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Evaluating energy efficiency for airlines: An application of VFB-DEA

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ABSTRACT

In this paper, the energy efficiency of airlines has been studied with number of employees, capital stock and tons of aviation kerosene as the inputs and Revenue Ton Kilometers, Revenue Passenger Kilometers, total business income and CO_2 emissions decrease index as the outputs. A new model, Virtual Frontier Benevolent DEA Cross Efficiency model (VFB-DEA), is proposed to calculate the energy efficiencies of 11 airlines from 2008 to 2012. Spearman correlation coefficient is applied to validate the applicability of the new model. The results indicate that capital efficiency is an important factor in driving energy efficiency, and the American financial crisis had a significant influence on the change in energy efficiency during this period.

1. Introduction

In recent years, with the rapid development of the world economy and the improvement of the household consumption level, the gap between the demand and supply of energy has widened. According to the statistical data of the International Air Transport Association (2013), in 2012, the total energy cost of all of the airlines in the world was more than 160 billion dollars, and the carbon dioxide emission volume was more than 0.676 billion tons. Airline industry is one of the few sectors where energy consumption has increased at a rate of more than 6% over the past 10years. However, energy production has lagged behind, increasing at less than 6% over the same period. The gap between the energy supply and demand is becoming more and more pronounced. Meanwhile, according to the Commercial Aircraft Corporation of China (COMAC, 2014) forecast for the coming 20 years, the Revenue Passenger Kilometers (RPK) of the total aviation industry will increase by 4.8% a year, and the total passenger transport demand will be 2.6 times the current level. This huge demand for air transport will stimulate a much higher level of energy consumption. Furthermore, in 2011, the aviation industry produced approximately 676 million tons of CO_2, which is approximately 2% of the total global CO_2 emissions. Thus, the energy utilization problem of the airline industry has drawn great public attention. Energy efficiency is defined to reflect whether energy has been used efficiently (Clinch et al., 2001; Blomberg et al., 2012). For the past few years, energy efficiency has been a popular research topic, and many papers have focused on the evaluation of energy efficiency.

The energy efficiencies of different countries, regions and industries have been evaluated (Herring, 2006; Zhou et al., 2008; Worrell et al., 2009; Kaufman and Palmer, 2012; Wang et al., 2012; Hasanbeigi et al., 2013; Cui et al., 2014; Cui and Li, 2015), and the main research method is Data Envelopment Analysis. In Clinch et al. (2001), the energy efficiency of Ireland's dwelling industry was evaluated, and the national savings in energy costs, CO_2 and other environmental emissions were also assessed. Ramanathan (2005) used the Data Envelopment Analysis model to analyze the energy consumption and carbon dioxide emissions from 17 countries of the Middle East and North Africa. Önüt and Soner (2006) evaluated the energy efficiency of 32 five-star hotels in the Antalya Region. In Azadeh et al. (2007), an integrated approach based on data envelopment analysis (DEA), principal component analysis (PCA) and numerical taxonomy (NT) was proposed to assess the total energy efficiency of manufacturing sectors in some OECD (Organization for Economic Cooperation and Development) countries. In Zhou and Ang (2008), the Data Envelopment Analysis model was applied to measure the energy efficiencies of 21 OECD countries. In Mukherjee (2008a), Data Envelopment Analysis was used to measure energy efficiency in the Indian manufacturing sector. Mukherjee (2008b) measured the energy use efficiency of the U.S. manufacturing sector from 1970 to 2001 using the Data Envelopment Analysis model. Song et al. (2013) utilized a Super-SBM model to measure and calculate the

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energy efficiency of the BRIC countries. Wang et al. (2013) analyzed the total-factor energy and environmental efficiency of 29 administrative regions of China during the period from 2000 to 2008 through an improved Data Envelopment Analysis model. In Cui et al. (2014), the inputs and outputs of energy efficiency were calculated by the Economics Value Added (EVA) method. Data Envelopment Analysis (DEA) and the Malmquist index were applied to calculate the energy efficiencies of nine countries during the period from 2008 to 2012. Cui and Li (2014) proposed a three-stage virtual frontier DEA model to evaluate the energy efficiency of transportation sectors in 30 Chinese provincial administrative regions during 2003–2012.

Babikian et al. (2002) analyzed the fuel efficiency of different aircraft types, and the results showed fuel efficiency differences could be explained largely by differences in aircraft operations. Morrell (2009) analyzed the potential for greater fuel efficiency through using larger aircraft and different operational patterns. Miyoshi and Merkert (2010) evaluated carbon and fuel efficiency of 14 European airlines during the period from 1986 to 2007 to understand the relationship between fuel efficiency and fuel price, distance flown and load factors. Zou et al. (2014) employed ratio-based, deterministic and stochastic frontier approaches to investigate fuel efficiency of fifteen large jet operators in the U.S. The results showed that potential cost savings of mainline airlines could reach approximately one billion dollars in 2010.

