AN INVESTIGATION OF OPERATING COST OF AIRPORTS: FOCUS ON THE EFFECTS OF OUTPUT SCALE

by

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ABSTRACT

In the air transport industry, airports play a key and active role as infrastructural providers, business partners, and economic enablers. With the projected robust growth in passenger and cargo traffic in the future, airports must expand to accommodate the increasing demand in traffic, which will invariably lead to increased operating and capital costs for airport operators. Some have argued that with expansion, airports will benefit from economies of scale, whereas others have suggested the opposite. Thus, the effect of increased airport output on costs remains controversial and not fully known.

To date, there has been a paucity of studies that have directly assessed the potential impact of economies of scale in the airport industry. The few studies that have addressed this issue have had significant limitations in modeling cost functions with capital inputs. Additionally, these studies used different functional forms and airport sampling procedures, which may have contributed to the large discrepancy in the results. Moreover, these studies evaluated economies of scale by using partial view of passengers or Work Load Unit (WLU) rather than as an aggregated output index. Many of these previous studies also lacked sufficient statistical power to properly address this issue. The main objectives of this thesis are to: 1) determine whether economies of output scale are indeed present in the airport industry; 2) quantify the magnitude of the economies; and 3) determine the threshold size of airport at which the economies change. To address these objectives, this analysis used data from 94 U.S. airports and employed translog cost functions and Variable Factor Productivity (VFP) in terms of passenger, WLU and output index.

This study found that economies of output scale in the airport industry were present to a threshold output index of 0.7, which is equivalent to 2.5 million passengers or 3 million WLU. Beyond this threshold, the economies disappeared. The volume of international passengers had a significant positive impact on operating costs. Delays, cargo volume, contract-out costs, snowbelt, and financial management approaches, on the other hand, did not materially affect economies of airports.

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1 INTRODUCTION

1.1 Background

Air transport industry is one of the fastest growing sectors in our economy. From 1971 to 2001, air passengers grew by six-fold translating into an average growth rate of 7% per year. Additionally, according to estimates generated by the International Civil Aviation Organization (ICAO), the annual growth rate in air passenger traffic from 2001 to 2005 was 2.7%. The future looks even more bullish. Boeing forecasts a growth rate in passenger traffic of 5.1% per annum over the next two decades [Figure 1.1]. The new emerging markets (i.e. China, India and South America) will lead the growth, while North America, the largest current market, will grow at a more modest rate of 4.1% per year [Figure 1.2]. These data indicate that, while the catastrophic events of September 11, 2001 had a negative short-term impact on passenger demands, it will have negligible effect on the long-term growth of air passenger traffic over the twenty years. The overall demand in air transport services will remain strong and robust.

Figure 1.1 Air Travel Trends Upward

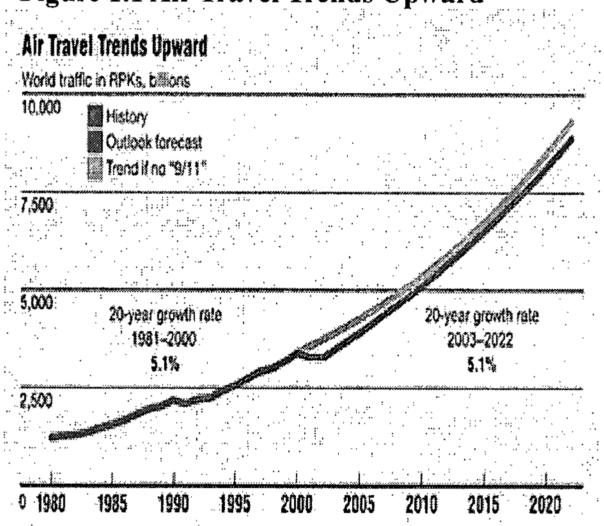
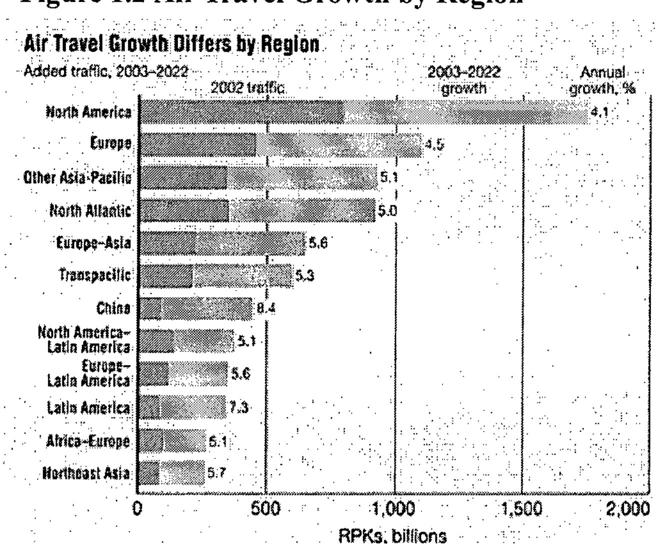
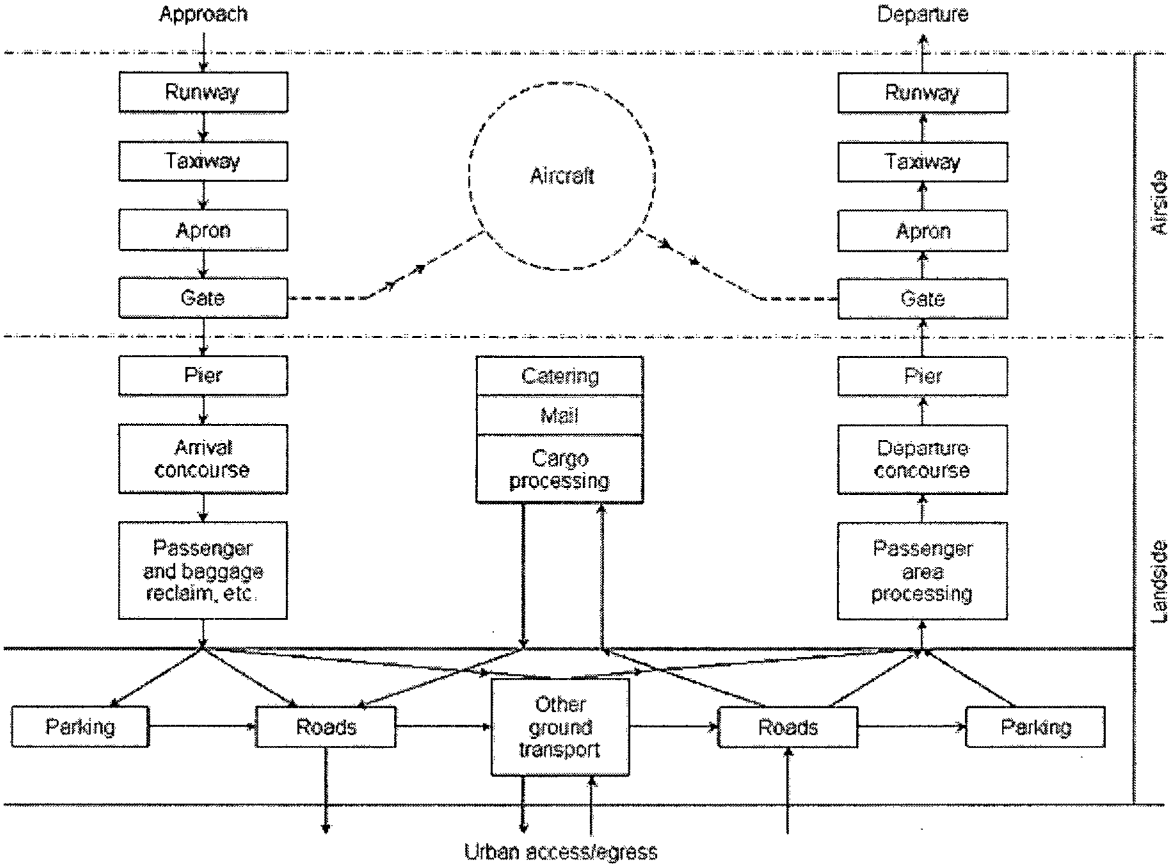


Figure 1.2 Air Travel Growth by Region



Source: Current Market Outlook (Boeing, 2003)

Figure 1.3 The Airport System



Source: Airport Operations (Ashford, Stanton and Moore; 1991)

Airports have played a key and active role in the air transport industry. Airports provide not only the place for landing and takeoff of aircraft, but also various services and facilities for airlines, passengers and other customers including government bodies and concessionaires. Moreover, airports generate a large amount of benefits for the local economy directly through employment of workers and indirectly through spin-off services and other economic activities (TRB, 2003). Figure 1.3 depicts the airside and landside operations of a prototypical airport.

With the projected growth in passenger and cargo traffic in the future, airports must expand to accommodate the increased workload, which invariably will lead to increased operating and capital costs for airport operators. Some have suggested that with expansion, airports will benefit from economies of scale (i.e. less expenditure per unit of output) by enhancing efficiencies in operations and spreading out of the overhead costs; others, however, have suggested the opposite, arguing that increases in size will lead to increased operational and administrative complexities that will result in a loss of efficiencies.

1.2 Purpose and Significance

There have been many studies that have examined the issues of efficiency and price regulation in the airport industry. However, only a few studies (Doganis and Thompson, 1973, 1974; Keeler, 1970; Main et al, 2003; Tolofari et al, 1990)[1] have directly investigated the underlying economies including economies of scale[2] at airports and these studies have produced inconsistent findings because they used different functional forms and sampled different airports. Many of these studies also had insufficient sample sizes, making it difficult to evaluate the full range of output levels including those at the extreme ends of the spectrum, which may still be salient (i.e. small airports with less than 10 million passengers or large airports with greater than 20 million passengers). In addition, the studies dealt with economies of scale by using partial view of passengers, WLU[3] or aircraft movements rather than as an aggregated output reflecting the overall airport operations including terminal side, airside and non-aviation activities.

The main objectives of this paper are: 1) to investigate whether economies (diseconomies) of output scale are present in the airport industry; 2) if the economies (diseconomies) are present, to

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[1] Morrison (1983) also studied on airport economies but his research focused on pricing rather than economies of scale. See Section 2.2 "Empirical Studies on Airports" (p. 15)

[2] All of these studies on airport economies had shortcomings in constructing total cost functions with capital costs and input levels. For the current study I also experienced the same difficulties, so decided to limit the scope to operating cost and use the term, "economies of output scale" instead of "economies of scale" which the previous studies used. For details about the challenges , see Section 1.3 "Scope" (p.5)

[3] WLU is a commonly used output measure combining both passengers and cargo volume: a WLU is equivalent to one passenger or 100kg of cargo (Doganis, 1992).

quantify the magnitude of the economies (diseconomies); and 3) to examine the threshold size of airport at which the economies (diseconomies) change. To address these objectives, this study used data from 94 airports in the United States (US), ranging in volume from 65,901 passengers to 79.1 million passengers per year. Of these, 63 (67% of total) airports processed less than 10 million passengers per year and 17 (18% of total) handled over 20 million passengers annually. The analyses were conducted by using the output index[4] as well as number of passengers and WLU.

This study is relevant because despite the increasing importance of the airport industry in modern economies, there is a scarcity of studies that have examined the potential impact of economies of output scale in the airport industry. Specifically, the findings in this paper will offer a framework for increasing efficiencies in the design and operations of airports across the U.S. and elsewhere by adding to the understanding of efficiency and productivity in airport operations and providing fundamentals of pricing issues in airport operations.

1.3 Scope

This paper will focus primarily on airports in the U.S. for several reasons. First, North America is the world's largest air transport market and accounts for 37.8 per cent of the world's passenger traffic. Second, U.S. airports are very sophisticated with over 400 commercial airports serving more than 600 million passengers annually (ATA, 2004). Third, there is relative uniformity in the managerial and regulatory structure across most U.S. airports because they are all governed under the auspices of the Department of Transportation (DOT) and Federal Aviation Administration

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[4] This aggregate output index is calculated using multilateral index procedure introduced by Caves et al (1982). For details, see equation (3.4) and following explanation in Section 3.2 "Estimation Model" (p.32)

(FAA). Fourth, U.S. airports provide extensive, reliable, and valid data on their direct operational costs, making it possible to accurately estimate costs for a large number of airports.

This paper will examine economies of output scale in airport operations under the given state of capital infrastructure and facilities. It is a major challenge to accurately value capital inputs and to collect consistent and comparable information on capital expenditures because: 1) expenditures on capital equipments, buildings (e.g. terminals) and other infrastructural costs (e.g. runways), are often invested over many years and, as such, may be "hidden" in the explicit (or published) costs; 2) facilities at airports may be built and operated by airlines or other enterprises. Airport operators may only play the role of landlords and as such may not need to invest any direct capital. Examples of this arrangement include United Airlines, which have their own passenger terminal and facilities at Washington Dulles International Airport (IAD), and Continental Airlines, which built and operate Terminal E of Bush Intercontinental Airport (IAH) in Houston; 3) the sources of financing and accounting systems vary among airports. Large hub airports, for instance, rely mostly on tax-exempt bonds, whereas small hub and nonhub airports depend heavily on Airport Improvement Program (AIP) grants provided by the US federal government (US GAO, 2003); and 4) taxation and interest rates also vary across states and across cities. For such reasons, the current study will focus on the effect of "output scale" on airport operations.

1.4 Organization

Chapter 1 briefly introduces the background, purpose, scope, and the overall organization of the study. In Chapter 2, a number of previous studies related to economies of scale in the airport industry are critically reviewed and analyzed. The data set and methodology for this study are described in Chapter 3. The results from cost and VFP analyses are provided in Chapter 4. In

Chapter 5, the conclusions of the study are presented.

2 LITERATURE REVIEW

2.1 Economies of Scale

2.1.1 Definition of Economies of Scale

> "In the long run, it may be in the firm's interest to change the input proportions as the level of output changes. When input proportions do change, the concept of returns to scale no longer applies. Rather, we say that a firm enjoys *economies of scale* when it can double its output for less than twice the cost. Correspondingly, there are *diseconomies of scale* when a doubling of output requires more than twice the cost. The term, *economies of scale,* includes increasing returns to scale as a special case, but it is more general because it allows input combinations to be altered as the firm changes its level of production."(Pindyck and Rubinfeld, 1997, pp. 223-224)

According to the definition by Pindyck and Rubinfeld, economies of scale are the relationship between a firm's long-run average costs and its level of output. In general, the long-run average cost curve of a firm is U-shaped. Economies of scale exist at relatively low levels of output, while diseconomies of scale are found at higher levels of output [Figure 2.1].

