in China since 2001.

Strategic alliances (e.g., the East Asia Airport Alliance, and Northeastern Hinterland and Bohai Rim Region Aviation Market Strategic Airport Alliance) in China were founded in the form of an annual meeting or cooperation agreement. Due to the lack of an effective management system (the lack of any binding contracts or shared economic interests), the main mission of some strategic alliances is only to provide a platform for airlines and airports to negotiate air routes. Some other strategic alliances were dissolved continuously. Thus, the strategic airport alliances fall short of expectations for promoting operational efficiency.[1]

Meanwhile, three cross-regional multi-airport companies have been established in China since the institutional reform of the air transport industry: the Capital Airports Holding Company (CAH), China West Airport Group (CWA) and HNA Airport Group (HNA). These three companies use Beijing Capital International Airport (PEK), Xi'an Xianyang International Airport (XIY) and Haikou Meilan International Airport (HAK), respectively, as their base airports. Since the institutional reform, local governments have been responsible for the operational efficiency of airports. To improve operational efficiency, airports joined alliances through integration or in trust to access greater expertise in airport management and investment.[2] The development of multi-airport companies in China has been much more stable than the strategic alliances. Thus, airports from the three multi-airport companies were selected as study objectives to identify the existence of more obvious technology spillover.

(2) Data source and collection of airport data in China

Considering the data sensitivity of DEA models, this paper selected all the airports in China (110 civil airports, including 37 allied airports from the three multi-airport companies and 73 non-allied airports) that operated normally during the period of 2003–2014[3] as the sample to collect their operational data from *Statistical Data on Civil Aviation of China (2004–2015)*, to explore whether the member airports of multi-airport companies enjoy technology spillover. The information on the civil airports is listed in Appendix 1.

According to the research of Fung et al. (2008) and the availability of operational data of civil airports in China (airport operation data in China are not released to the public), this paper selected two input variables (terminal area and runway length) and three output variables (passenger traffic, cargo traffic and aircraft movements). The significant and high values of the correlation coefficients in Table 1 ensure that the inputs and outputs can be applied to the DEA model.

Since the external economic environment might have an impact on airport operational efficiency (Sarkis, 2000), this paper initially selected per capita GDP, the permanent population and whether or not the airport city is a tourist destination as three environmental variables. However, as will be seen in the following discussion, only two

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[1] http://www.hkxyedu.com/minhang/html/39443.html (access time: 2019.2.13).

[2] http://www.westaport.com/gaikuang.php?cat_id=1681 (access time: 2019.2.13).

[3] The data during the period of 2003–2014 were selected because the airport alliance in China first appeared in 2003, and the information on the HNA is unavailable after 2014.

Table 1
The correlation between input and output variables.

Variables	Output		
	Passenger traffic	Cargo traffic	Aircraft movements
Input			
Runway length	0.845** (0.000)	0.852** (0.000)	0.797** (0.000)
Terminal area	0.865** (0.000)	0.735** (0.000)	0.799** (0.000)

Note: Values in parentheses are p-values; **: $P < 0.05$, indicates significance at the 5% level.

environmental variables were kept. The data for these two variables were directly collected from the *China City Statistical Yearbook (2004–2015)*.

(1) Per capita GDP: An airport's scale of production is highly correlated with the economic development of its catchment area. Movements of people and cargo are more frequent, and the volume transported is much larger between developed cities and other areas, propelling the increase in the airport's production scale. However, a large scale of production does not necessarily equal high operational efficiency for an airport. To reasonably evaluate the operational efficiency of different airports, the influence of the urban economy should be removed from the evaluation.
(2) Permanent population: The scale of production of an airport is also influenced by the permanent population in its catchment area, though some researchers have taken the service radius instead (Cui et al., 2013). Under the same travel mode structure, a catchment area with a larger permanent population generates more trips via the corresponding airport. However, a larger throughput does not necessarily denote a higher operational efficiency for an airport. Therefore, the impact of the permanent population should be removed from the evaluation.
(3) Whether or not the airport city is a tourist destination: If an airport is located in a tourist city, part of its annual passenger traffic should be tourist traffic. The operational efficiency of airports may impact the reputation of the city as a tourist destination and may be given special importance by the local government. However, most airports worldwide are located in tourist cities. All of airports selected for this study are in cities listed in the Top Tourist City of China report, which is released by the China National Tourism Administration (CNTA).[4] Thus, this variable should not be considered in our methodology here.

