Impact of Flights Delays on Productivity of Yangtze River Delta Airports

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Abstract: - This paper assesses productivity of 10 airports around Yangtze River Delta in 2007. This study differs from previous work in that both desirable and undesirable outputs (i.e., number of delays flights) are considered. A non-parametric directional output distance function, rather than the traditional Data Envelopment Analysis (DEA), was applied. For comparison purposes, a DEA model without consideration of undesirable outputs was also estimated. The results show that after flights delays are taken into assessment, many small, less congested airports are found more efficient, which even on the efficient frontier. Overall, the evaluation results should be more comprehensive and fairer in sense. They indicate that there may be a balance between quantity and quality of outputs in the achievement of efficient outcomes.

Key-Words: - airport productivity; Yangtze River Delta; undesirable outputs; delayed flights; directional output distance function; DEA.

1 Introduction

As the aviation industry has become more competitive, airports have had to adapt their operations to become more productive. So do Yangtze River Delta airports. In recent years, a number of academic studies have been conducted assessing productivity of airport around the world, especially in China [1][2][3][4][5][6][7][8][9][10][11][12]. From an airport operator's perspective, the number of aircraft movements, passengers, and cargo throughput perhaps are the most widely accepted outputs benchmark in analyzing the airports' efficiency because the busier airports yield the larger outputs.

However, it is noteworthy that there is another important benchmark on the downside of airport operations, such as delay and noise. It is generally known that the majority businessmen would prefer on-time flights to delayed flights. To certain extent, flight delays can be considered to be an undesirable output of the air transport system. To date, few studies have covered both the production of desirable outputs and the production of undesirable in assessing the productivity of airports around the world [13][14][15][16]. This is the major thrust of this research.

This study reevaluates airport productivity by taking both desirable and undesirable outputs into consideration because of the importance of delays to airport management. Based on our analysis, we are able to compare the efficiency of airports after accounting for undesirable outputs, namely delays. To our knowledge, this is the first airport productivity study that directly considers aircraft delays as an undesirable output in China. The rest of the paper is organized as follows. It first reviews previous studies relevant to airport productivity (Section 2). This is followed by a description of our study's methodology (Section 3). We will then describe the data set used for the analysis, followed by a discussion of our results (Section 4 and 5). Section 6 concludes this article.

2 Literature Review

Airport efficiency has been the subject of a number of research studies applied DEA[1][2][3][4][5][6][7][8][9][10][11][12]. These studies typically model an airport as a decision making unit (DMU) taking multiple inputs and producing multiple outputs. Inputs may include production factors such as land area, runway, terminal area, and labor units. While major outputs are passengers, aircraft movements and cargo throughput. We observe that the results tend to identify busy airports as efficient. In fact, it may be more "efficient" at producing more undesirable outputs. This is mainly because the chosen set of outputs overemphasizes on quantity of traffic, but none on its quality. Such results may never be acceptable in practice. As we know, as desirable outputs are produced, there are generally undesirable byproducts produced as well, notably mishandled baggage, delay and noise. So, we should not ignore the downside of facilities and give credit to airports that keep delays at low level. The results may become more meaningful and practical for the airport business.

Although Data Envelopment Analysis (DEA) seems to be a prevailing technique for analyzing productivity of airports [1][2][3][4][5][6][7][8][9][10][11][12], it may be quite problematic in consideration of undesirable outputs[17][18][19]. The reason lies in its mathematical mechanism in determining whether an airport is on the efficient frontier. In reality, an airport manager never wishes to expand both number of passengers and delay simultaneously. To account for joint production characteristic, we resort to the non-parametric directional output distance function [20][21] which will be described in the next section. To the best of our knowledge, this approach has been applied to study airport productivity only once by Ming-Miin Yu, in whose study noise was identified as the lone undesirable output [13][14].

3 Research Methodology

3.1 Characterizing airports joint producing of desirable and undesirable outputs

The methodology should be able to deal with two main questions. First, it should be able to consider multiple inputs and outputs simultaneously. Second, it should be able to assess efficiency when both desirable and undesirable outputs are produced.

To implement above notion, we resort to the non-parametric distance function. The distance function introduced by Shephard [22] provides a complete characterization of the structure of production technology. The distance function allows one to describe a multi-input, multi-output production technology without the need to specify a behavioral objective.