Figure 2.1 U-Shaped Average Cost Curve

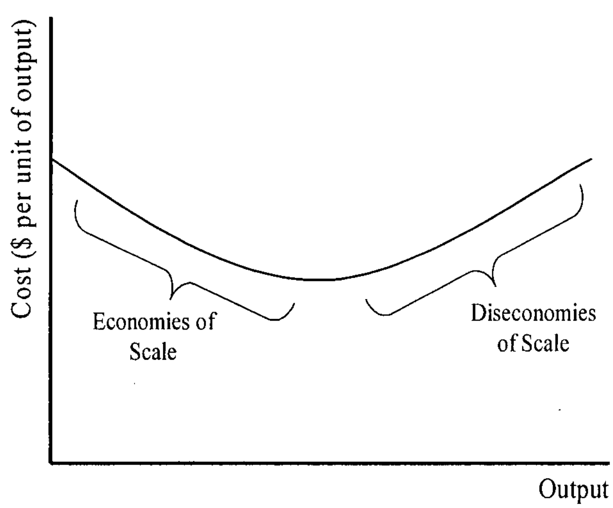
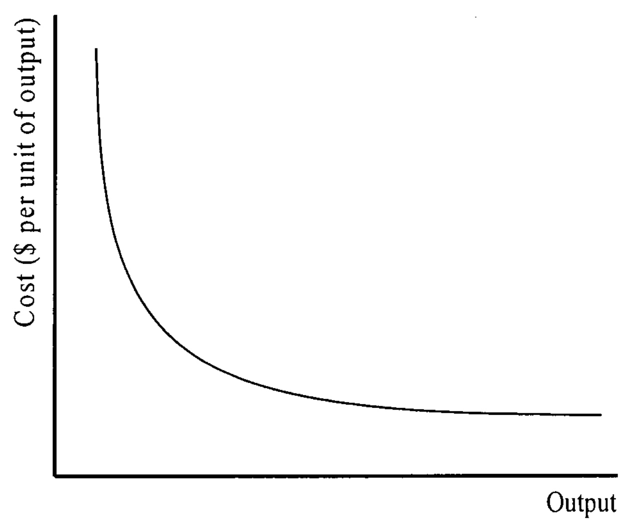


Figure 2.2 L-Shaped Average Cost Curve



Interestingly, Wiles (1956) found that in 60% of forty-four samples, the long-term average cost curve was L-shaped leading to large economies of scale at relatively low output. However, with increasing output, the economies diminished and eventually were exhausted [Figure 2.2]. The results from Johnston (1960)'s empirical study supported Wiles' initial observations.

2.2 Empirical Studies on Airports

2.2.1 Direct Studies on Economies

Keeler (1970) is one of the pioneers in using statistical modeling to analyze cost data for airports. By using pooled time series and cross sectional data from 13 U.S. airports between 1965 and 1966, Keeler created cost function models using capital or operating costs of airports as a dependent variable, and commercial air movements and general aviation as independent variables. Based on his analysis, he argued for constant returns to scale in airport operations. However, his findings were limited because he used data from only nine large hub, two medium hub and two small hub airports. Moreover, he failed to consider the operating characteristics of airports. His study has also been criticized for separating capital and operating cost estimates rather than constructing a total cost model. Since error terms in capital and operating cost models are inter-related, this approach may have biased the parameter estimates. Additionally, he used the Cobb-Douglas functional form[5] in his models, which imposed certain modeling restrictions that may have distorted the parameter estimates (Tolofari et al, 1990).

In a study of 18 British Airports for the fiscal year 1969, Doganis and Thompson (1973, 1974) categorized expenses into total, capital, maintenance, labor, administrative and operating costs, and estimated the cost curves with WLU as the output variable. They took into account factors

[5] The form assumes that the elasticity of substitution between inputs always equals to 1; for example, a 1% rise in the labor price increases the capital: labor ratio by 1% (McCathy, 2001)

affecting costs including recent investments in development programs and air traffic control services. They calculated the average cost function from the cost curves generated from the model. The average cost function demonstrated that there were significant economies of scale at 1 million WLU, but by 3 million WLU, the economies began to dissipate and later became totally exhausted. However, this study suffered from the same limitations in modeling as that of Keeler. Moreover, the study included data from not only airports but also air navigational services, which in many cases were operated by external agencies.

Tolofari et al (1990) addressed many of the shortcomings of the previous studies. They used panel data from seven BAA airports between 1979 and 1987, and employed a translog rather than Cobb-Douglas cost function. They then constructed a model with WLU as the output variable; labor, equipment and residual factors as input variables; and capital stock, passenger per air movement, percentage of international passengers and terminal capacity utilization as other explanatory variables. They found that there were economies of scale, which disappeared by 20.3 million WLU. However, generalizations regarding scale economies in the airport industry could not be made because only one (London Heathrow (LHR)) of the studied airports had more than 20 million WLU; most of data points were derived from airports that had less than 3.3 million WLU.

Using data sets from the Centre for the study of Regulated Industries (CRI)[6] and the Transport Research Laboratory (TRL)[7], Main et al (2003) investigated economies of scale across different

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[6] CRI is an interdisciplinary research centre of the University of Bath School of Management, UK, which investigates how regulation and competition are working in practice, both in the UK and abroad.

[7] TRL is a centre of excellence providing world-class research, advice and solutions for all issues relating to transport. In particular, TRL conducts airport performance benchmarking surveys annually. TRL is part of the Transport Research Foundation group (TRF).

sized airports. Most of the airports in this study were between 16 to 40 million passengers. They used CRI dataset of 27 airports in the United Kingdom for 1988, and constructed four Cobb-Douglas cost function models, using definitions of operating costs that did and did not include depreciations, and two output measures, WLU and number of passengers. The models included input prices such as staff costs, air passenger movements, percentage of international passengers, and total assets. The models produced L-shaped cost curves. This meant that the average cost declined significantly until a threshold of 5 million WLU or 4 million passengers was reached, after which the cost curves became flat. Using TRL data of 44 airports around the world between 1998 and 2000, Main et al (2003) analyzed the models with the same variables as in the CRI models, and found that economies of scale existed, but the curve was not as steep at lower output scales as that observed in the CRI models. However, in both analyses, they failed to account for the pooled data which may have led to biased estimates and inaccurate p-values. Additionally, this study has been criticized for the same errors and modeling restrictions as those found in studies by Keeler, and by Doganis and Thompson

On the basis of the studies of British (Doganis and Thompson, 1973), Australian and Spanish airports (Assaily, 1989; Doganis, Graham and Lobbenberg, 1995), Graham (2001) argued for the existence of economies of scale in airport operations. She pointed to the ICAO study (ICAO, 2000), which concluded that the unit costs per WLU were $15 (USD) for airports of less than 300,000 WLU, $9.4 (USD) for airports between 300,000 and 2.5 million WLU, and $8 (USD) for airports between 2.5 million and 25 million. However, the ICAO study included data from not only airports but also air navigational services. Because of incomplete costing data, the author of this report recommended that the study results be interpreted with caution.

Table 2.1 Studies on Economies of Scale in the Airport Industry

Study	Functional Form	Data	Output	Conclusion
Doganis and Thompson (1973, 1974)	Cobb-Douglas	Cross section, 18 UK airports, 1969	WLU	Significant economies of scale exist by 1 million WLU. Economies of scale disappear after 3 million WLU.
Keeler (1970)	Cobb-Douglas	Panel of 13 US airports, 1965-1966	Commercial aviation, General aviation	No economies of scale exist in aircraft movements.
Main et al (2003)	Cobb-Douglas	Cross section, 27 UK airports, 1988 (CRI) Panel, 44 airports worldwide, 1998-2000 (TRL)	Passenger, WLU	Economies of scale exist by 4 million passengers or 5 million WLU
Tolofari et al (1990)	Translog	Panel of 7 BAA airports, 1979-1987	WLU	Economies of scale exist by 20.3 million WLU

Some experts have taken a different perspective on the issue of economies of scale in airport operations. Based on data from an economic survey in airports, Walters (1978) argued that there were economies of scale in runway operations but diseconomies of scale in the operations of terminals. He indicated that in runway operations, there were economies of scale because of lumpiness in investment even for a minimal requirement;[8] however, in terminal operations, since there was little lumpiness in investment, and large service commitment in facilitating acceptable passenger movement, diseconomies of scale existed.

Starkie and Thompson (1985) also pointed out that economies of scale in airport operations might be adversely influenced by the costs associated with maintaining access between airside and terminal-side facilities, and suggested that there might be diseconomies of scale at large airports because of these costs. Their argument was based on the fact that as airports become larger, additional infrastructure linking aircraft arrival area with baggage handling facilities becomes necessary. Airbridges, moving walkways or even rapid transit connecting the main and satellite terminals are very expensive. With continued airport expansion, airports will need to upgrade roads, add additional car parking facilities and provide links to public transit, which will further add to the overall costs.

2.2.2 Applied Studies on Efficiency and Regulation

With deregulation and liberalization of airlines, and commercialization and privatization of airports, airport operators have been pressured to provide the best possible services in the most efficient way. Studies on efficiency and productivity of airports are therefore very germane to the present airport industry (ATRS, 2004).

Furthermore, pricing and regulatory issues related to social welfare and increasing airport

[8] Airport operations require at least one runway for services.

congestion are other problems plaguing the airport industry. Despite the trend toward commercialization and privatization of the airport industry, policy makers have placed more stringent regulatory governance to prevent airports from abusing market power and to increase the quality of service that is being provided. Additionally, with increasing demand and with the advent of the hub-and-spoke system, major hub airports have experienced increasing congestions since the end of 1990's (Brueckner, 2002).

Many studies on these topics have been reported. In this section, a representative sample of published papers is briefly reviewed.

Salazar de la Cruz (1999) studied airport efficiency by using panel data from 16 Spanish airports between 1993 and 1995. He employed the Data Envelopment Analysis (DEA)[9] method with the assumption of variable returns to scale (VRS). He used total returns (total revenue), returns from infrastructure services (infra related aviation revenue), operative returns (non-infra related aviation revenue), final returns (non-aviation revenue) and number of passengers as outputs, and total economic cost (total cost) as the input. He found that airports with 3.5 to 12.5 million passengers had constant returns to scale, whereas airports with over 12.5 million passengers exhibited decreasing returns to scale. However, as he indicated in the paper, his conclusions should be interpreted cautiously due to the small size of data at the end of the frontier; the overall degree of scale economies and its turning point may vary according to samples.

Martin and Roman (2001) explored the efficiencies of Spanish airports in 1997 with three inputs: labor, capital, and material expenses, and three outputs: air movements, passenger and cargo volume. On the basis of CRS and VRS DEA models, they concluded that the operations of twenty

[9] DEA is a linear programming-based efficiency measure for multiple outputs and inputs. The non-parametric method determines the economic efficiency by estimating a cost or production frontier and comparing this with the performance of airports. According to the assumption of the envelopment surface, there are two basic DEA models: variable returns to scale (VRS) and constant returns to scale (CRS).

airports exhibited increasing returns to scale, while those of nine airports demonstrated decreasing returns to scale.

Oum et al (2003) used a different approach, gross total factor productivity (TFP)[10], and measured efficiencies for 50 major airports in the world. They found that larger airports had achieved higher gross TFP because of economies of scale, and with a larger share of international passenger the gross TFP levels tended to decrease. Airports with a larger share of non-aviation revenue and capacity constraints were also more likely to have higher productivity. Interestingly, they found that ownership and service quality did not significantly influence efficiencies.

On the other hand, Gillen and Lall (1997) classified airport operations into airside (aircraft movements) and landside (passenger movements) and estimated the efficiency and productivity for each side by using DEA models.[11] Additionally, a second-stage analysis was carried out in order to examine the performance changes over time and across airports. Data from 21 US airports for the periods of 1989-1993 were used as the performance measures. They did not address the issue of whether economies of scale existed at airports. Their main objective was to separate airport operations into various in order to identify the source of efficiencies.

Sarkis (2000), by using a panel data from 44 major US airports over the period of 1990-1994, explored operational efficiencies at airports. He constructed various DEA methods with four inputs including operating costs, number of employees, gates and runways; five outputs including operating revenue, number of passengers, commercial and general aviation movements, and cargo

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[10] TFP is one of non-parametric productivity measures, which uses multilateral index procedure introduced by Caves et al (1982), and is defined as the ratio of aggregate output over aggregate input. In the paper, Oum et al (2003) included passengers, cargo volume, air movements and non-aviation revenue as outputs and labor, capital and softcost as inputs.

[11] In the models air movements were assumed to be operated under CRS and passenger movements were modeled under the assumption of VRS.

volume; and explanatory variables such as hubbing, multi or single airport system, and snowfalls. He found that, on average, efficiencies have increased over the years and that hubbing and snowfalls strongly affected efficiencies at U.S. airports. In contrast, airport system was not a significant determinant of efficiencies. Although he did not specifically examine the issue of economies of scale, he took into account many operating characteristics in the efficiency models.

Pels et al (2003), similar to Gillen and Lall (1997), examined the economic efficiencies and economies of scale in airside and landside operations. By using DEA and SFA[12] models, and data from 34 European airports between 1995 and 1997, they found that European airports, on average, were relatively inefficient, and most airports displayed constant returns to scale in terms of air transport movement but exhibited increasing returns to scale in terms of passenger movements. They also reported that a low load factor may be contributing to inefficiencies of operations at these airports. Although interesting, the study had a major shortcoming: it did not consider labor inputs.

Another study area relevant to economies of scale is the regulation field including pricing. Morrison (1983) examined optimal landing charges and investment levels by using data from 10 U.S. airports. Firstly, he estimated various cost functions including maintenance, operation and administration, runway construction, land acquisition, capacity rental, and delay expenditures, and then he optimized capacity variables and computed optimal long-run toll costs. Comparing optimal charges with actual fees, he concluded that airports were inefficient in terms of pricing and investment.

A study on airport regulation and competition was conducted by Starkie (2002). He pointed out

12 Stochastic Frontier Analysis (SFA), similar to DEA, is one of efficiency measures but uses parametric procedure.

that in a spatial context the airport industry was no longer under a natural monopoly, but rather under an imperfect or monopolistic competition. This transformation occurred because with privatization, airports became involved in a fierce competition with other airports for the connecting service of airlines. Based on the change in the market structure, he suggested that ex-post regulation for natural competition is likely the most appropriate model for the industry.

Oum et al (2004) examined the relationship between different types of price regulation and airport efficiency as well as non-aviation activities at airports. Their empirical analysis found that airports under the dual-till price cap regulations tended to have higher levels of gross TFP than those with a single-till price cap or those that operate under the single-till rate-of-return (ROR) regulation. Those airports that operated under a dual-till regulation had better economic efficiencies than those under a single-till regulation, particularly for large, congested airports. The latter finding supported the arguments by Starkie and Yarrow (2000), Starkie (2001) and Forsyth (2002).