4.2. Results

Based on the collected data, each allied airport from the three airport alliances was paired with a non-allied airport (Appendix 2), and the significant difference and spillover effects of pure technical efficiency (*vrste*) for each pair were tested following the methodological framework (the details of the results are shown in Appendix 3, Table 2 and Table 3).

First, according to the significance test of the pure technical efficiency difference (Table 2), 22 out of 37 paired samples (62.3%) had a significant difference with a significance level of 90% (P-value < 0.1), while 15 paired samples (37.8%) were not significantly different in terms of pure technical efficiency. Therefore, it is concluded that airport alliances probably have a remarkable effect on the pure technical efficiency of their member airports. Meanwhile, more than 60% of the airports in the CAH and HNA are significantly different from the paired airports, while the number for CWA is just 32.3%. That is, among the three largest multi-airport groups in China, it seems that only the CAH and HNA benefit the majority of their member airports through technology spillover. Most of the allied airports from the CWA are in the undeveloped western part of China, and there is no significant technology spillover among them.

Second, according to the results of the difference comparison analysis (Table 4.3), of the 22 paired airports with significant differences, the pure technical efficiency of only 8 allied airports (21.6% of all the allied airports) showed an increasing tendency or had an obvious advantage over their paired airports (the airports with bolded font in Table 3).

Against expectation, the number of allied airports with technology spillover had a negative relationship with allied time span. The most reasonable explanation for this is as follows. The development of the civil aviation industry in China during this period was far behind that of developed countries. In past decades, the civil airports in China relied heavily on passenger traffic to maintain their operations, which meant that most civil airports were still in the stage of fast development. However, when a mismatch between the supply of airport infrastructures and air transport demand began appearing frequently in most airports, airport operators gradually attached importance to technical efficiency over the last two decades. It is therefore contended that the later a civil airport joins an airport alliance in China, the more significant the technology spillover.

Meanwhile, among the 8 allied airports, only SYX and HRB achieved more than 10 million passengers annually, while the remaining 6 were all small- and mid-sized airports with millions of passengers per year and were located in mid-western China. According to Ye and Yang (2015), the urban economics of these airport cities were at the middle level and increasing at a very fast speed (12% annual rate of increase in per capita GDP). The operational efficiency of the local airports was in need of improvement to fulfil the increasing demand while the scale of the infrastructure was limited. Benefitting from the spillover effect of their airport alliances, the allied airports achieved obvious improvement in technical efficiency.

Finally, from the perspective of airport alliances, according to the evaluation results, the multi-airport companies in China should not blindly expand the scale of their alliances. At present, the operational efficiency of most civil airports in China is closely related to the high levels of air transport demand, and a minimal amount of spillover of technology will aggravate the structure of an unstable airport alliance. On the other hand, for the decision-makers of airport alliances in China, small- and mid-sized airports with dynamic urban economies should first be subsumed to spread the obvious technology spillover within an alliance to member airports.

5. Conclusions and implications

Unlike the stable development of airline alliances, the advantages of airport alliances have been a controversial topic since they were proposed because of the unclear technology spillover effects for their member airports. To explore whether airport alliances have significant technology spillover for member airports, this paper proposed a methodological framework based on the three-stage DEA model. In the context of airport operation studies, the existing studies discussed the advantages of airport alliances by qualitatively analyzing the potential impacts of alliances on the airport services industry. The methodological framework of the present study could be regarded as a quantitative analysis that is useful for operators of both airport alliances and airports in identifying technology spillover.

The results showed that at present, technology spillover within airport alliances in China does not outperform the self-development of unallied airports, and the few allied airports that benefited more from technology spillover than they would have from self-development were small- and mid-sized airports in areas with rapidly developing urban economies. For managers of local civil airports in China, it is necessary

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[4] http://www.china.com.cn/chinese/TR-c/617172.htm.

Table 2
Results of the paired airport T test.