However, the evaluation of fuel efficiency or energy efficiency for airlines in the above papers has not considered the undesirable output. In the existing energy efficiency papers, the main undesirable outputs are CO_2 emissions in Wei et al. (2007), CO_2 emissions in Zhou and Ang (2008), CO_2 emissions in Mandal (2010) and CO_2 emissions in Tao et al. (2012). This paper chooses CO_2 emissions as the undesirable output. Although airlines contribute only 2% of the global CO_2 emissions, the restriction imposed by the European Union on airline carbon emissions has caught the attention of many airlines.

In most papers, energy efficiency is defined to reflect the relationship between the outputs and the inputs. Based on the general definition of energy efficiency in Patterson (1996), energy efficiency refers to using less energy to produce the same amount of services or useful outputs. And in this paper, energy efficiency of an airline has considered CO_2 emissions based on the basic definition.

2. Methods

2.1. The selection of inputs and outputs

First, this paper summarizes the existing energy efficiency papers to lay a theoretical foundation for building a reasonable index system of airlines' energy efficiency. The inputs and outputs in selected studies are shown in Table 1.

In this paper, based on a review of the literature in Table 1 and the reality of the airline industry, the inputs and outputs of airlines' energy efficiency are selected. Three measurable variables are selected as inputs: labor (number of employees), capital (capital stock) and energy (tons of aviation kerosene). Because more than 95% of the energy consumption is aviation kerosene, this paper chooses it as the index of energy input. Four measurable variables are chosen as outputs: Revenue Ton Kilometers (RTK), Revenue Passenger Kilometers (RPK), total business income and CO_2 emissions decrease index.

Considering the impact of undesirable output on energy efficiency, this paper employs CO_2 emission decrease index as an indicator of airline CO_2 emission. The index is calculated as follows: If the CO_2 emission in year t is C_t and that in year $t-1$ is C_{t-1}, then the CO_2 emission decrease index is C_{t-1}/C_t. This index has two advantages. 1. It can eliminate the linear relationship between energy consumption and CO_2 emission. 2. The index transforms an undesirable output (CO_2 emission) into a desirable output. The larger the index, lower is the CO_2 emission. Furthermore, the index is a positive number, which can avoid the influence of 0 or a negative number on the final results. However, this paper has not considered the difference between jet and turboprop in CO_2 emission. Compared to jet aircrafts, turboprop aircrafts have lower energy consumption and slower speed, this difference may have some influence on the energy efficiency of airlines. This should be improved in the latter research.

2.2. Traditional Data Envelopment Analysis (DEA)

Data Envelopment Analysis (Charnes et al., 1978; Zhou et al., 2008) is a data planning method to evaluate the relative efficiency of decision-making units (DMUs) with multi-inputs and multi-outputs.

Table 1
The inputs and outputs in selected energy efficiency papers.

Papers	Objects	Inputs	Outputs
Boyd and Pang (2000).	Two segments of the glass industry	Electric, Fuel	Add value
Clinch et al. (2001)	Ireland's dwelling stock	Labor input, Cost input, Energy input	Energy benefit, Environmental benefits
Ramanathan (2005)	17 countries	CO_2 emissions per capita, Fossil fuel energy consumption	Gross domestic product per capita, Non-fossil fuel energy consumption
Önüt and Soner (2006)	32 five-star hotels	Number of employees, Annual electricity consumption, Annual water consumption, Annual liquefied petroleum gas consumption	Occupancy rate, Annual total revenue, Total number of guests
Azadeh et al. (2007)	OECD countries	Final consumption of electricity, Thermal aggregation of all fossil fuels final consumptions	Gross output, Value added from both categories
Hu and Kao (2007).	17 APEC economies	Labor input, Capital input, Energy input	Gross Domestic Product
Wei et al. (2007)	China's iron and steel sector	Industrial capital stock, Industrial labor force, Industrial energy consumption	Industrial value added, Industrial CO_2 emissions
Mukherjee (2008a)	Indian manufacturing sector	Labor, Capital, Energy, Materials.	Gross value of manufacturing production
Mukherjee (2008b)	U.S. manufacturing sector	Capital, Labor, Energy, Materials, Services	Gross output
Zhou and Ang (2008)	21 OECD countries	Capital stock, Labor force	Gross Domestic Product, CO_2 emissions
Blomberg et al. (2012)	Swedish pulp and paper industry	Labor, Electricity, Oil	Pulp or paper
Cui et al. (2014)	Nine countries	Number of employees in energy industry, Energy consumption amount, Energy services amount	CO_2 emissions per capita, Industrial profit amount
Cui and Li (2014)	30 provinces of China	Labor input, Capital input, Energy input	Passenger turnover volume, Freight turnover volume