2.3 Summary

Compared with studies on productivity and regulation, there is a paucity of studies that have directly addressed economies of scale in the airport industry. The few studies that have addressed this issue have reported varying and at times contradicting conclusions. Keeler (1970) concluded that there is no scale economies in aircraft movements, but Doganis and Thompson (1973, 1974), Tolofari et al (1990), and Main et al (2003) indicated that the economies of scale exist in passenger and cargo movements, Doganis and Thompson (1973, 1974) and Main et al (2003) had similar threshold size at which economies of scale ware reached (around 3 to 5 million WLU). Tolofari et al (1990), on the other hand, had the threshold at a much higher level, 20.3 million WLU. Other studies have found dissimilar results. Oum et al reported economies of scale (Oum et al, 2003); Salazar de la Cruz indicated no economies until 3 to 12.5 million passengers and diseconomies of scale at larger number of passengers (Salazar de la Cruz, 1999); Pels et al reported economies of scale in passenger movement but no economies in scale with air movement (Pels et al, 2003).

In terms of factors affecting economies at airports, the percentage of international passengers and average passenger per air movement are the most common operating characteristics that have been examined (Main et al, 2003; Oum et al, 2003; Tolofari et al, 1990). Some have also examined hubbing, snowfalls and capacity constraints.

Previous direct studies have had the following shortcomings. Firstly, they had major limitations in constructing total cost function with capital costs and capital input levels. Secondly, they did not have adequate sample sizes and failed to consider the variation in the sizes of airports as a function of economies of scale, which may in part reflect the difficulty in collecting comparable data across different sized airports. Thirdly, these studies dealt with economies of scale in terms of partial output rather than as an aggregated measure that encompasses all aspects of airport operations. Keeler (1970), for instance, examined aircraft movements, while three other studies (Doganis and Thompson, 1973, 1974; Main et al, 2003; Tolofari et al, 1990) examined passenger movements or WLU.

3 METHODOLOGY

3.1 Data

The current study used cross-sectional data from 94 U.S. passenger-oriented, commercial-service airports in 2003. The sample included 26 large hub, 22 medium hub, 30 small hub and 16 nonhub airports[13]. A list of these airports is provided in Appendix A.1.

Considerations

In collecting operational and financial data for analysis, the followings were taken into account: product mix, general aviation, unusual events in 2003, aggregate output, and single input factor.

The following restrictions were imposed in the data analysis. First, only "passenger-oriented airports" that have more than 50% of passenger portion in WLU were included in the sample because their product mix and related production technology are very different from those of "cargo-oriented airports" that have more than 50% of cargo portion in WLU. Thus, "cargo-oriented airports" such as Memphis International Airport (MEM) where FedEx operates its primary overnight package sorting facility, Louisville International Airport (SDF) where United Parcel Service (UPS) has facilities for overnight-delivery hub operations, Indianapolis International Airport (IND) where FedEx package sorting hub is located, Dayton International Airport (DAY) where FedEx operates a distribution centre, Columbia Metro Airport (CAE) where UPS operates Southeastern regional hub, and Fort Wayne International Airport (FWA) where Kitty Hawk Cargo operates a sorting hub were all excluded from the analysis.

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[13] FAA allocates the U.S. commercial airports based on percentage of annual passenger boardings into the following categories: large hub, medium hub, small hub and nonhub. Large hub airports are publicly owned airports that have ≥1% of the total passenger boardings, medium hub airports have between 0.25% and 1%, small hub airports have between 0.05% and 0.25%, and nonhub airports have more than 10,000 passengers but less than 0.05% of total. Large hub airports account for about 2/3 of all passenger enplanements and medium hub airports do about 1/4, and small hub and nonhub airports have the rest.

Second, airport services for general aviation are quite different from those for air carriers because general aviation does not require services for passenger or cargo handling, maintenance, or catering.[14] Thus, ideally it is desirable to exclude or separate general from commercial aviation to achieve accurate estimation of economies of output scale. However, in reality, this may be impossible since these "commercial-service airports,"[15] serve both air carrier as well as general aviation operations. The latter may account for 15-50% of total aircraft operations even at large airports. However, because FAA requires "commercial-service airports" to have facilities, equipment and capabilities for runway marking, lighting, navigation system, de-icing, fire fighting and emergency rescue in order to accommodate the medium- to large-capacity turbine aircraft for regional commute services (TRB, 2003), the inclusion of general aviations in the analysis probably did not impact materially on the overall results. This study investigated economies of output scale with sample airports as a whole, and after classifying airports according to their size and volume in order to compare the economies of output scale between large airports, which have relatively smaller general aviation operations and small airports, which have proportionally larger general aviation operations.

Third, since the traffic data of small hub and nonhub airports for previous years were unavailable, this paper used 2003 data only. The generalization of the results could have been affected by unusual events in the airport industry during the year of analysis. Fortunately, despite two external challenges, the War in Iraq and SARS epidemic, the U.S. air travel market in 2003 was stable and passenger traffic showed recovery from the 2001 recession caused largely by the 9/11 disaster. Therefore, the data are likely to be robust. We excluded airports which had unusually

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[14] Because of its nature, general aviation, compared to commercial aviation, brings about less operating costs as well as less passenger traffic and less non-aviation revenue. The latter two factors affect lower output index. However, the overall impact of general aviation on output scale parameter requires further research.

[15] Airports excluding general aviation airports which do not serve scheduled commercial aircraft

high operating costs during that year in order to ensure that "outliers" did not drive the analysis. These included John F. Kennedy International Airport (JFK), Newark International Airport (EWR), LaGuardia Airport (LGA), San Francisco International Airport (SFO) and Miami International Airport (MIA). Unusual costs of JFK, LGA, and EWR—airports under the Port Authority of New York and New Jersey (PANYNJ)—were caused mainly by $97 million of the rent payments in-lieu-of taxes to the City of New York and Newark.[16] For SFO, the $37 million of write-off costs related to the runway reconfiguration project, which was suspended on June 25, 2003 (City and County of San Francisco, 2003). High costs at MIA in 2003, compared with costs in 2002, resulted from the extraordinary increase in contractual service expenses (Miami-Dade County Aviation Dept., 2003).

Fourth, this paper relied primarily on output index, an aggregated output of overall airport operations. The paper also adopted two other output measures—number of passenger and WLU—to facilitate simple and explicit interpretation and comparisons with previous studies.

Traditionally, the number of passenger and WLU were adopted as outputs. The number of passenger is a simple and intuitive output measure indicating the size of an airport. WLU is also a commonly used output measure including both passenger and cargo volume. WLU, therefore, reflects the costs incurred for both passenger and cargo traffic. However, these two output measures failed to take into account airport operations as a whole; therefore, the paper will focus on output index, which aggregates all outputs including number of passengers, aircraft

[16] In 2003, the Port Authority entered into a Memorandum of Understanding (MOU) with the City of New York providing the extension of the lease agreement covering JFK and LGA to December 31, 2050. This MOU also included that upon execution of the lease extension, lump sum payment of $500 million and the additional base rent payments of $90 million for each of years 2002 and 2003 would be made to the City. The lump sum payment and the rent for 2002 have been postponed and will be amortized through 2050. In addition, the 2002 agreement between the City of Newark and the Port Authority contained that if the Port Authority renews the lease agreement with the City of New York for JFK and LGA, the City of Newark will have the right to amend the lease provision relative to EWR to conform to the terms in the case of JFK and LGA, but the amount of additional payments has not been determined yet (PANYNJ Annual Financial Report, 2003).

movements and non-aviation revenues. The cost data indicate the overall expenditures related to all outputs.

Ideally, the best index for input prices is an airport price index but such an index does not exist. Previous studies have used average employee compensations, defined as labor costs divided by the number of employees, and other factor prices, defined as other costs divided by tangible assets, instead of actual prices for labor and other factors. The average employee compensations are imperfect surrogates of actual labor prices because this measure may be affected not only by labor prices but also by the nature of responsibilities of airport operator. For example, in 2003 the average employee compensation at Hartsfield-Jackson Atlanta International Airport (ATL) was $119,752, the highest among sample airports. However, the actual contractual and labor costs at ATL accounted for 47.3% and 26.3%, respectively, suggesting that most of the operations at ATL were contracted out and that the $119 thousand figure was driven largely by salaries of executives and managers at the airport. Additionally, data on tangible assets, which can be used to compute prices for other factors, are not available for most of the sampled airports. Therefore, this paper used a cost-of-living index[17] created by the American Chamber of Commerce Researchers Association (ACCRA) as a proxy of a single aggregate input factor price.[18]

[17] Cost-of-living index includes following categories with weights: housing (28%), groceries (16%), transportation (10%), utilities (8%), health care (5%), and miscellaneous expenses such as services (33%). State and local taxes are not included in any category. This index is widely used to compare employee salaries as well as prices of consumer goods and services across U.S. cities, so the index can be a good proxy. Its one shortcoming for this study, however, is that it uses consumer rather than producer prices.

[18] Producer Price Index (PPI), which measures the average changes over time in the production of material goods at a particular city, was also considered but was not adopted because the index is less applicable in comparing prices at US airports.

Data sources

For the present study, the financial data on operating costs, labor costs, softcosts[19] and contractual service costs were obtained from the U.S. FAA Form 5100-127 "Airport Financial Report." Traffic statistics including the number of total and international passengers, cargo volume and aircraft movements were compiled from the 2003 traffic report of the Airport Council International-North America (ACI-NA), 2003 annual reports from individual airports, and Survey of American Association of Airport Executives (AAAE, year 2000). The data on number of employees were obtained from the AAAE Survey (year 2000), and information on financial management of airports was compiled from various sources including the 2003 annual report from individual airports, the year 2000 AAAE Survey, and the U.S. Congress Office of Technology Assessment (OTA), and FAA/OST Task Force. The data on delays and days with snowfalls were collected from Air Travel Consumer Report by U.S. Department of Transportation (U.S. DOT, 2004) and the website of US National Climatic Data Center (NCDC), respectively.

If relevant data were not available, this analysis used proxies or the most recently available data for that airport. For instance, the information on flight delays in 2003 was used as a proxy for capacity constraints,[20] and the data on international passengers and employee number for the year 2000 were used if the year 2003 data were not available. This assumed that there was no significant variation in this variable between the two years in question. This was reasonable because in the 21 airports that reported data from these two years there was indeed little heterogeneity in the proportion of international passengers (+0.4%) or employee number (-4.5

[19] All operating costs other than labor cost

[20] Ideal information is designed capacity but this was unavailable for most airports. Thus, this study attempted to use air movements per runway and/or passengers per terminal size as a proxy for capacity constraints, but unfortunately number of runways and terminal size for small hub and nonhub airports were not available. Thus, aggregate delays converted from on-time performance data in "Air Travel Consumer Report" were adopted for the analysis. For further details, see "Capacity Constraint" in Section 3.3 (p.35)

employees). In the analysis, more than half of the airports did not serve international passengers. Since the analytic models do not permit the inclusion of the null value, zero values were replaced with the value, 0.0001.[21]

There were some missing data fields in the 94 sample airports. For example, data on international passenger number was found in 93 airports; 88 airports had available data regarding percentage of delays; 91 airports had information on cargo volume; 92 airports had data on contractual service costs; and 87 airports had data on the financial management structure. Therefore, it should be noted that for each individual analysis only the airports with plausible data were included. The results should therefore be interpreted cautiously.

Before going into the cost analysis, it is necessary to understand the characteristics of sample airports because there are micro-structural variations between these airports (e.g. size, types of financial management, and geographic locations.) (See also Appendix A.2)

As shown in Figure 3.1, number of passengers ranged from 65,901 passengers at Barkley Regional Airport (PAH) to 79.1 million passengers at ATL. There were 30.2 and 7.7 million passengers, respectively, at large and medium hub airports, whereas at small and nonhub airports, there were 1.5 and 0.4 million passengers, respectively. This indicates that the volume of passenger traffic at large hub airports is over 70 times greater than at nonhub airports.

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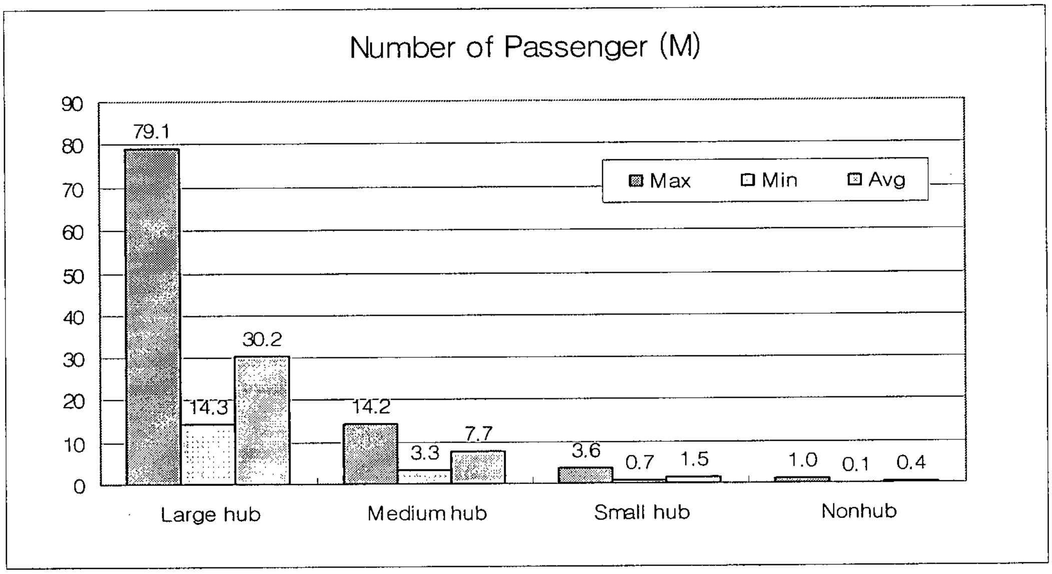
[21] This value is acceptable. The smaller value—10^{-5} or 10^{-6}—changes very little in results. Also Box-Cox transformation was considered but not adopted because this method is based on Maximum Likelihood (ML) rather than Ordinary Least Squares (OLS) which is underlying technique in regression analysis.

Figure 3.1 Sample Airports: Number of Passengers



The average WLU for large and medium hub airports were 34.0 and 8.6 million WLU, respectively. Those for small and nonhub airport were 1.7 and 0.5 million WLU, respectively. As with passenger traffic, ATL was the largest airport in terms of WLU at 87 million WLU and PAH was the smallest at 66,210 WLU. There were also large variations in WLU across airports [Figure 3.2].