Pair	Code	Alliance	Allied Year	df	T-Sat (one-tailed)	P-Value (one-tailed)	T-Crit (one-tailed)
1	HAK&CTU	HNA	2003	10	−1.55	0.16	1.81
2	SYX&HFE	HNA	2003	10	1.44	0.09	1.81
3	WEF&WEH	HNA	2003	10	−2.42	0.02	1.81
4	PEK&PVG	CAH	2003	10	–	–	1.81
5	KOW&YBP	CAH	2003	10	2.00	0.04	1.81
6	TSN&TYN	CAH	2003	10	−2.14	0.03	1.81
7	JDZ&ZAT	CAH	2003	10	−0.81	0.21	1.81
8	KHN&NNG	CAH	2003	10	−2.22	0.03	1.81
9	HZG&MXZ	CWA	2003	10	−1.02	0.17	1.81
10	XIY&KMG	CWA	2003	10	0.49	0.32	1.81
11	ENY&PZI	CWA	2003	10	0.20	0.42	1.81
12	UYN&CGD	CWA	2003	10	0.08	0.35	1.81
13	DOY&SYM	HNA	2004	9	1.50	0.04	1.83
14	YIH&TXN	HNA	2004	9	1.93	0.01	1.83
15	XFN&JUZ	CAH	2004	9	−9.09	0.00	1.83
16	CKG&CTU	CAH	2004	9	−0.67	0.26	1.83
17	WUH&DLC	CAH	2004	9	−0.31	0.38	1.83
18	INC&HFE	CWA	2004	9	1.15	0.14	1.83
19	AQG&BSD	HNA	2005	8	5.82	0.00	1.86
20	BAV&TXN	CAH	2005	8	2.19	0.02	1.86
21	CIF&NAO	CAH	2005	8	0.23	0.41	1.86
22	HET&DYG	CAH	2005	8	3.82	0.00	1.86
23	TGO&LCX	CAH	2005	8	3.45	0.00	1.86
24	WUA&NAY	CAH	2005	8	0.56	0.29	1.86
25	CGQ&HFE	CAH	2005	8	−0.56	0.29	1.86
26	AEB&LCX	HNA	2006	7	−0.65	0.27	1.89
27	DNH&PZI	HNA	2006	7	2.47	0.02	1.89
28	JGN&LLF	HNA	2006	7	−0.60	0.29	1.89
29	LHW&ZUH	HNA	2006	7	2.14	0.03	1.89
30	IQN&BHY	HNA	2006	7	2.41	0.02	1.89
31	HEK&DDG	CAH	2006	7	1.91	0.05	1.89
32	HEK&DDG	CAH	2006	7	2.18	0.03	1.89
33	JMU&YHZ	CAH	2006	7	2.21	0.03	1.89
34	MDG&LZH	CAH	2006	7	4.18	0.00	1.89
35	NDG&DAX	CAH	2006	7	2.77	0.01	1.89
36	XNN&NAY	CWA	2006	7	3.12	0.01	1.89
37	LYG&LZO	HNA	2007	6	4.76	0.00	1.94

Note: The vrste of airports in pair 4 is equal to 1, so there is no need to test pair 4; Missing values in the treatment group are filled by values from the control group.

Table 3
The results of difference comparison.