Let us denote $y \in R_M^+$, $b \in R_J^+$ and $x \in R_N^+$ as vectors of desirable outputs (goods), undesirable outputs (bads), and inputs respectively. In this context, we examine production of K airports with (x^k, y^k, b^k), where k is an index of an individual airport. Then the production technology can be characterized by the output set:

$$P(x) = \{(y,b); x\, can\, produce(y,b)\} \tag{1}$$

According to Fare and Grosskopf[18], for well operation we assume the $P(x)$ is a bounded and closed set and satisfies the following three properties:

P1. Outputs are weakly disposable. If $(y,b) \in P(x)$ and $0 \le \theta \le 1$, then $(\theta y, \theta b) \in P(x)$. In our airport operation context, this assumption implies that holding inputs x constant, if delays are to be decreased then the number of operations must also be decreased. In other words, both desirable and undesirable outputs may be proportionally contracted. If a reduction in delays is desired, airport managers could also divert some of the constant inputs to clean up delays. It models the idea that there is a cost to 'cleaning up' undesirable outputs.

P2. Desirable outputs and undesirable outputs are null-joint. If $(y,b) \in P(x)$ and $b = 0$ then $y = 0$. It states that the only way to eliminate all undesirable outputs is to end the production process. In our airport operation context, null-joint implies that where there are aircraft movements, there must be some delays. These may result from any number of causes (e.g., air carrier, extreme weather condition, airport operations, late arrival aircraft, security, and accident).

P3. Desirable outputs and inputs are strong disposability. If $(y,b) \in P(x)$ then for $y' \le y$, $(y',b) \in P(x)$ and for $x' \ge x$, $(y',b) \in P(x) \subseteq P(x')$. Strong disposability of desirable outputs implies that it is possible to freely dispose of desirable outputs and still remain in $P(x)$. Strong disposability of inputs implies that an increase in any one input dose not reduce the size of $P(x)$.

Based on the above three assumptions, we identify the production technology for an individual airport as output set $P(x)$:

$$\begin{aligned} P(x_k) = \{(y,b):& \\ &\sum_{k \in K} \lambda_k y_{km} \ge y_{km}, m = 1 \ldots M \\ &\sum_{k \in K} \lambda_k b_{kj} = b_{kj}, j = 1 \ldots J \\ &\sum_{k \in K} \lambda_k x_{kn} \le x_{kn}, n = 1 \ldots N \\ &\lambda_k \ge 0, k = 1 \ldots K\} \end{aligned} \tag{2}$$

Where k, m, j and n are indexes of airports, desirable outputs, undesirable outputs, and inputs respectively. λ is an intensity scalar that allows for convex combination between airports. The constraints for the undesirable outputs b_j , $j = 1...J$ are equality constraints that model the idea that these outputs are not freely disposable. Meanwhile free disposability of desirable outputs y_m , $m = 1...M$ and inputs x_n , $n = 1...N$ are allowed by using the inequalities in their respective constraints.