Figure 3.2 Sample Airports: Work Load Unit

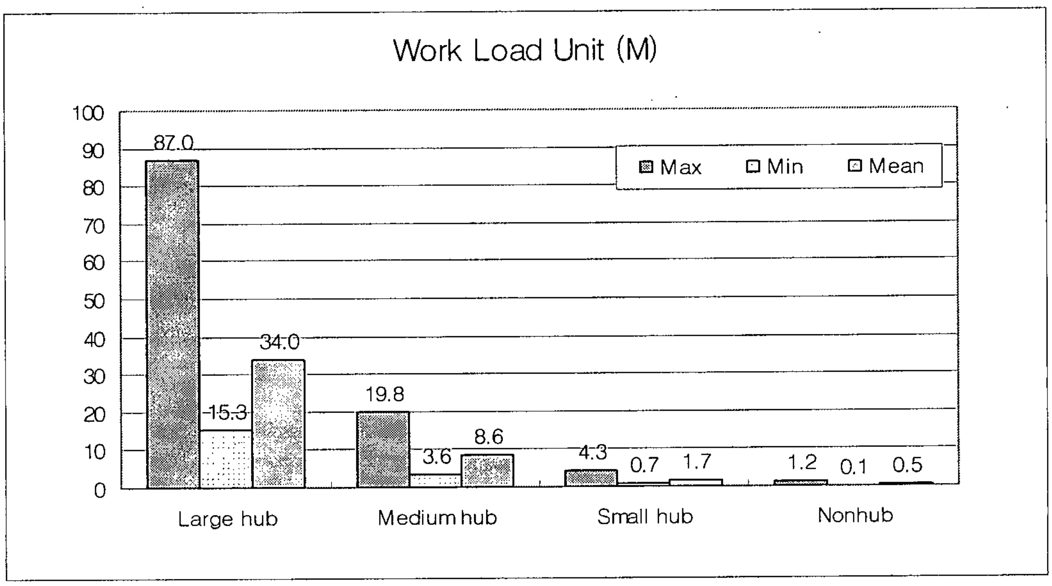
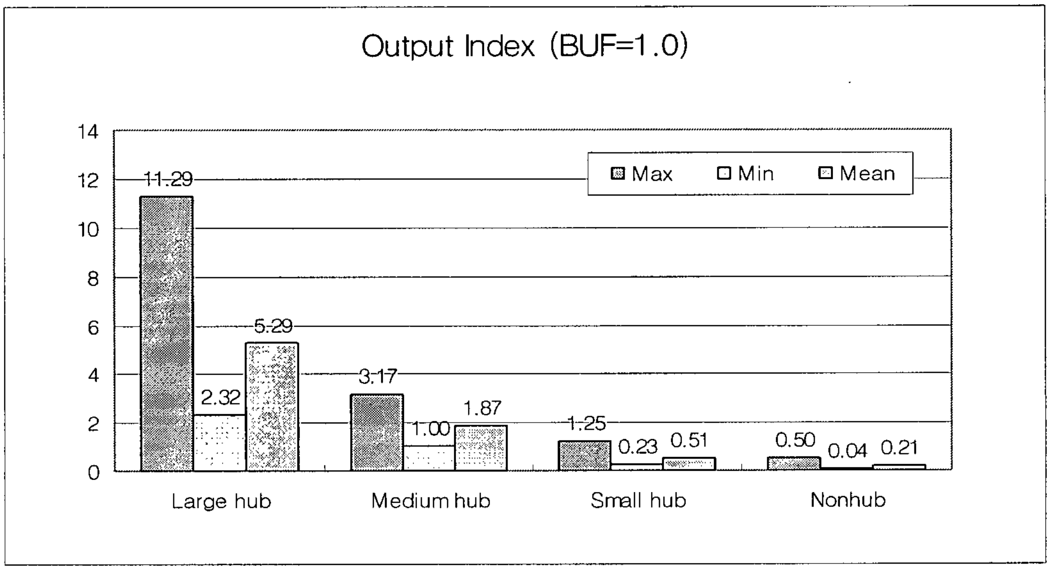


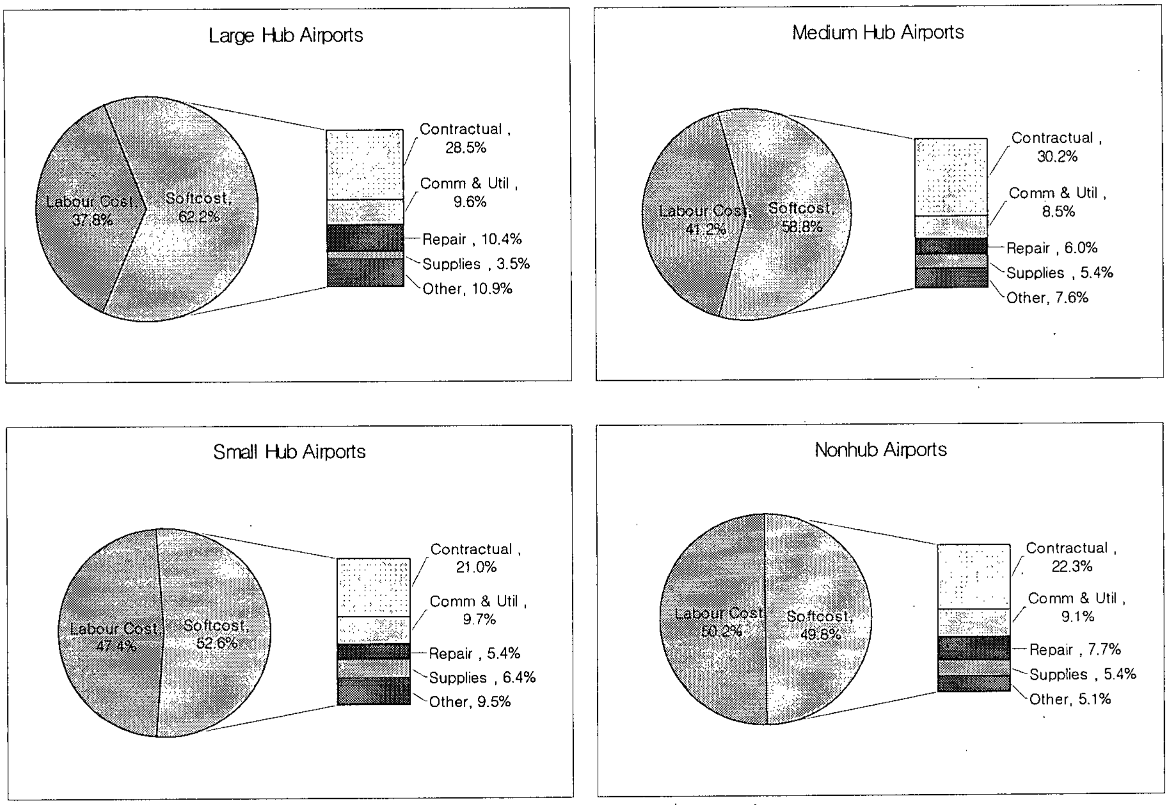
Figure 3.3 Sample Airports: Output Index



With Greater Buffalo International Airport (BUF) as the base of 1.0, the output index ranged from 0.04 at PAH to 11.29 at ATL. Small hub and nonhub airports had smaller output index of 0.51 and 0.21, whereas large and medium hub airports had larger output indices of 5.29 and 1.87, which are almost 26 and 9 times greater than those of nonhub airports, respectively [Figure 3.3].

As shown in Figure 3.4, cost categories can be dichotomized into labor and softcosts. Labor cost shares for small and nonhub airports were 47.4% and 50.2%, respectively. The shares at large airports were much lower—37.8% for large and 41.2% for medium hub airports—compared with the shares in smaller airports. This variation occurred because many services at large airports were contracted out. The share of contractual service cost was 28.5% for large hub airports and 30.2% for medium hub airports, figures which were considerably higher than those for small and nonhub airports. In contrast to labor costs, the share of softcosts—the residual component of operating costs—for large and medium hub airports was 62.2% and 58.8%, figures that were higher than those for small and nonhub airports.

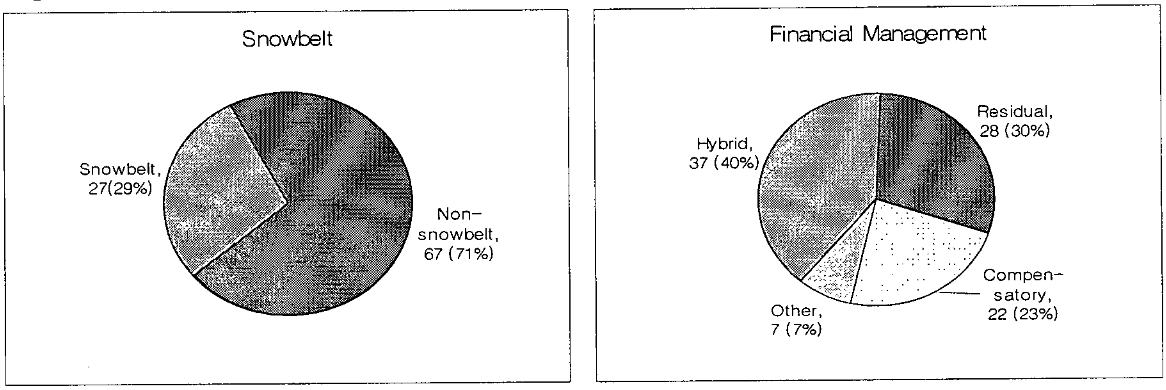
Figure 3.4 Sample Airports: Cost Share in Total Operating Cost



Softcosts included expenditures for contractual services, communications and utilities, repair and maintenance, supplies and materials. Contractual services were the largest component of softcosts. The remaining items were responsible 3% to 11% of the soft costs. These figures did not vary significantly along the hub size gradient.

Airports which had more than ten days of snowfalls and snow accumulations of over one inch per year were defined as snowbelts (Sarkis, 2000). As shown in Figure 3.5, 27 airports, located predominantly in Northeastern and North-central U.S. were within the snowbelt area. The remaining 67 airports were in the non-snowbelt areas. Snowbelt and non-snowbelt airports accounted for 29% and 71% of total number of airports, respectively.

Figure 3.5 Sample Airports: Snowbelt and Financial Management



Dissimilar to airports in most other countries, U.S. airports operate in close collaboration with individual airlines under the auspices of the *airport-use agreements,* which provide a detailed framework for using airport facilities including airport charges and rental rates (Doganis, 1992). There are three approaches that are generally used in these agreements: residual, compensatory and hybrid approaches.

Under the residual cost approach, the airlines are responsible for making up any remaining deficit incurred by the airport after adjusting for non-airline sources of revenue. The compensatory approach, on the other hand, requires that airport operators set fees and rates for the use of their facilities in order to cover actual costs incurred by the airports. The hybrid approach combines both residual and compensatory approaches. The residual approach is used for the airside and compensatory method is used for terminal side, or vice versa. Another case of hybrid approach is a revenue-sharing system, which is currently being employed at Washington Dulles International Airport (IAD) and Ronald Reagan Washington National Airport (DCA) (Vasigh and Hamzaee, 1998).

Among sampled airports, 37 (40%) have adopted the hybrid approach, whereas 28 (30%) and 22 (23%) airports used the residual and compensatory approaches, respectively. Figure 3.5 summarizes the airports according to their financial management structure.

3.2 Estimation Models

As discussed in Chapter 2, all previous studies on economies of scale in the airport industry were based on cost functions by using either Cobb-Douglas or translog cost functions. General total cost function in transportation economic studies is as follows (McCarthy, 2001):

$$TC = f(Q; w, r, o, t)$$

where TC is total cost, Q indicates output, w represents the input price for labor, and r represents the input price for capital, o indicates operating characteristics which reflect the technological conditions caused by output heterogeneity, and t is a time variable representing a residual influence after considering all other effects on total costs.

As for the functional form, previous studies on airport economies used a Cobb-Douglas cost function except that reported by Tolofari et al (1990). The main limitation of this function is that it assumes the elasticity of substitution between inputs to be always one. In other words, the function assumes a firm's ability to substitute an input (i.e., labor) for another (i.e., capital) is fixed at a constant ratio. In contrast, translog cost functions, which has been promoted by Christensen et al (1973), allow for greater flexibility because it does not impose any restrictions on a firm's returns to scale, permits elasticity of substitution between inputs, and reasonably mimics cost-minimization behavior. These properties have made the translog function popular in recent transportation cost studies.

In this vein, the present study used a "flexible" translog cost functions to investigate economies of output scale in the airport industry.

The followings are the basic translog cost function model and the modified model[22] for airports as a whole that were used in the paper.

1) Basic Model

$$\ln TOC = \alpha_0 + \alpha_1 d_{snow} + \alpha_2 d_{comp} + \alpha_3 d_{res} + \beta_0(\ln Q - \ln \overline{Q}) + \gamma\ (\ln p - \ln \overline{p}\ )$$
$$+ \phi_1(\ln o_{\text{int}} - \ln \overline{o}_{\text{int}}) + \phi_2(\ln o_{cong} - \ln \overline{o}_{cong}) + \phi_3(\ln o_{crg} - \ln \overline{o}_{crg}) + \phi_4(\ln o_{cont} - \ln \overline{o}_{cont})$$
$$+ \text{"second-order and interaction terms"} + \varepsilon \tag{3.1}$$

2) Modified Model

$$\ln TOC' = \ln\left(\frac{TOC}{p}\right) = \alpha_0 + \alpha_1 d_{snow} + \alpha_2 d_{comp} + \alpha_3 d_{res} + \beta_0(\ln Q - \ln \overline{Q})$$
$$+ \phi_1(\ln o_{\text{int}} - \ln \overline{o}_{\text{int}}) + \phi_2(\ln o_{cong} - \ln \overline{o}_{cong}) + \phi_3(\ln o_{crg} - \ln \overline{o}_{crg}) + \phi_4(\ln o_{cont} - \ln \overline{o}_{cont})$$
$$+ \text{"second-order and interaction terms"} + \varepsilon \tag{3.2}$$

The modified model for categorized airports by size is as follows:

$$\ln TOC' = \ln\left(\frac{TOC}{p}\right) = \alpha_0 + \alpha_1 d_{snow} + \alpha_2 d_{comp} + \alpha_3 d_{res}$$
$$+ \beta_1(\ln Q - \ln \overline{Q}) \cdot d_{sn} + \beta_2(\ln Q - \ln \overline{Q}) \cdot d_m + \beta_3(\ln Q - \ln \overline{Q}) \cdot d_l$$
$$+ \phi_1(\ln o_{\text{int}} - \ln \overline{o}_{\text{int}}) + \phi_2(\ln o_{cong} - \ln \overline{o}_{cong}) + \phi_3(\ln o_{crg} - \ln \overline{o}_{crg}) + \phi_4(\ln o_{cont} - \ln \overline{o}_{cont})$$
$$+ \text{"second-order and interaction terms"} + \varepsilon \tag{3.3}$$

In the models *TOC* indicates total operating cost, *TOC'*, that is, TOC/p represents price-independent operating cost, Q is output, p is overall input price, and o represents operating

[22] The modified model (3.2) was obtained after applying homogeneity condition, that is, $\gamma = 1$, in the basic model (3.1).

characteristics. As factors affecting operating costs, this paper considered four characteristics: the percentage of international passengers (o_{int}), the percentage of delays (o_{cong}), the percentage of cargo volume in WLU (o_{crg}), and the share of contractual costs as a function of the total operating cost (o_{cont}). The average passenger traffic per aircraft and the percentage of connecting passengers were often included in airport studies, but they were excluded in this paper because of high correlation and multicollinearity with outputs and the percentage of international passengers, respectively.