Pair No.	Airport (IATA Code)	Airport Alliance	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013v	2014
2	**SYX**	**HNA**	**0.001**	**0.013**	**0.02**	**0.023**	**0.108**	**−0.07**	**0.122**	**0.121**	**0.11**	**0.172**	**0.203**
3	WEF	HNA	−0.052	−0.037	−0.02	−0.028	0.03	0.003	−0.034	−0.037	−0.039	−0.021	0.027
4	PEK	CAH	0	0	0	0	0	0	0	0	0	0	0
5	KOW	CAH	0	−0.016	−0.021	−0.023	0.01	−0.022	−0.027	−0.008	−0.013	−0.012	−0.001
6	TSN	CAH	0.028	0.019	0.011	0.016	0.085	−0.003	−0.285	−0.246	−0.282	−0.245	−0.189
8	KHN	CAH	0.003	0.005	0.005	0	0.092	−0.084	−0.093	−0.091	−0.052	−0.043	−0.073
13	**DOY**	**HNA**		**0.035**	**0.013**	**0.018**	**0.175**	**−0.008**	**0.03**	**0.034**	**0.038**	**0.02**	**−0.069**
14	**YIH**	**HNA**		**−0.002**	**−0.005**	**−0.004**	**0.015**	**−0.011**	**0.003**	**0.019**	**0.025**	**0.049**	**0.024**
15	XFN	CAH		−0.024	−0.031	−0.038	−0.036	−0.045	−0.032	−0.018	−0.011	−0.023	−0.034
19	AQG	HNA			−0.01	−0.019	−0.042	0.019	−0.042	−0.018	−0.018	−0.049	−0.059
20	BAV	CAH			−0.009	−0.014	0.009	0.003	−0.011	−0.001	0.022	−0.006	−0.035
22	HET	CAH			−0.001	−0.002	−0.131	−0.013	−0.093	−0.084	−0.038	−0.052	−0.076
23	**TGO**	**CAH**			**−0.008**	**−0.006**	**0.014**	**−0.012**	**0**	**0.019**	**0**	**0.017**	**0.033**
27	DNH	HNA				−0.002	0.004	0.003	−0.004	0.008	0.005	−0.013	−0.007
29	**LHW**	**HNA**				**0.001**	**0.047**	**0.042**	**−0.001**	**0.002**	**0.019**	**0.06**	**0.119**
30	**IQN**	**HNA**				**0.024**	**0.246**	**−0.083**	**0.087**	**−0.076**	**0.089**	**0.287**	**0.296**
31	**HRB**	**CAH**				**0.003**	**0.025**	**0.029**	**0.024**	**0.017**	**0.03**	**−0.02**	**−0.053**
32	**HEK**	**CAH**				**0**	**0.015**	**−0.002**	**0.003**	**0.005**	**−0.005**	**0.019**	**0.039**
33	JMU	CAH				−0.001	−0.042	0.001	0.004	−0.002	−0.005	−0.032	−0.024
34	MDG	CAH				−0.005	−0.016	0.004	−0.008	−0.006	−0.006	−0.031	−0.019
35	NDG	CAH				−0.004	−0.057	0.008	−0.015	0.004	0.001	−0.067	−0.07
36	XNN	CWA				−0.011	−0.221	0.048	−0.004	−0.001	−0.038	−0.169	−0.199
37	LYG	HNA					−0.018	0.017	−0.029	0.007	−0.021	0.011	−0.035

to keep abreast of the operational performance of their airports. Due to the rapid development of regional economies in China, it is only a matter of time before the operational performance of civil airports will rely on improvements in technical efficiency instead of pure demand increments. The decision-makers for civil airports should consider entering into airport alliances at the right time.