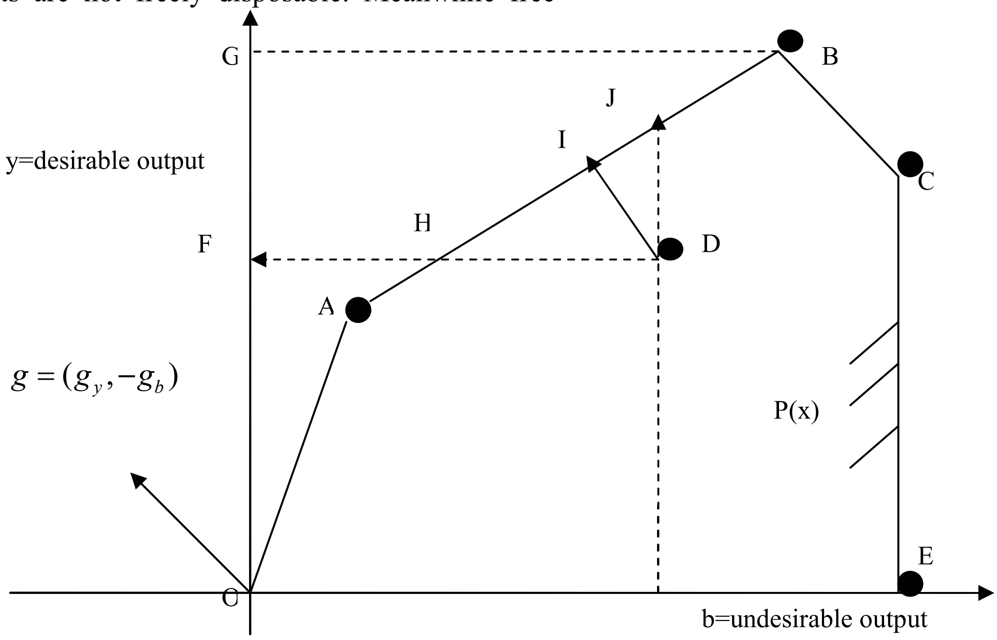

Fig.1 Illustraion of airports efficiency

In Fig.1, we assume four airports (A, B, C, D) with the same amount of inputs x , produce different amount of desirable outputs y , and undesirable outputs b . $P(x)$ is drawn as piecewise linear as we make use of linear programming. This figure illustrates how the assumptions (P1, P2 and P3) are used in the construct. First, $P(x)$ is convex and compact. It is bounded by 0ABCE. The origin is included in $P(x)$ because of the P2 assumption. Seeing from Fig.1 airports A, B and C are on the efficient frontier. The vertical line segment CE occurs because of P3 assumption. The negative slope portion, BC, is possible because traffic may be blocked due to a long queue of delayed flights, hence reducing throughput. The P1 implies that for any point on, or inside $P(x)$, a proportional contraction in both (y,b) is feasible. Note that if we ignore undesirable outputs, $P(x)$ will be the area bounded by 0GBCE, implying that an airport can service very high traffic volume without incurring delays which may be contrary to reality.

3.2 Measuring relative productivity

To measure the inefficiency level of airport D in Fig.1, the desired measurement is along the diagonal line DI or in the direction of vector $g = (g_y, -g_b)$. This measurement is justified on the premise that we seek to maximize the expansion of desirable outputs and the contraction of undesirable outputs simultaneously. The directional output distance function is expressed as follows:

$$\vec{D}_o(x, y, b; g_y, -g_b) = \max\{\beta : (y + \beta g_y, b - \beta g_b) \in P(x)\} \tag{3}$$

In equation (3) the subscript 'o' is used to show that it is an output-orientated measure. To assess the level of inefficiency for individual airports, we solve the following linear programming problem:

$$\begin{aligned} &\max \beta_k \\ &s.t. \\ &\sum_{k \in K} \lambda_k y_{km} \geq y_{km} + \beta_k g_y, m = 1...M \\ &\sum_{k \in K} \lambda_k b_{kj} = b_{kj} - \beta_k g_b, j = 1...J \\ &\sum_{k \in K} \lambda_k x_{kn} \leq x_{kn}, n = 1...N \\ &\lambda_k \geq 0, k = 1...K \end{aligned} \tag{4}$$

Selection of the directional vector $g = (g_y, -g_b)$ is rather flexible. For example, using $g = (0, b)$

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implies that we measure the level of inefficiency along the horizontal line DF, or project airport D to the frontier at H. Meanwhile, using $g = (y, 0)$ yields the projection on the frontier at J.

4 Modeling airport operations

An airport may be viewed as a production unit. There are four common physical inputs that we consider in this study i.e., terminal area, apron area, runway area and land area. Most airport managers set targets to maximize the movement of aircraft, passenger throughput and quantity of cargo transported. In this study, delays are considered as undesirable outputs from airport operations. The Civil Aviation Administration of China (CAAC) has defined a 15-min deviation from scheduled time as the criterion for classifying delayed flights. We have adopted the same definition for this study. A flight is identified as delayed if it is operated more than 15 min later than the scheduled time. In our study we consider delayed flights in order to capture more completely the effect of delays. Fig.2 shows the production model of airport operations.

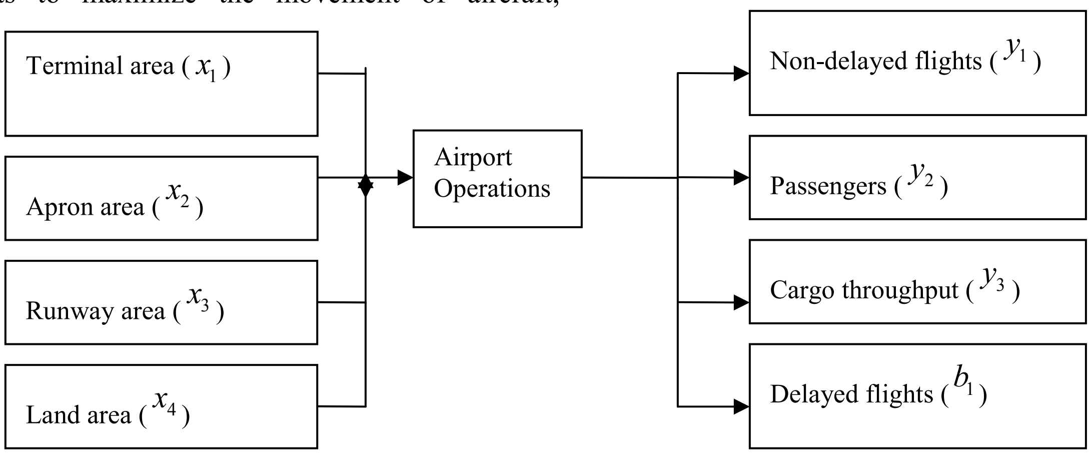

Fig.2 Production model of airport operations

In this study, we will use $g = (y, -b)$ which means that the projected direction depends on individual airport's outputs. The linear program in (4) is rewritten as (5).