In addition, dummy variables for hub size (d_{sn} for small hub and nonhub airports, d_m for medium hub airports, and d_l for large hub airports) were included in the model to examine the differences of output scale economies as a function of airport size, dummy variables for snowbelt (d_{snow}) area and financial management structure (d_{comp} for compensatory approach, d_{res} for residual approach, and the base case is hybrid approach) were taken into account in the model to investigate the differences of impacts on total operating costs. All variables were normalized by their sample means.

The constant term α_0 indicates the natural logarithm of total operating costs at the sample means. Because it is assumed that the mean value of the error term is zero, the total operating costs of sample mean can be derived using the equation $exp(\alpha_0)$. The coefficient of the dummy variable for snowbelt, α_1, represents the difference in the natural logarithm of total operating costs between airports within snowbelt area and those not in the area; that is,

$$\alpha_1 = \ln\left(\frac{\text{Total operating cost of snowbelt airports}}{\text{Total operating cost of non-snowbelt airports}}\right)$$

The ratio of operating costs equals $exp(\alpha_1)$. Likewise, α_2 and α_3 represent the differences in the natural logarithm of total operating costs between airports, which use a compensatory approach and those, which use a residual approach, relative to those that employ a hybrid approach:

$$\alpha_2 = \ln(\frac{\text{Total operating cost of compensatory airports}}{\text{Total operating cost of hybrid airports}})$$

$$\alpha_3 = \ln(\frac{\text{Total operating cost of residual airports}}{\text{Total operating cost of hybrid airports}})$$

The coefficients of output variables, β_0, β_1, β_2, and β_3 indicate the elasticity of total operating costs with respect to output for sample airports as a whole, small and nonhub airports, medium hub airports and large hub airports, respectively. The cost elasticity provides information on economies of output scale. Simply, if β_i (i=0, 1, 2, 3) < 1, then there are economies of output scale in the airport industry, if β_i = 1, there are no economies of output scale, and if β_i >1, there are diseconomies of output scale.

The coefficients, φ_i (i=1, 2, 3, 4) indicate the effects of operating characteristics on total operating costs, and represent the impact caused by a 1% change in the percentage of international passengers, the percentage of delays, the percentage of cargo volume in WLU, and the contractual cost share on the total operating costs.

On the other hand, another way to examine economies of output scale, in other words, returns to output scale, is using aggregated productivity indicators such as Variable Factor Productivity (VFP).[23] Thus, this study examined whether the airport industry operates under increasing, constant or decreasing returns to output scale using VFP model in order to double check the validity of findings on economies of output scale.

[23] VFP is, similar to TFP, one of aggregate productivity indicators which uses multilateral index procedure, but measures a firm's efficiency under the given level of capital inputs. For airports efficiency, ATRS used this measure in their airport benchmarking report in 2004.

VFP is based on the multilateral index procedure by Caves et al (1982). The translog multilateral output index ($\ln Y_{kl}$) can be written as:

$$\ln Y_{kl} = \ln Y_k - \ln Y_l = \frac{1}{2}\sum_i (R_{ik} + \overline{R}_i)\ (\ln Y_{ik} - \overline{\ln Y_i}) - \frac{1}{2}\sum_i (R_{il} + \overline{R}_i)\ (\ln Y_{il} - \overline{\ln Y_i}) \quad (3.4)$$

where Y_{ik} indicates the i^{th} output for the k^{th} airport, R_{ik} represents the revenue share of the i^{th} output for the k^{th} airport, $\overline{R}_i$ is the arithmetic mean of the revenue share of the i^{th} output over all sample airports and $\overline{\ln Y_i}$ is the geometric mean of the i^{th} output over all sample airports. The translog multilateral input index ($\ln X_{kl}$) can be written as:

$$\ln X_{kl} = \ln X_k - \ln X_l = \frac{1}{2}\sum_i (W_{ik} + \overline{W}_i)\ (\ln X_{ik} - \overline{\ln X_i}) - \frac{1}{2}\sum_i (W_{il} + \overline{W}_i)\ (\ln X_{il} - \overline{\ln X_i}) \quad (3.5)$$

where X_{ik} indicates the i^{th} input for the k^{th} airport, W_{ik} represents the cost share of the i^{th} input for the k^{th} airport, $\overline{W}_i$ is the arithmetic mean of the cost share of the i^{th} input over all sample airports and $\overline{\ln X_i}$ is the geometric mean of the i^{th} input over all sample airports. The translog multilateral VFP index ($\ln VFP_{kl}$) can be written as:

$$\ln VFP_{kl} = \ln VFP_k - \ln VFP_l = \ln Y_{kl} - \ln X_{kl} \quad (3.6)$$

This paper used number of passengers, aircraft movements and non-aviation revenues for outputs and labor and other expenditures for inputs.

Followings are VFP regression models used for this analysis:

1) Model for airports as a whole

$$\ln VFP = A_0 + A_1 d_{snow} + A_2 d_{comp} + A_3 d_{res}$$
$$+ B_0(\ln Q - \ln \overline{Q})$$
$$+ C_1(\ln o_{\text{int}} - \ln \overline{o}_{\text{int}}) + C_2(\ln o_{cong} - \ln \overline{o}_{cong}) + C_3(\ln o_{crg} - \ln \overline{o}_{crg}) + C_4(\ln o_{cont} - \ln \overline{o}_{cont})$$
$$+ C_5(\ln o_{nav} - \ln \overline{o}_{nav}) + \text{"second-order and interaction terms"} + \varepsilon \quad (3.7)$$

2) Model for categorized airports by size

$$\ln VFP = A_0 + A_1 d_{snow} + A_2 d_{comp} + A_3 d_{res}$$
$$+ B_1(\ln Q - \ln \overline{Q}) \cdot d_{sn} + B_2(\ln Q - \ln \overline{Q}) \cdot d_m + B_3(\ln Q - \ln \overline{Q}) \cdot d_l$$
$$+ C_1(\ln o_{\text{int}} - \ln \overline{o}_{\text{int}}) + C_2(\ln o_{cong} - \ln \overline{o}_{cong}) + C_3(\ln o_{crg} - \ln \overline{o}_{crg}) + C_4(\ln o_{cont} - \ln \overline{o}_{cont})$$
$$+ C_5(\ln o_{nav} - \ln \overline{o}_{nav}) + \text{"second-order and interaction terms"} + \varepsilon \quad (3.8)$$

where *VFP* indicates variable factor productivity index, and Q is output.[24] As in the above cost function models, o represents operating characteristics. As factors affecting productivity, the VFP models added the percentage of non-aviation revenue (o_{nav}), which reflects airports' business diversification strategy, to the previous four characteristic variables in the cost function models: the percentage of international passengers (o_{int}), the percentage of delays (o_{cong}), the percentage of cargo volume in WLU (o_{crg}), and the contractual cost share in total operating cost (o_{cont}). However, dummy variables for hub size (d_{sn}, d_m, d_l), snowbelt (d_{snow}) and type of financial management (d_{comp}, d_{res}) were the same as in the cost function models. Similarly, all variables were normalized by their sample means.

The constant term A_0 indicates the natural logarithm of VFP at the sample means. Because it is

[24] This paper used output index only for VFP analysis.

assumed that the mean value of the error term is zero, the VFP of the sample mean can be derived using the equation $exp(A_0)$. The coefficient of dummy for snowbelt, A_1 represents the difference in the natural logarithm of VFP between snowbelt airports and non-snowbelt airports; that is,

$$A_1 = \ln(\frac{\text{VFP of snowbelt airports}}{\text{VFP of non - snowbelt airports}})$$

The ratio of VFP equals $exp(A_1)$. Likewise, A_2 and A_3 represent the differences in the natural logarithm of VFP between compensatory airports and residual airports, relative to hybrid airports:

$$A_2 = \ln(\frac{\text{VFP of compensatory airports}}{\text{VFP of hybrid airports}})$$

$$A_3 = \ln(\frac{\text{VFP of residual airports}}{\text{VFP of hybrid airports}})$$

The coefficients of output variables, B_0, B_1, B_2, and B_3 indicate the elasticity of VFP with respect to output for sample airports as a whole, small and nonhub airports, medium hub airports and large hub airports, respectively. The elasticity provides information on returns to output scale. In other words, if B_i (i=0, 1, 2, 3) > 0, then there are increasing returns to output scale in the airport industry, if $B_i = 0$, there are constant returns to output scale, and if $B_i < 0$, there are decreasing returns to output scale.

The coefficients, C_i (i=1, 2, 3, 4, 5) indicate the effects of operating characteristics on VFP, and represent the impact caused by a 1% change in the percentage of international passengers, the percentage of delays, the percentage of cargo volume, the contractual cost share, and the percentage of non-aviation revenue.

3.3 Hypotheses

For analysis, the following hypotheses on economies of output scale, in other words, returns to output scale as well as factors affecting operating cost and VFP were tested.

Output

As pointed out by Golaszewski (2003), the airport industry is a capital-intensive industry requiring huge investments in infrastructure such as runways and passenger terminals. Even under the given state of capital infrastructure, there is overcapacity in the airport infrastructure and large overhead costs in maintaining excess (and underutilized) infrastructure. As shown in the previous studies by Doganis and Thompson (1973, 1974), Tolofari et al (1990) and Main et al (2003), it is widely accepted that economies of output scale exist and that the economies come from lumpiness in investment and high overheads in operations. The elasticity of total operating costs with respect to output, β_i (i=0, 1, 2, 3), is expected to be less than one ($\beta_i < 1$), whereas the elasticity of VFP, B_i (i=0, 1, 2, 3), is expected to be greater than zero ($B_i > 0$).

International Passenger

International passengers require more resources than domestic passengers because of security checks, custom clearances and other factors (ATRS, 2004; Doganis, 1992). An increase in international traffic is expected to increase operating costs; that is, $\varphi_I > 0$. Conversely, its increase is expected to decrease VFP; that is, $C_I < 0$.

Capacity Constraints

According to Brueckner (2002), delays in takeoff and landing result mostly from inclement weather, which account for over half of the total delays at airports. The second largest source is traffic volume (i.e., traffic exceeding airport capacity), accounting for 1.2-46.2% of all delays at major airports. In actuality, however, even weather-related delays may reflect capacity constraints at airports because such delays are in part related to excess number of flights landing and taking off relative to the total airside capacity. Therefore, in the present study, aggregate delays (as a percentage of total flight departures and landing) were used as a proxy for capacity constraints. Delays invariably translate into longer wait times for flights in aprons, taxiways or runways, and for passengers in terminals; thus increasing the number of delays are expected to increase costs; that is, $\varphi_2 > 0$. In contrast, their increase is expected to decrease VFP; $C_2 < 0$

Percentage of Cargo Volume

This factor is defined as the percentage of cargo volume in WLU. The impact of percentage of cargo volume on total operating cost varies by output measures. In terms of number of passenger, and output index which partly includes cargo operation, cargo handling requires extra resources; thus, an increase in cargo shares is expected to increase operating costs; that is, $\varphi_3 > 0$ in terms of passenger and output index. However, in terms of WLU including passenger and cargo, cargo is less costly to handle than are passengers, so an increase of the share is expected to reduce costs; that is, $\varphi_3 < 0$ in terms of WLU.

On the other hand, in contrast to its impact on operating cost in terms of output index, an increase of the share is expected to decrease VFP; that is, $C_3 < 0$ in terms of output index.

Percentage of Contractual Service Cost

Contractual service cost is defined as "cost of services paid to commercial enterprises and government agencies. Such costs include consulting, legal, accounting, auditing, security, firefighting, advertising, engineering, training, lobbying, maintenance, janitorial services, architectural fees, and financial services." (FAA, 2004) Many U.S. airports contract out some of their non-core activities to other agencies, which have expertise in this area in order to achieve financial efficiencies by reducing costs, allowing them to focus their resources on core business, and limiting risks from liabilities, from increased input prices, and changes in technology or regulatory policies (Gilley and Rasheed, 2000; Green, 2003).

Thus, an increase in the share of contractual service costs is expected to decrease total operating cost; that is, $\varphi_4 < 0$. Conversely, its increase is expected to increase VFP; $C_4 > 0$.

Snowbelt

Increment weather conditions such as snowfalls and storms affect airport operations in variety of different ways. For instance, during winter storms, airports require extra resources for snow removal, and de-icing of planes. These extra procedures can delay flight arrivals and departures. In this study, data on snowfalls to model the influence of increment weather conditions on airport operations was used. The snowfalls may increase the cost because extra resources are required for airports to cope with difficult environmental conditions.

Thus, airports within snowbelt areas are expected to have higher operating cost; that is, $\alpha_1 > 0$. Converse result for VFP is expected for snowbelt airports: $A_1 < 0$.

Financial Management

There is a general temporal trend towards a compensatory or hybrid approach in building an airport financial management structure because due to its very nature, compensatory approach lends itself to reducing costs and retain earnings. Hybrid airports use a combination of compensatory and residual approaches and partly achieve this objective, but residual airports usually cannot (AAAE, 2000; FAA/OST Task Force, 1999; US Congress OTA, 1984; Vasigh and Hamzaee, 1998).

Thus, compensatory airports are expected to have lower costs than hybrid airports, and residual airports are expected to have higher costs than hybrid airports; that is, $\alpha_2 < 0$ and $\alpha_3 > 0$.

In contrast, compensatory airports are expected to have higher productivity than hybrid airports, and residual airports expected to have lower productivity than hybrid airports; that is, $A_2 > 0$ and $A_3 < 0$.

4 ESTIMATION RESULTS

Using the dataset and models described in Chapter 3, this paper estimated the operating cost functions and conducted VFP regression analyses. The estimation results are presented in the order of output measures: number of passenger, WLU and output index. Then, the results about VFP regression follow.

4.1 Estimations of Cost Function

Number of Passenger

The estimations were conducted using a restricted translog model to the first-order in addition to an unrestricted translog model and the hypothesis test of whether the unrestricted model produced different results compared with a restricted model. The F-statistic for the hypothesis is:

$$F[J,n-K]=\frac{(R^2-R_*^2)/J}{(1-R^2)/(n-K)} \tag{4.1}$$

where R^2 for the unrestricted model and R_*^2 for the restricted model, n is the number of samples, K is the number of total estimates and J is the number of restrictions.

The value of F [21, 49] from the above formula was 1.4, whereas the critical value from the F-table at 0.05 level was 1.77. This implies that the unrestricted model does not differ significantly from the restricted model; the restricted model is, therefore, appropriate for analytic purposes.

Since total operating cost and all explanatory variables except three dummies were expressed in natural logarithmic form and were normalized, the first-order coefficients represent cost elasticities at the sample mean values. The first-order coefficients of the restricted model are summarized in Table 4.1.