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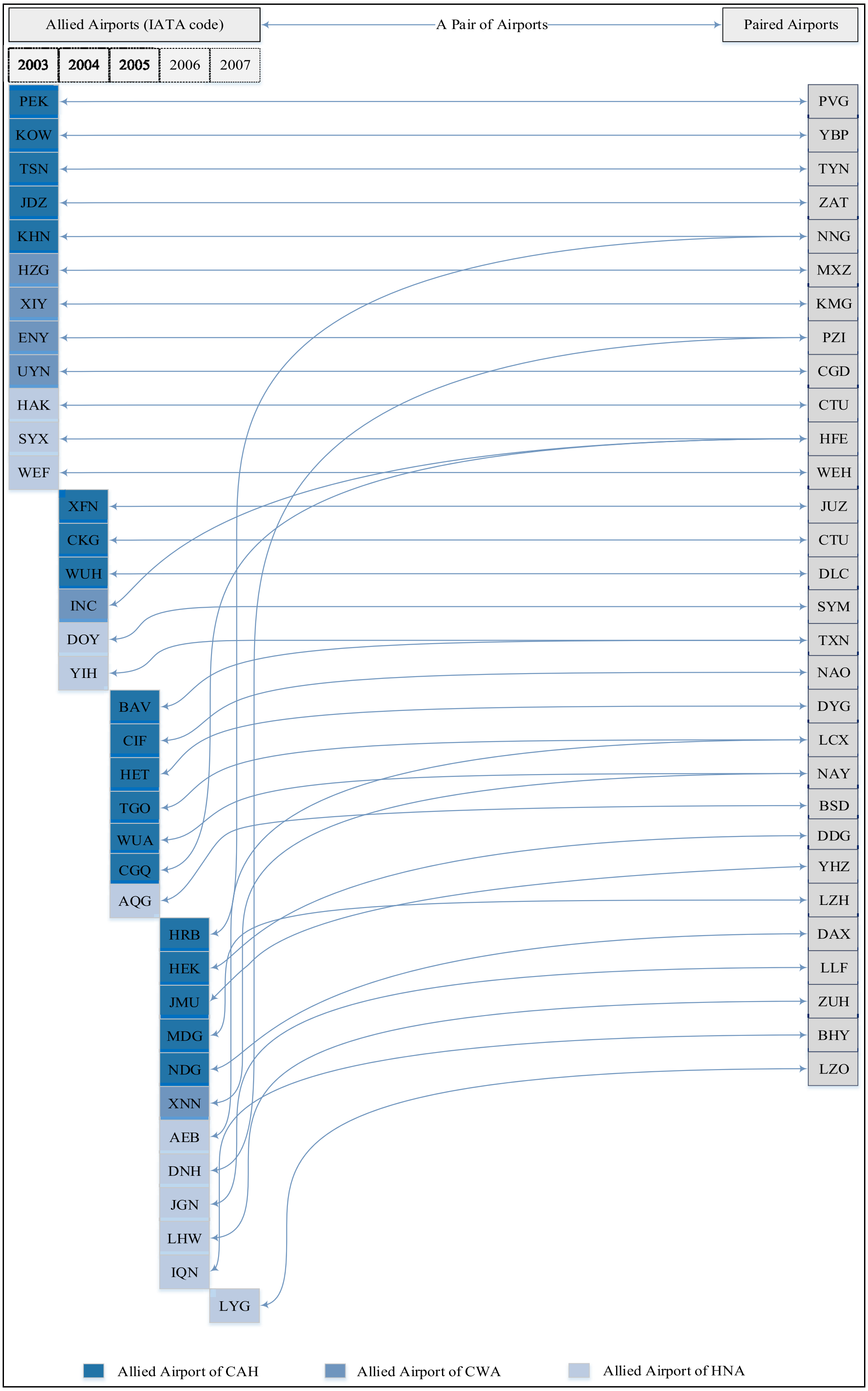
Appendix 1. information of 110 sample airports

City Name	Airport Code	Alliance	Allied Year	City Name	Airport Code	Alliance	Allied Year
Haikou	HAK	HNA	2003	Hefei	HFE	–	–
Sanya	SYX	HNA	2003	Huangshan	TXN	–	–
Weifang	WEF	HNA	2003	Jinan	TNA	–	–
Dongying	DOY	HNA	2004	Jinzhou	JNZ	–	–
Yichang	YIH	HNA	2004	Karamay	KRY	–	–
Anqing	AQG	HNA	2005	Kunming	KMG	–	–
Baise	AEB	HNA	2006	Lijiang	LJG	–	–
Dunhuang	DNH	HNA	2006	Liancheng	LCX	–	–
Jiayuguan	JGN	HNA	2006	Lincang	LNJ	–	–
Lanzhou	LHW	HNA	2006	Linyi	LYI	–	–
Qingyang	IQN	HNA	2006	Liuzhou	LZH	–	–
Lianyungang	LYG	HNA	2007	Luzhou	LZO	–	–
Beijing	PEK	CAH	2003	Luoyang	LYA	–	–
Ganzhou	KOW	CAH	2003	Meixian	MXZ	–	–
Tianjin	TSN	CAH	2003	Mianyang	MIG	–	–
Jingdezhen	JDZ	CAH	2003	Nanchong	NAO	–	–
Nanchang	KHN	CAH	2003	Nanjing	NKG	–	–
Xiangfan	XFN	CAH	2004	Nanning	NNG	–	–
Chongqing	CKG	CAH	2004	Nantong	NTG	–	–
Wuhan	WUH	CAH	2004	Nanyang	NNY	–	–
Baotou	BAV	CAH	2005	Ningbo	NGB	–	–
Chifeng	CIF	CAH	2005	Panzhihua	PZI	–	–
Hohehot	HET	CAH	2005	Qingdao	TAO	–	–