$$\max \beta_k$$
$$s.t.$$
$$\sum_{k \in K} \lambda_k y_{km} \geq y_{km}(1+\beta_k), m = 1...M$$
$$\sum_{k \in K} \lambda_k b_{kj} = b_{kj}(1-\beta_k), j = 1...J$$
$$\sum_{k \in K} \lambda_k x_{kn} \leq x_{kn}, n = 1...N$$
$$\lambda_k \geq 0, k = 1...K \tag{5}$$

To assess the productivity of K airports, we solve (5) K times, each for an individual airport. A higher value of β_k indicates a lower level of efficiency. An efficient airport has β_k =0. It can also be used to rank the performance of airports.

5 Results and discussion

We are first interested in assessing the productivity of airports around Yangtze River delta in considering the undesirable outputs, delays. Overall, there are 10 airports in our dataset, namely, Shanghai Pudong International Airport, Shanghai Hongqiao International Airport, Hangzhou Xiaoshan International Airport, Nanjing Lukou International Airport, Ningbo Lishe International Airport, Wuxi Airport, Changzhou Airport, Taizhou Luqiao Airport, Zhoushan Airport and Nantong Airport. We will apply our model to analyze the effect of these operational characteristics on productivity to gain more insights into the efficiency scores.

In order to analyze the impact of undesirable outputs on productivity, we modeled two separate cases. All cases have the same set of inputs, but different sets of outputs. Specifications of the data sets are listed as follows:

Case1: The model is restricted since undesirable outputs are not taken into consideration. In this case, aircraft movements include total movements both delayed and non-delayed flights.

Set of inputs= {runway area, terminal area, apron area, land area}.

Set of desirable outputs= {passengers, aircraft movements, cargo throughput}.

Set of undesirable outputs= {none}

Case 2: This case separates aircraft movements into non-delayed and delayed flights. Non-delayed flights are included in the set of desirable outputs. Delayed flights are included in the set of undesirable outputs. The difference between Case 1 and Case 2 is the impact of delays in the determination of productivity.

Set of inputs= {runway area, terminal area, apron area, land area}.

Set of desirable outputs= {non-delayed flights, passengers, aircraft movements, cargo throughput}.

Set of undesirable outputs= {delayed flights}.

Table 1 Efficiency scores for two cases

Airport name	Airport code	Case1	Case2
Shanghai pudong	PVG	0	0
Shanghai hongqiao	SHA	0	0
Hangzhou xiaoshan	HGH	0	0
Nanjing lukou	NKG	0.590	0
Ningbo lishe	NGB	0.522	0.084
Wuxi shuofang	WUX	3.973	0.809
Changzhou benniu	CZX	0.758	0.309
Taizhou huangyan	HYN	1.330	0.461
Zhoushan putuoshan	HSN	1.348	0.330
Nantong xingdong	NTG	0	0
Sum		8.521	1.993
Average over the inefficient airports		1.420	0.399
Average over all airports		0.852	0.199

The efficiency scores between two cases are shown in Table1, in which the airports are arranged according to the annual passenger number in 2007. First, the results in case1 show the efficient airports are generally very busy airports, such as PVG and SHA. Second, delayed flights do affect the efficiency measure of airports clearly. A comparison between Case1 and 2 shows that there are more efficient airports when an undesirable output, such as the delayed flights, is taken into consideration. Furthermore, the efficiency scores in Case 1 are much higher than in Case 2. It means that the level of inefficiency may be overestimated by ignoring delays as an output. For example, in Case2 NGB receives a relatively lower score of 0.084, implying that NGB only needs to increase all outputs by 8.4% to be efficient. The average efficient score of 10 airports implies that all airports increase all outputs by 19.9% to achieve efficient utilization of facilities without incurring excessive delays, compared to 85.2% in Case1. The Case2 explains the interplay between traffic volume and system capacity considering the delays as undesirable outputs. Finally, the airports can be ranked by the efficiency scores. The airports are ranked in descending order by their scores exclude zero which identified as more and more efficiency. As shown in Table1, the less busy airports, such as NGB, CZX and HSN turn out to be ranked highly once delays are considered.

6 Conclusion

This paper first considered the delays in analyzing the productivity of airports in China. Since the traditional Data Envelopment Analysis (DEA) has a limitation to deal with undesirable outputs when assessing efficiency, we innovatively adopted the directional output distance function. The efficiency of 10 airports around Yangtze River Delta in 2007 has been analyzed in the study. The results indicate that when the factor of delays is considered, airport efficiency increases in many airports, especially those small and less congested airports. We conclude that an airport productivity study should consider both desirable and undesirable outputs. This will give more meaningful and practical results.

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