Table 4.1 Cost Analysis Results: Passenger

Regressor	Coefficient (Standard Error)
Constant	17.792 (0.056)[a]
Output	0.700 (0.031)[b]
Input Price	1
% International Passenger	0.045 (0.016)[c]
% Delays	0.099 (0.132)
% Cargo	0.020 (0.023)
% Contractual Service Cost	0.055 (0.042)
Snowbelt	0.018 (0.069)
Compensatory	-0.036 (0.078)
Residual	0.015 (0.066)
R^2	0.964

[a] Significant at 0.05 for test, $\alpha_0 \neq 0$ [b] Significant at 0.05 for test, $\beta_i < 1$
[c] Significant at 0.05 for test, $\Phi_i \neq 0$

The estimated coefficient for output was 0.700. As expected, the coefficient was less than one. This indicates that a 1 % increase in output leads to a 0.7% increase in the total operating costs, all else constant. To test the statistical significance of the result, the present study used a one-tailed t-test, where the null and alternative hypotheses were:

$$H_0: \beta_i = 1$$
$$H_A: \beta_i < 1$$

The relevant t-statistic of $(\hat{\beta} - 1)/s_{\hat{\beta}}$, where $\hat{\beta}$ is the coefficient of estimate of β, and $s_{\hat{\beta}}$ is the standard error of the estimate, produced a value of -9.68, leading to the rejection of the null hypothesis at a 0.05 level of significance.[25] Thus, this suggests that there are economies of output scale in the airport industry in view of passenger.

[25] Critical value for the one-tailed test is approximately -1.67.

As for operating characteristics, all of the coefficients of regressors except contractual service cost had the expected signs. The contract-out costs, in contrast to a priori expectations, had a positive impact on costs.[26]

The coefficients of variables for operating characteristics suggest that a 10% increase in the percentage of international passenger, delays, cargo volume and contractual service cost increases total operating cost by 0.5%, 1.0%, 0.2% and 0.6%, respectively. In addition, snowbelt airports had 1.9% higher operating costs than non-snowbelt airports; while compensatory airports had 3.5% lower operating costs than hybrid airports, and residual airports had operating costs that were 1.5% higher than hybrid airports. Among these coefficients, only the coefficient for the percentage of international passenger was statistically significant at the level of 0.05.

For a graphical representation of the results, the present study plotted the observed and predicted operating costs based on the following formula:

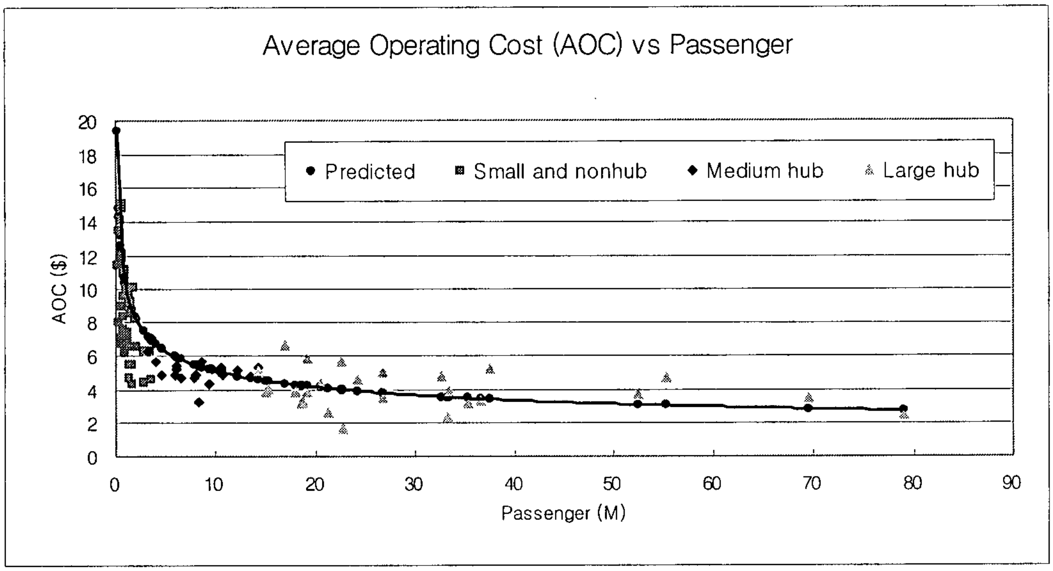
$$\begin{aligned}\ln TOC' = {} & \alpha_0 + \beta_0 \ln Q \\ & + \phi_1(\ln o_{\text{int}} - \ln \bar{o}_{\text{int}}) + \phi_2(\ln o_{cong} - \ln \bar{o}_{cong}) + \phi_3(\ln o_{crg} - \ln \bar{o}_{crg}) \\ & + \phi_4(\ln o_{cont} - \ln \bar{o}_{cont}) + \varepsilon \end{aligned} \tag{4.2}$$

$$\Downarrow$$

$$\begin{aligned}\ln AOC' = {} & \alpha_0 + (\beta_0 - 1) \cdot \ln Q \\ & + \phi_1(\ln o_{\text{int}} - \ln \bar{o}_{\text{int}}) + \phi_2(\ln o_{cong} - \ln \bar{o}_{cong}) + \phi_3(\ln o_{crg} - \ln \bar{o}_{crg}) \\ & + \phi_4(\ln o_{cont} - \ln \bar{o}_{cont}) + \varepsilon \end{aligned} \tag{4.3}$$

[26] Because the financial benefits of "contracting-out" result from turning fixed costs into variable costs, soothe practice of contracting-out may reduce capital costs but may increase operating costs. For example, commonly, airports contract-out winter maintenance, pavement maintenance, security, and janitorial services to external agencies. By contracting-out these services, the airports no longer need to invest any capital neither in maintenance or service equipments nor in storage facilities for snow removal, de-icing, pave maintenance, and so on. However, they must pay for these services to external agencies at certain prices, which reflect the costs of labor, capital and other costs to the suppliers.

Figure 4.1 Average Operating Costs: Passenger



In the above models *TOC'* indicates price-independent total operating costs and *AOC'* represents price-independent average operating costs.

Figure 4.1 depicts the graph of average operating costs against number of passengers, which was L-shaped curve. The predicted values based on the following equation (4.4) were evaluated at sample means of all variables except output. Dummy variables were included in the analyses but excluded in the graph for simplicity.

$$\ln AOC' = 6.462 - 0.300 \cdot \ln Q \qquad (4.4)$$

This study performed the same analysis using airports divided in categories of size—small and nonhub airports, medium airports and large hub airports—in order to examine the effects of airport sizes on total operating costs. As shown in Table 4.2, the coefficients of outputs for small and nonhub airports, medium airport and large airports were 0.682, 0.659 and 0.755, respectively, all of which were considerably below one. The t-statistics of the null hypotheses, $\beta_i = 1$, for each coefficient were -8.15, -2.56 and -3.22, respectively.

Table 4.2 Cost Analysis Results: Passenger (By Size)

Regressor		Coefficient (Standard Error)
Constant		17.757 (0.072)[a]
Output	SN	0.682 (0.039)[b]
	M	0.659 (0.133)[b]
	L	0.755 (0.076)[b]
Input Price		1
% International Passenger		0.045 (0.016)[c]
% Delays		0.094 (0.134)
% Cargo		0.022 (0.024)
% Contractual Service Cost		0.058 (0.043)
Snowbelt		0.018 (0.070)
Compensatory		-0.047 (0.081)
Residual		0.013 (0.067)
R^2		0.964

SN: Small and nonhub airports, M: Medium hub airports, L: Large hub airports
[a] Significant at 0.05 for test, $\alpha_0 \neq 0$ [b] Significant at 0.05 for test, $\beta_i < 1$
[c] Significant at 0.05 for test, $\Phi_i \neq 0$

This suggests that economies of output scale exist in all categories of airports and that the magnitude of the economies slightly increases in mid-size airports and diminishes with output scale. T-tests were used to test the null and alternative hypotheses:

$$H_0: \beta_i = \beta_j$$
$$H_A: \beta_i \neq \beta_j$$

where i, j = 1, 2, 3; 1 = small/nonhub airports, 2 = medium hub airports, 3 = large hub airports. The relevant t-statistics of $(\hat{\beta}_i - \hat{\beta}_j)/s_{\hat{q}}$, where $\hat{\beta}_i$ and $\hat{\beta}_j$ are the coefficients of estimates of β_i and β_j, and $s_{\hat{q}}$ is the standard error of $\hat{q}$, where $\hat{q} = \beta_i - \beta_j$, produced values, 0.19 for $(\beta_1 - \beta_2)$, -0.55 for $(\beta_2 - \beta_3)$, and 0.79 for $(\beta_3 - \beta_1)$, all of these tests failed to reject the null hypotheses at a 0.05 level of significance.[27] These data suggest that there are no differences in the magnitude of economies of output scale between airports of different sizes.

Work Load Unit (WLU)

As with the analyses using number of passenger, those which evaluated WLU were conducted using both the restricted translog model to the first-order terms and the unrestricted translog model.

Hypothesis testing to determine whether the unrestricted model differed from the restricted model produced the following results; the F-statistic for the hypothesis was F [21, 49] = 1.35. The critical value from the F-table at 0.05 level was 1.77, suggesting that the unrestricted model does not differ from the restricted model and the restricted model is appropriate.

Table 4.3 Cost Analysis Results: WLU

Regressor	Coefficient (Standard Error)
Constant	17.773 (0.054)[a]
Output	0.706 (0.030)[b]
Input Price	1
% International Passenger	0.043 (0.015)[c]
% Delays	0.069 (0.128)
% Cargo	-0.016 (0.023)
% Contractual Service Cost	0.060 (0.040)
Snowbelt	0.017 (0.066)
Compensatory	-0.018 (0.075)
Residual	0.029 (0.064)
R^2	0.967

[a] Significant at 0.05 for test, $\alpha_0 \neq 0$ [b] Significant at 0.05 for test, $\beta_i < 1$
[c] Significant at 0.05 for test, $\Phi_i \neq 0$

[27] Critical value for the two-tailed test is approximately -1.99.

The first-order coefficients of the restricted model are depicted in Table 4.3. The estimated coefficient for output was 0.706. As expected, the coefficient was less than one. This suggests that a 1 % increase in output, all else constant, leads to a 0.706% increase in total operating costs. To test the statistical significance of the null hypotheses, $\beta_i = 1$, a one-tailed t-test was used, which produced a value of -9.8. The hypothesis that the coefficient equals to one was rejected at a 0.05 level of significance. This suggests that economies of output scale exist in the airport industry in terms of WLU.

As for operating characteristics, all of the regression coefficients except contractual service cost had the expected signs. The coefficient of the percentage of international passenger was statistically significant at the level of 0.05.

Based on these findings, it can be said that a 10% increase in the percentage of international passenger, delays and contractual service cost increases total operating costs by 0.4%, 0.7% and 0.6%, respectively, but a 10% of increase in cargo volume decreases operating cost by 0.2%. Snowbelt airports had a 1.7% higher operating costs compared to non-snowbelt airports. The operating costs of compensatory airports were 1.7% lower than hybrid airports, while residual airports had 2.8% higher operating costs than hybrid airports.

The graph plotting the average operating costs against WLU derived from the following equation (4.5) is shown in Figure 4.2.

$$\ln AOC' = 6.259 - 0.294 \cdot \ln Q \qquad (4.5)$$

Similar to data on passengers, the costs varied markedly with WLU at small and nonhub airports; the impact of WLU was much more modest in medium and large hub airports.

Figure 4.2 Average Operating Costs: WLU

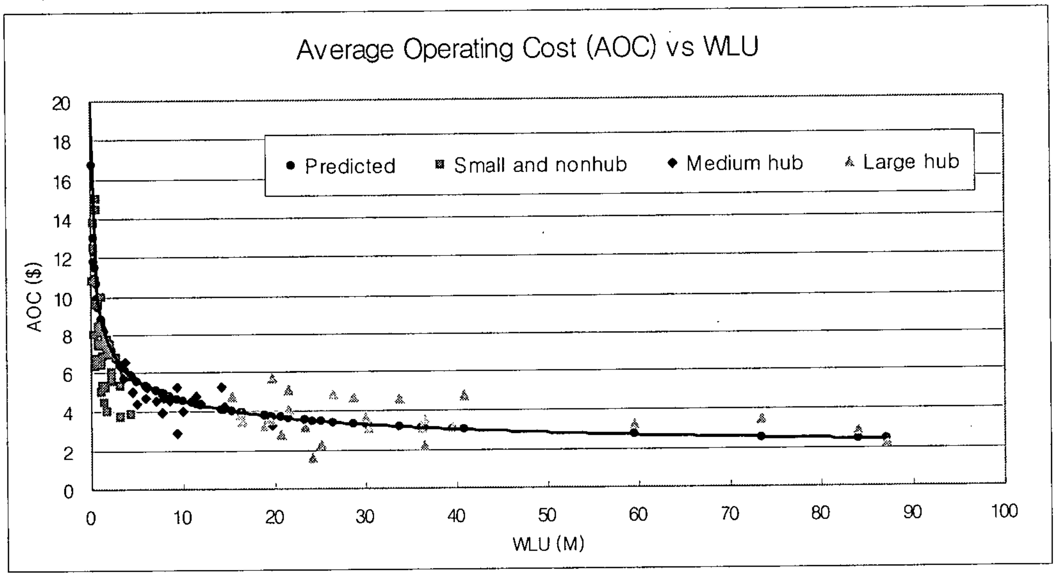


Table 4.4 Cost Analysis Results: WLU (By Size)

Regressor		Coefficient (Standard Error)
Constant		17.732 (0.069)[a]
Output	SN	0.686 (0.037)[b]
	M	0.621 (0.120)[b]
	L	0.767 (0.072)[b]
Input Price		1
% International Passenger		0.043 (0.016)[c]
% Delays		0.065 (0.129)
% Cargo		-0.014 (0.023)
% Contractual Service Cost		0.066 (0.041)
Snowbelt		0.021 (0.067)
Compensatory		-0.035 (0.078)
Residual		0.024 (0.065)
R^2		0.967

SN: Small and nonhub airports, M: Medium hub airports, L: Large hub airports
[a] Significant at 0.05 for test, $\alpha_0 \neq 0$ [b] Significant at 0.05 for test, $\beta_i < 1$
[c] Significant at 0.05 for test, $\Phi_i \neq 0$

As summarized in Table 4.4, the coefficients of outputs for small and nonhub airports, medium airport and large airports were 0.686, 0.621 and 0.767, respectively, all of which are considerably below one. The t-statistics of the null hypotheses, $\beta_i = 1$, for each coefficient were -8.49, -3.16 and -3.24, respectively, suggesting that economies of output scale exist in all size categories of airports and the magnitude of the economies slightly increases in mid-size airports and diminishes with output scale.

T-tests were used to determine the differences between these coefficients, which produced the values, 0.61 for $(\beta_1 - \beta_2)$, -0.93 for $(\beta_2 - \beta_3)$, and 0.93 for $(\beta_3 - \beta_1)$. They failed to reject the null hypotheses at a 0.05 level of significance. This suggests that there are no differences in the magnitude of economies of output scale between different size airports.