Tongliao	TGO	CAH	2005	Quanzhou	JJN	–	–
Wuhai	WUA	CAH	2005	Quzhou	JUZ	–	–
Changchun	CGQ	CAH	2005	Xiamen	XMN	–	–
Harbin	HRB	CAH	2006	Shanghai	SHA	–	–
Heihe	HEK	CAH	2006	Shanghai	PVG	–	–
Kiamusze	JMU	CAH	2006	Shenzhen	SZX	–	–
Mudanjiang	MDG	CAH	2006	Shenyang	SHE	–	–
Qiqihar	NDG	CAH	2006	Simao	SYM	–	–
Hanzhong	HZG	CWA	2003	Taiyuan	TYN	–	–
Xi'an	XIY	CWA	2003	Wanxian	WXN	–	–
Yan'an	ENY	CWA	2003	Weihai	WEH	–	–
Yulin	UYN	CWA	2003	Wenzhou	WNZ	–	–
Yinchuan	INC	CWA	2004	Urumqi	URC	–	–
Xining	XNN	CWA	2006	Wuxi	WUX	–	–
Baoshan	BSD	–	–	Wuzhou	WUZ	–	–
Beihai	BHY	–	–	Wuyishan	WUS	–	–
Beijing	NAY	–	–	Xuzhou	XUZ	–	–
Changde	CGD	–	–	Yantai	YNT	–	–
Changzhou	CZX	–	–	Yancheng	YHZ	–	–
Chengdu	CTU	–	–	Yibin	YBP	–	–
Dalian	DLC	–	–	Yiwu	YIW	–	–
Datong	DAT	–	–	Yongzhou	LLF	–	–
Dazhou	DAX	–	–	Yuncheng	YCU	–	–
Dandong	DDG	–	–	Zhanjiang	ZHA	–	–
Ordos	DSN	–	–	Zhangjiajie	DYG	–	–
Fuzhou	FOC	–	–	Changsha	CSX	–	–
Fuyang	FIG	–	–	Changzhi	CIH	–	–
Guangzhou	CAN	–	–	Zhaotong	ZAT	–	–
Guiyang	KWE	–	–	Zhengzhou	CGO	–	–
Guilin	KWL	–	–	Zhijiang	HJJ	–	–
Handan	HDG	–	–	Zhoushan	HSN	–	–
Hangzhou	HGH	–	–	Zhuhai	ZUH	–	–