Output Index

Like the above estimations, those in terms of output index were conducted from a restricted translog model to the first-order terms and an unrestricted translog model and the hypothesis testing of whether the unrestricted model differs from the restricted model followed. The F-statistic for the hypothesis was $F\,[21, 49] = 1.10$. The critical value from the F-table at 0.05 level was 1.77, implying that the unrestricted model does not differ from the restricted model and the use of a restricted model is appropriate.

The first-order coefficients of the restricted model are depicted in Table 4.5. The estimated coefficient for output was 0.868, a bit higher than those of the previous estimators. As expected, the coefficient was below one, which indicates that a 1 % increase in output, all else constant, leads to a 0.868% increase in total operating costs.

Table 4.5 Cost Analysis Results: Output Index

Regressor	Coefficient (Standard Error)
Constant	17.685 (0.051)[a]
Output	0.868 (0.034)[b]
Input Price	1
% International Passenger	0.057 (0.014)[c]
% Delays	0.160 (0.118)
% Cargo	0.012 (0.021)
% Contractual Service Cost	0.024 (0.037)
Snowbelt	0.101 (0.061)
Compensatory	-0.162 (0.069)[c]
Residual	0.028 (0.059)
R^2	0.971

[a] Significant at 0.05 for test, $\alpha_0 \neq 0$ [b] Significant at 0.05 for test, $\beta_i < 1$
[c] Significant at 0.05 for test, $\Phi_i \neq 0$

To test the statistical significance of the null hypotheses, $\beta_i = 1$, a one-tailed t-test was conducted, which produced a value of -3.88, leading to the rejection of the null hypothesis at a 0.05 level of significance. This implies that economies of output scale exist in the airport industry in terms of output index.

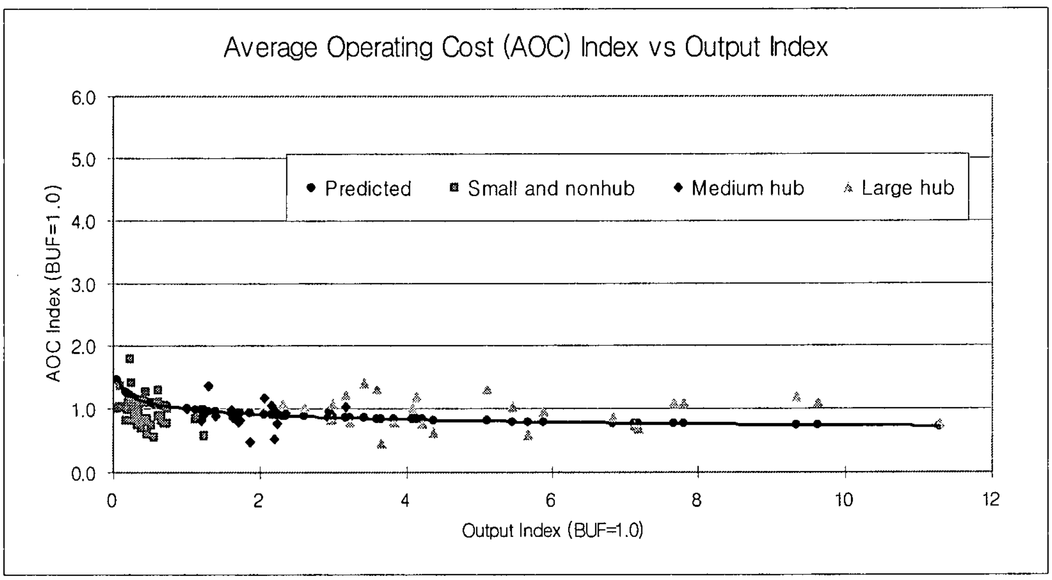
As for operating characteristics, all of the regression coefficients except contractual service cost had the expected signs. The coefficients of the percentage of international passenger and dummy for compensatory airports were statistically significant at the level of 0.05.

Based on these findings, it can be said that a 10% increase in the percentage of international passenger, delays, cargo volume and contractual service cost increases total operating costs by 0.6%, 1.6%, 0.1% and 0.2%, respectively. Snowbelt airports had 10.1% higher operating costs than did non-snowbelt airports; while compensatory airports had 15.0% lower operating costs than did hybrid airports, and residual airports had 2.8% higher operating costs than did hybrid airports. Dissimilar to above estimations, snowbelt airports exhibited a greater difference from non-snowbelt airports, and compensatory airports showed much lower operating costs than hybrid airports.[28] The costs of residual airports, on the other hand, demonstrated no significant differences from those at hybrid airports.

Figure 4.3 exhibits the graph of average operating costs against output index. The curve estimated on the basis of the following equation (4.6) and normalized with BUF as a base of 1.0.

$$\ln AOC' = 17.042 - 0.132 \cdot \ln Q \qquad (4.6)$$

Figure 4.3 Average Operating Cost Index: Output Index



[28] Such discrepancies might result from the nature of output index constructed by number of passenger as well as airside movements and non-aviation revenue. Snow-related costs are incurred mostly by "airside" de-icing and snow removal operations, and compensatory airports are likely to stimulate more "commercial activities" in order to produce surplus for future development. These two factors reflected in output index might make the gaps bigger.

Similar to the graphs in the above analyses, the average operating cost curve was L-shaped, but the impact was modest in small and nonhub airports.

As shown in Table 4.6, the coefficients of outputs for small and nonhub airports, medium airport and large hub airports were 0.836, 0.778 and 0.960, respectively, all of which were below one. The t-statistics of the null hypotheses, $\beta_i = 1$, for each coefficient were -4.1, -1.31 and -0.56. The latter t-statistic for medium hub and large hub airports failed to reject the null hypothesis at a 0.05 level of significance.[29] This implies that economies of output scale exist for small and nonhub airports, but there are no economies of output scale for medium and large hub airports in terms of output index.

Table 4.6 Cost Analysis Results: Output Index (By Size)

Regressor		Coefficient (Standard Error)
Constant		17.636 (0.060)[a]
Output	SN	0.836 (0.040)[b]
	M	0.778 (0.169)[c]
	L	0.960 (0.071)[c]
Input Price		1
% International Passenger		0.055 (0.014)[d]
% Delays		0.161 (0.118)
% Cargo		0.015 (0.021)
% Contractual Service Cost		0.031 (0.039)
Snowbelt		0.094 (0.061)
Compensatory		-0.178 (0.070)[d]
Residual		0.027 (0.059)
R^2		0.972

SN: Small and nonhub airports, M: Medium hub airports, L: Large hub airports
[a] Significant at 0.05 for test, $\alpha_0 \neq 0$ [b] Significant at 0.05 for test, $\beta_i < 1$
[c] Insignificant at 0.05 for test, $\beta_i < 1$ [d] Significant at 0.05 for test, $\Phi_i \neq 0$

[29] Critical value for the one-tailed test is approximately -1.67.

To test the differences in coefficients between medium and large hub airports, t-tests were conducted, which produced a value, -0.96 for ($\beta_2 - \beta_3$), failing to reject the null hypotheses at a 0.05 level of significance. This implies that there is no difference of economies of output scale between these types of airports.

Furthermore, with the increase in the breaking point by output index of 0.1, the study determined the threshold size of airports at which economies of output scale disappear. As depicted in Table 4.7, the coefficient of output for airports with output index of less than 0.7 was 0.854 and its t-statistic of the null hypotheses, β_i = 1, was -4.06, which was statistically significant. The coefficient for airports with an output index of greater than 0.7 was 0.928 and its t-statistic was -1.2, which failed to reject the null hypothesis at a 0.05 level of significance.

Table 4.7 Cost Analysis Results: Output Index (Breaking Point=0.7)

Regressor		Coefficient (Standard Error)
Constant		17.657 (0.055)[a]
Output	Below	0.854 (0.036)[b]
	Above	0.928 (0.060)[c]
Input Price		1
% International Passenger		0.052 (0.014)[d]
% Delays		0.143 (0.119)
% Cargo		0.016 (0.021)
% Contractual Service Cost		0.020 (0.037)
Snowbelt		0.103 (0.061)[d]
Compensatory		-0.180 (0.071)[d]
Residual		0.026 (0.059)
R^2		0.972

[a] Significant at 0.05 for test, $\alpha_0 \neq 0$
[b] Significant at 0.05 for test, $\beta_i < 1$
[c] Insignificant at 0.05 for test, $\beta_i < 1$
[d] Significant at 0.05 for test, $\Phi_i \neq 0$

This implies that economies of output scale disappear beginning at an output index of 0.7, which is approximately equivalent to 2.5 million passengers or 3.0 million WLU. These figures were estimated on the basis of the number of passengers or WLU of the airports which have the output indices near the breaking point [30]

4.2 VFP Regression

The regression analyses were conducted using only a restricted translog model to the first-order terms with respect to output index to facilitate the comparison of results between both approaches.

The first-order coefficients of the restricted model are depicted in Table 4.8.

Table 4.8 VFP Regression Results: Output Index

Regressor	Coefficient (Standard Error)
Constant	-0.069 (0.053)
Output	0.139 (0.036)[a]
% International Passenger	-0.046 (0.015)[b]
% Delays	-0.101 (0.119)
% Cargo	0.004 (0.021)
% Contractual Service Cost	-0.038 (0.038)
% Non-aviation Revenue	0.455 (0.117)[b]
Snowbelt	0.081 (0.067)
Compensatory	0.027 (0.075)
Residual	-0.073 (0.060)
R^2	0.440

[a] Significant at 0.05 for test, $B_i > 0$ [b] Significant at 0.05 for test, $C_i \neq 0$

[30] Wichita Mid-continent Airport (ICT), McGhee Tyson Airport (TYS), Spokane International Airport (GEG), Tulsa International Airport (TUL), and Colorado Springs Airport (COS) have output indices ranging from 0.66 to 0.74, which translate into 1.5-2.8 million passengers or 1.8-3.3 million WLU.

The estimated coefficient for output was 0.139. As expected, the coefficient was considerable greater than zero, which indicates that a 1 % increase in output, all else constant, leads to a 0.139% increase in VFP. To test the statistical significance of the result, the present study used a one-tailed t-test, where the null and alternative hypotheses were:

$$H_0: B_i = 0$$
$$H_A: B_i > 0$$

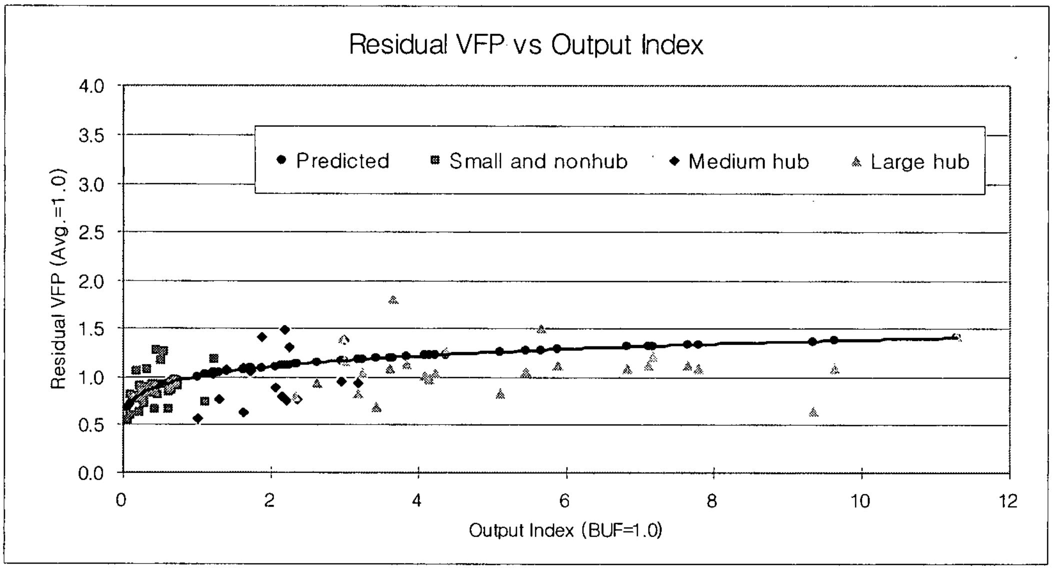
The relevant t-statistic of $\hat{B}/s_{\hat{B}}$ produced a value of 3.86, leading to the rejection of the null hypothesis at a 0.05 level of significance.[31] This implies that economies of output scale—increasing returns to output scale—exist in the airport industry in terms of output index, which is consistent with the results from cost functions.

The coefficients of variables for operating characteristics suggest that a 10% increase in the percentage of international passenger, delays, and contractual service cost decrease VFP by 0.5%, 1.0% and 0.4%, respectively, and the same level of increase in the percentage of cargo volume and non-aviation revenue increase the productivity measure by 0.04% and 4.6%, respectively. In addition, snowbelt airports had 8.4% higher VFP than non-snowbelt airports; while compensatory airports had 2.8% higher productivity than hybrid airports, residual airports had productivity that were 7.0% lower than hybrid airports. Among the coefficients of operating characteristics variables, those of cargo volume, contractual service cost and snowbelt had the unexpected signs, but they are very insignificant at the level of 0.05.

Figure 4.4 depicts the graph of residual VFP, which indicates productivity at airports after removing uncontrollable factors in operations. In contrast to the average operating cost curves, residual VFP rose steeply at small and nonhub airports and almost flattened out at large hub airports.

[31] Critical value for the one-tailed test is approximately 1.67.

Figure 4.4 Residual VFP: Output Index



This study performed the same analysis using airports divided in categories of size—small and nonhub airports, medium airports and large hub airports—in order to examine the effects of airport sizes on productivity.

As shown in Table 4.9, the coefficients of outputs for small and nonhub airports, medium airport and large airports were 0.151, 0.330 and 0.107, respectively, all of which were considerably above zero.

The t-statistics of the null hypotheses, $B_i = 0$, for each coefficient were 3.60, 1.93 and 1.49, respectively. The latter t-statistic for large hub airports failed to reject the null hypothesis at a 0.05 level of significance. This suggests that there are increasing returns to output scale for medium, small and nonhub airports but constant returns to output scale for large hub airports in terms of output index.

Table 4.9 VFP Regression Results: Output Index (By Size)

Regressor		Coefficient (Standard Error)
Constant		-0.049 (0.062)
Output	SN	0.151 (0.042)[a]
	M	0.330 (0.171)[a]
	L	0.107 (0.072)[b]
% International Passenger		-0.046 (0.015)[c]
% Delays		-0.106 (0.120)
% Cargo		0.004 (0.021)
% Contractual Service Cost		-0.051 (0.039)
% Non-aviation Revenue		0.454 (0.118)[c]
Snowbelt		0.082 (0.067)
Compensatory		0.032 (0.076)
Residual		-0.072 (0.060)
R^2		0.451

SN: Small and nonhub airports, M: Medium hub airports, L: Large hub airports
[a] Significant at 0.05 for test, $B_i > 0$ [b] Insignificant at 0.05 for test, $B_i > 0$
[c] Significant at 0.05 for test, $C_i \neq 0$

As opposed to the results obtained via the cost function analysis, medium hub airports exhibited increasing returns to output scale. This discrepancy might be caused by the categorization method employed to determine the airport size groups, since the 95% confidence intervals for the VFP coefficient of output, B_i (i=1,2,3), and the mirror of the output scale parameter in cost analysis, ($\beta_i - 1$) (i=1,2,3), were largely overlapping,[32] as is to be expected vis-à-vis duality theory.[33]

[32] 95% confidential intervals for B_i in VFP analysis were 0.066~0.236, -0.012~0.672 and -0.038~0.257, respectively, and those for ($\beta_i - 1$) in cost analysis were 0.084~0.234, -0.115~0.558, and -0.103~0.182, respectively.