Appendix 2. Pairs of alliance and non-allied airports



Appendix 3. the pure technical efficiency of paired airports (2003–2014)

Pair No.	Airport (IATA Code)	Airport Alliance	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	*Mean*
1	HAK	HNA	**0.889**	0.939	0.948	0.939	0.917	0.665	1	0.85	0.893	0.939	0.774	0.801	*0.880*
	CTU		**0.968**	0.971	0.98	0.986	0.984	0.912	0.963	0.977	0.9	0.825	0.699	0.805	*0.914*
2	SYX	HNA	**0.825**	0.883	0.919	0.929	0.919	0.82	0.789	0.891	0.925	0.966	0.889	0.954	*0.892*
	HFE		**0.864**	0.921	0.945	0.948	0.935	0.751	0.898	0.808	0.843	0.895	0.756	0.79	*0.863*
3	WEF	HNA	**0.886**	0.947	0.962	0.958	0.944	0.742	0.998	0.901	0.939	0.935	0.789	0.783	*0.899*
	WEH		**0.887**	1	1	0.979	0.973	0.713	0.996	0.936	0.977	0.975	0.811	0.757	*0.917*
4	PEK	CAH	**1**	1	1	1	1	1	1	1	1	1	1	1	*1.000*
	PVG		**1**	1	1	1	1	1	1	1	1	1	1	1	*1.000*
5	KOW	CAH	**0.966**	0.974	0.98	0.976	0.969	0.835	0.996	0.946	0.97	0.969	0.878	0.901	*0.947*
	YBP		**0.947**	0.955	0.977	0.978	0.973	0.806	0.999	0.954	0.959	0.963	0.871	0.883	*0.939*
6	TSN	CAH	**0.778**	0.895	0.929	0.93	0.909	0.701	0.985	0.539	0.609	0.619	0.47	0.509	*0.739*
	TYN		**0.774**	0.863	0.906	0.915	0.889	0.612	0.984	0.82	0.851	0.897	0.711	0.694	*0.826*
7	JDZ	CAH	**0.879**	0.883	0.955	0.971	0.963	0.73	0.971	0.899	0.884	0.934	0.81	0.809	*0.891*
	ZAT		**0.88**	0.875	0.947	0.964	0.954	0.756	1	0.919	0.905	0.923	0.797	0.814	*0.895*
8	KHN	CAH	**0.818**	0.89	0.92	0.925	0.9	0.76	0.842	0.737	0.782	0.854	0.797	0.832	*0.838*
	NNG		**0.826**	0.895	0.923	0.928	0.908	0.676	0.934	0.838	0.881	0.914	0.848	0.913	*0.874*
9	HZG	CWA	**1**	1	1	0.994	0.993	0.914	1	0.986	0.999			0.996	*0.988*
	MXZ		**1**	1	1	0.994	0.992	0.926	0.999	0.986	0.998	0.997	0.997	1	*0.991*
10	XIY	CWA	**0.928**	0.923	0.938	0.922	0.986	0.889	0.967	0.989	1	0.767	0.633	0.731	*0.889*
	KMG		**0.955**	0.958	0.973	0.98	0.976	0.891	0.901	0.89	1	0.884	0.554	0.623	*0.882*
11	ENY	CWA	**0.849**	0.867	0.931	0.947	0.931	0.652	0.998	0.881	0.902	0.916	0.733	0.713	*0.860*
	PZI		**0.859**	0.902	0.949	0.952	0.936	0.648	1	0.885	0.916		0.729	0.71	*0.862*
12	UYN	CWA	**0.871**	0.912	0.939	0.941	0.922	0.664	0.992	0.889	0.936	0.952	0.758	0.743	*0.877*
	CGD		**0.876**	0.876	0.949	0.957	0.943	0.715	0.955	0.872	0.878	0.89	0.844	0.839	*0.883*
13	DOY	HNA		**0.944**	1	0.979	0.973	0.897	0.999	0.945	0.972	0.977	0.785	0.707	*0.925*
	SYM			**0.936**	0.957	0.958	0.947	0.714	0.999	0.907	0.93	0.931	0.757	0.768	*0.891*
14	YIH	HNA		**0.951**	0.968	0.961	0.948	0.711	0.994	0.909	0.961	0.969	0.8	0.777	*0.904*
	TXN			**0.944**	0.963	0.959	0.945	0.689	0.998	0.899	0.935	0.937	0.744	0.746	*0.887*
15	XFN	CAH		**0.941**	0.958	0.954	0.939	0.713	0.968	0.917	0.944	0.954	0.803	0.784	*0.898*
	JUZ			**0.926**	0.967	0.97	0.962	0.734	0.998	0.934	0.947	0.95	0.811	0.803	*0.909*
16	CKG	CAH		**1**	1	0.962	0.958	1	0.951	1	0.623	0.762	0.742	0.824	*0.893*
	CTU			**0.971**	0.98	0.986	0.984	0.912	0.963	0.977	0.9	0.825	0.699	0.805	*0.909*
17	WUH	CAH		**0.932**	0.95	0.955	0.954	0.751	0.974	0.917	0.941	0.986	0.938	0.939	*0.931*
	DLC			**0.954**	0.969	0.966	0.955	0.753	0.988	0.93	0.975	0.991	0.929	0.875	*0.935*
18	INC	CWA		**0.89**	0.928	0.926	0.901	0.619	0.956	0.83	0.868	0.896	0.723	0.731	*0.843*
	HFE			**0.921**	0.945	0.948	0.935	0.751	0.898	0.808	0.843	0.895	0.756	0.79	*0.863*
19	AQG	HNA			**0.931**	0.936	0.917	0.674	0.999	0.861	0.888	0.891	0.718	0.721	*0.854*
	BSD				**0.951**	0.966	0.956	0.736	1	0.923	0.926	0.929	0.787	0.8	*0.897*
20	BAV	CAH			**0.956**	0.943	0.924	0.691	0.994	0.881	0.927	0.952	0.731	0.704	*0.870*
	TXN				**0.963**	0.959	0.945	0.689	0.998	0.899	0.935	0.937	0.744	0.746	*0.882*
21	CIF	CAH			**0.937**	0.938	0.919	0.666	0.997	0.869	0.901	0.904	0.719	0.733	*0.858*
	NAO				**0.929**	0.935	0.919	0.703	0.966	0.885	0.881	0.888	0.722	0.733	*0.856*
22	HET	CAH			**0.965**	0.96	0.947	0.572	0.98	0.81	0.848	0.9	0.697	0.679	*0.836*
	DYG				**0.968**	0.964	0.952	0.706	0.996	0.906	0.935	0.941	0.752	0.758	*0.888*
23	TGO	CAH			**0.975**	0.974	0.968	0.762	0.998	0.951	0.97	0.968	0.86	0.853	*0.928*
	LCX				**0.964**	0.971	0.963	0.737	0.999	0.94	0.94	0.957	0.832	0.809	*0.911*
24	WUA	CAH			**0.971**	0.966	0.955	0.679	0.999	0.931	0.976	0.984	0.806	0.752	*0.902*
	NAY				**0.967**	0.934	0.913	0.837	0.965	0.833	0.872	0.93	0.793	0.829	*0.887*
25	CGQ	CAH			**0.935**	0.933	0.909	0.665	0.985	0.854	0.896	0.927	0.774	0.769	*0.865*
	HFE				**0.945**	0.948	0.935	0.751	0.898	0.808	0.843	0.895	0.756	0.79	*0.857*
26	AEB	HNA				**0.969**	0.968	0.794	0.97	0.933	0.909	0.943	0.859	0.866	*0.912*
	LCX					**0.971**	0.963	0.737	0.999	0.94	0.94	0.957	0.832	0.809	*0.905*
27	DNH	HNA				**0.947**	0.929	0.647	0.998	0.876	0.919	0.918	0.711	0.698	*0.849*
	PZI					**0.952**	0.936	0.648	1	0.885	0.916		0.729	0.71	*0.847*
28	JGN	HNA				**0.953**	0.937	0.722	0.996	0.883	0.937	0.95	0.726	0.672	*0.864*
	LLF					**0.952**		0.713	0.999	0.892	0.912	0.915	0.757	0.765	*0.863*
29	LHW	HNA				**0.809**	0.767	0.497	0.96	0.676	0.717	0.745	0.563	0.608	*0.705*
	ZUH					**0.876**	0.833	0.517	0.985	0.744	0.782	0.793	0.57	0.556	*0.740*
30	IQN	HNA				**0.912**	0.905	0.839	0.915	0.899		0.95	0.92	0.925	*0.908*
	BHY					**0.908**	0.877	0.589	0.994	0.808	0.854	0.857	0.629	0.625	*0.793*
31	HRB	CAH				**0.941**	0.924	0.714	0.976	0.875	0.911	0.957	0.841	0.873	*0.890*
	NNG					**0.928**	0.908	0.676	0.934	0.838	0.881	0.914	0.848	0.913	*0.871*
32	HEK	CAH				**0.96**	0.948	0.709	0.999	0.911	0.92	0.924	0.762	0.769	*0.878*
	DDG					**0.958**	0.946	0.692	0.999	0.906	0.913	0.927	0.741	0.728	*0.868*
33	JMU	CAH				**0.979**	0.973	0.783	0.998	0.953	0.974	0.972	0.856	0.86	*0.928*
	YHZ					**0.98**	0.975	0.826	0.998	0.95	0.977	0.978	0.889	0.885	*0.940*
34	MDG	CAH				**0.957**	0.942	0.694	0.997	0.902	0.939	0.94	0.752	0.757	*0.876*
	LZH					**0.962**	0.952	0.715	0.998	0.915	0.95	0.951	0.788	0.781	*0.890*
35	NDG	CAH				**0.978**	0.972	0.808	0.999	0.95	0.953	0.954	0.864	0.876	*0.928*
	DAX					**0.986**	0.984	0.873	0.999	0.973	0.957	0.961	0.939	0.954	*0.958*

36	XNN	CWA	**0.893**	0.861	0.575	0.972	0.788	0.83	0.851	0.583	0.589	*0.771*
	NAY		**0.934**	0.913	0.837	0.965	0.833	0.872	0.93	0.793	0.829	*0.878*
37	LYG	HNA		**0.951**	0.73	0.997	0.912	0.925	0.933	0.794	0.799	*0.880*
	LZO			**0.956**	0.753	0.998	0.924	0.947	0.947	0.804	0.823	*0.894*

Note: the bolded are the efficiency value of allied airport attending the alliances.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.tranpol.2019.05.004.

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