[33] There is a duality between cost and production functions if either of these functions can describe the technology of the firm equally well in certain circumstances. That is to say that both functions contain equivalent information.

Table 4.10 VFP Regression Results: Output Index (Breaking Point=1.3)

Regressor		Coefficient (Standard Error)
Constant		-0.042 (0.062)
Output	Below	0.148 (0.042)[a]
	Above	0.113 (0.070)[b]
% International Passenger		-0.046 (0.015)[c]
% Delays		-0.101 (0.120)
% Cargo		0.004 (0.021)
% Contractual Service Cost		-0.039 (0.038)
% Non-aviation Revenue		0.446 (0.119)[c]
Snowbelt		0.081 (0.067)
Compensatory		0.034 (0.076)
Residual		-0.072 (0.060)
R^2		0.442

[a] Significant at 0.05 for test, $B_i > 0$ [b] Insignificant at 0.05 for test, $B_i > 0$
[c] Significant at 0.05 for test, $C_i \neq 0$

To test the differences in coefficients between small and nonhub and medium hub airports, a t-test for null hypothesis, $B_1 = B_2$, was conducted, which produced a value of 1.10 for $(B_1 - B_2)$, failing to reject the hypothesis at a 0.05 level of significance. This implies that there is no difference of returns to output scale between small and nonhub airports and medium hub airports.

By increasing the breakpoint of the output index by 0.1, the study determined that the threshold size of airports at which increasing returns to output scale disappear. As summarized in Table 4.10, the coefficient of output for airports with output index of less than 1.3 was 0.148 and its t-statistic of the null hypotheses, $B_i = 0$, was 3.49 which was significant. The coefficient for airports with an output index of greater than 1.3 was 0.113 and its t-statistic was 1.61, which failed to reject the null hypothesis at a 0.05 level of significance. This implies that increasing returns to output scale disappear at an output index of 1.3, which is approximately equivalent to 5.5 million passengers or 6.0 million WLU. These figures were estimated on the basis of the number of passengers or WLU of the airports which have the output indices near the breaking point.[34]

This breaking point is higher than that observed in the cost analyses. This discrepancy can be explained on the same grounds as in the VFP analysis, with classified airports by size. 95% confidence intervals for B in VFP analysis were 0.064~0.233 for airports with an output index of less than 1.3 and -0.027~0.253 for airports with an output index of greater than 1.3, and those for $(\beta-1)$ in cost analysis were 0.075~0.218 for airports with an output index of less than 0.7 and -0.048~0.192 for airports with an output index of greater than 0.7. The 95% confidence intervals for the coefficients in both analyses were largely overlapping.

[34] Manchester Airport (MHT), New Orleans International Airport (MSY), Jacksonville International Airport (JAX) and Dallas Love Field Airport (DAL) had output indices ranging from 1.25 to 1.34, which translate into 3.6-9.3 million passengers or 4.3-10 million WLU.

5 CONCLUSIONS

5.1 Findings

The results from cost and VFP analyses were similarly demonstrating the existence of economies of output scale and common factors that influenced its characteristics. For simplicity, the conclusions of this study will be grounded mostly on results from the cost analyses.

Economies of Output Scale

In the airport industry, economies of output scale exist to an output index of 0.7, which translates to approximately 2.5 million passengers or 3 million WLU. Beyond this threshold, the economies disappear. This threshold is similar to that reported by Doganis and Thompson (1973, 1974) and that by Main et al (2003), both of whom indicated that economies of output scale occurred at 3 to 5 million WLU.

The main reason for the dissipation of economies of output scale at higher levels of output is from increased operational complexities, particularly with airside operations, and traffic congestion at airports. This observation is consistent with reports by Salazar de la Cruz (1999) who argued that no economies of output scale exist beyond 3 to 12.5 million passengers. Starkie and Thompson (1985) predicted that with increasing traffic there would be increased capital and operating costs from a variety of sources including infrastructure needed to link aircraft to arrival areas and with baggage handling facilities and to bridge airside and terminal side facilities together.

Factors Affecting Operating Cost

The percentage of international passengers made a significant impact on costs. This indicates that international passengers require more resources for services because they have to clear customs and pass through security check-ins. A 10% of increase in international passenger traffic will increase total operating cost by 0.4 to 0.6%. *Capacity constraints*, defined by the percentage of delays, also had an impact on costs. Increasing number of delays led to increased airport congestion and longer wait-times in flight aprons, taxiways, runways and in passenger terminals, thereby increasing operating costs. A 10% increase in delays will likely increase total operating cost by 0.7 to 1.6%. *Cargo volume*, on the other hand, was inversely related to WLU but positively related to passenger and output index. This result supports the notion that cargos are less costly to handle than passengers, but in terms of passenger and output index, cargo handling requires extra resources. *The contract-out costs*, in contrast to a priori expectations, had a positive impact on costs. The analysis indicated that a 10% increase in contract-out costs increased total operating costs by 0.2 to 0.7%. The current study focused on operating rather than total costs. Because the financial benefits of "contracting-out" result from turning fixed into variable costs, contracting-out services might reduce capital costs but increase operating costs. Finally, *snowbelt* airports tended to spend more on operating costs compared to non-snowbelt airports. In terms of *financial management approach*, compensatory airports had lower operating costs than did hybrid airports. Residual airports had higher operating costs than did hybrid airports.

5.2 Implication

The findings from the present study have certain implications. According to de Neufville (1995, 2000), airport operators and policy makers worldwide have been concerned about how to develop and manage multi-airport systems.[35] Examples of multi-airport systems include O'Hare International Airport (ORD) and Midway International Airport (MDW) in Chicago, and Washington Dulles International Airport (IAD), Ronald Reagan Washington National Airport (DCA) and the Baltimore/Washington International Airport (BWI) in the Batimore/Washington region.

[35] The multi-airport systems are simply defined as the set of airports serving passenger or cargo traffic at a metropolitan area, in order to distribute traffic from large congested airports to relatively small under-utilized airports and to provide more convenient service at a low cost to air travelers in their region.

ORD is one of the most congested airports in the world, which on average has one landing or takeoff every 56 seconds all year round; any major delays at this airport lead to delays at all other airports nationwide. In 2003 ORD, the hub of the American Airlines and United Airlines, served 70 million passengers including 37 million connecting passengers. This figure, however, is only 3.4% higher than the figure for 1995 when ORD served 67 million passengers. MDW, on the other hand, doubled passenger traffic during this time, increasing from 10 million passengers in 1995 to 20 million in 2003. In the Baltimore/Washington region, BWI, IAD and DCA served 19, 17, and 14 million passengers, respectively, in 2003. The number of passenger at DCA, the primary airport in this region, declined slightly from the 15 million in 1995 to 14 million in 2003. On the other hand, passenger traffic at BWI and IAD increased from 13 and 12 million passengers, in 1995 to 19 and 17 million in 2003, respectively.

The multi-airport systems in such metropolitan areas have been successful in relieving congestion at the primary airports by increasing the number of airlines and passengers who use secondary airports (termed the "Southwest Effect"[36]). However, the success in traffic distribution is not sufficient for the multi-airport systems to be a viable solution for airports in a metropolitan area because compared to investments secondary airports have been usually under-utilized. Thus, the multiple-airport systems can only be justified by the cost-benefit analysis on the basis of overall airport costs in view of airport operators.

de Neufville (1995, 2000) suggested a threshold airport size of between 10 and 12 million originating passengers per year. This figure can be meaningfully interpreted in the context of financial viability of secondary airports. The current study took the first step in determining the financial threshold at which multi-airport systems model becomes justifiable by conducting a cost analysis. The analysis indicates that the break point at which economies of output scale disappear

[36] The phenomena of the increase in passenger boardings and the decrease in average fares at airports that Southwest Airlines serve (Vowles, 2001)

is 2.5 million passengers or 3 million WLU.

5.3 Further Research

The results of this paper will provide a key and fundamental framework for increasing efficiencies in the design and operations of airports across North America and elsewhere. This study is important because despite the increasing importance of the airport industry in the modern economy, there is a scarcity of studies that have examined the potential impact of economies of output scale at airports.

The findings of the current study provide impetus for future studies that will also consider capital inputs. In the present study, we excluded capital inputs because we could not adequately collect reliable costing data on capital investment. For the study on "economies of scale," capital costs and capital input levels must be considered in a cost analysis.

Future research on economies of scope between aviation and non-aviation activities would be useful in understanding productions and costs in the airport industry. Economies of scope indicate that as the number of different goods produced increases the average total costs of production decrease for each product because of sharing of labor resources and of equipment. In the context of increasing importance of commercial activities, the investigation of airports' economies of scope between two exclusive services—aeronautical and non-aeronautical–will shed light on airport management and operations.

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APPENDICES

Appendix A.1 List of Sample Airports

Airport	Hub Size	Name	State	Airport	Hub Size	Name	State
ABI	N	ABILENE REGIONAL	TX	MCO	L	ORLANDO INTL	FL
ABQ	M	ALBUQUERQUE INTL	NM	MDT	S	HARRISBURG INTL	PA
ACY	S	ATLANTIC CITY INTL	NJ	MDW	L	CHICAGO MIDWAY INTERNATIONAL	IL
ATL	L	WILLIAM B HARTSFIELD	GA	MFR	N	ROGUE VALLEY INTL	OR
BGR	N	BANGOR INTL	ME	MHT	S	MANCHESTER	NH
BIS	N	BISMARCK MUNI	ND	MKE	M	GENERAL MITCHELL INTL	WI
BMI	N	CENTRAL ILLINOIS REGIONAL	IL	MLI	S	QUAD-CITY	IL
BNA	M	NASHVILLE INTL	TN	MSN	S	DANE COUNTY REGIONAL-TRUAX	WI
BOS	L	GENERAL EDWARD LAWRENCE LOGAN	MA	MSP	L	MINNEAPOLIS-ST PAUL INTL	MN
BTR	S	BATON ROUGE METRO	LA	MSY	M	NEW ORLEANS INTL	LA
BUF	M	GREATER BUFFALO INTL	NY	MYR	S	MYRTLE BEACH INTL	SC
BWI	L	BALTIMORE-WASHINGTON INTL	MD	OAK	M	OAKLAND INTL	CA
CHS	S	CHARLESTON INTL	SC	OKC	M	WILL ROGERS WORLD	OK
CID	S	CEDAR RAPIDS MUNI	IA	ORD	L	CHICAGO O'HARE INTL	IL
CLE	M	CLEVELAND-HOPKINS INTL	OH	ORF	S	NORFOLK INTERNATIONAL	VA
CLT	L	CHARLOTTE/DOUGLAS INTL	NC	PAH	N	BARKLEY REGIONAL	KY
COS	S	COLORADO SPRINGS	CO	PBI	M	PALM BEACH INTL	FL
CPR	N	NATRONA COUNTY INTL	WY	PDX	M	PORTLAND INTL	OR
CVG	L	CINCINNATI/NORTHERN KENTUCKY	KY	PFN	N	PANAMA CITY-BAY CO INTL	FL
DAB	N	DAYTONA BEACH INTL	FL	PHL	L	PHILADELPHIA INTL	PA
DAL	M	DALLAS LOVE FIELD	TX	PHX	L	PHOENIX SKY HARBOR INTL	AZ
DCA	M	RONALD REAGAN WASHINGTON NATIONAL	DC	PIE	N	ST PETERSBURG/ CLEARWATER INTL	FL
DEN	L	DENVER INTL	CO	PIT	L	PITTSBURGH INTERNATIONAL	PA
DFW	L	DALLAS/FORT WORTH INTL	TX	PNS	S	PENSACOLA REGIONAL	FL
DSM	S	DES MOINES INTL	IA	RDU	M	RALEIGH-DURHAM INTL	NC
DTW	L	DETROIT METRO WAYNE	MI	RNO	M	RENO/TAHOE INTL	NV
FAI	S	FAIRBANKS INTL	AK	ROA	N	ROANOKE REGIONAL	VA
FLL	L	FORT LAUDERDALE/ HOLLYWOOD INTL	FL	RSW	M	SOUTHWEST FLORIDA INTL	FL
GEG	S	SPOKANE INTL	WA	SAN	L	SAN DIEGO INTL	CA
GPT	S	GULFPORT-BILOXI REGIONAL	MS	SAT	M	SAN ANTONIO INTL	TX
GRR	S	KENT COUNTY INTL	MI	SBA	S	SANTA BARBARA MUNI	CA
HNL	L	HONOLULU INTL	HI	SBN	S	MICHIANA RGNL TRANSPORTATION	IN
HOU	M	WILLIAM P HOBBY	TX	SEA	L	SEATTLE-TACOMA INTL	WA
HPN	S	WESTCHESTER COUNTY	NY	SFB	S	ORLANDO SANFORD	FL
HSV	S	HUNTSVILLE INTL-CARL T JONE	AL	SGF	N	SPRINGFIELD REGIONAL	MO
IAD	L	WASHINGTON DULLES INTERNATI	DC	SJC	M	SAN JOSE INTERNATIONAL	CA
IAH	L	GEORGE BUSH INTERCONTINENTAL	TX	SLC	L	SALT LAKE CITY INTL	UT
ICT	S	WICHITA MID-CONTINENT	KS	SMF	M	SACRAMENTO METRO	CA
JAN	S	JACKSON INTERNATIONAL	MS	SRQ	S	SARASOTA/BRADENTON INTL	FL
JAX	M	JACKSONVILLE INTL	FL	STL	L	LAMBERT-ST LOUIS INTL	MO
LAN	N	CAPITAL CITY	MI	SYR	S	SYRACUSE HANCOCK INTL	NY
LAS	L	MC CARRAN INTL	NV	TLH	S	TALLAHASSEE REGIONAL	FL
LAX	L	LOS ANGELES INTL	CA	TPA	L	TAMPA INTL	FL
LEX	S	BLUE GRASS	KY	TRI	N	TRI-CITIES REGIONAL TN/VA	TN
LFT	N	LAFAYETTE REGIONAL	LA	TUL	S	TULSA INTL	OK
LNK	N	LINCOLN MUNI	NE	TUS	M	TUCSON INTL	AZ
MCI	M	KANSAS CITY INTL	MO	TYS	S	MC GHEE TYSON	TN

Appendix A.2 Characteristics of Sample Airports

Hub Size	Airport	Passengers (000's)	Movement	WLU (000's)	Output Index (BUF=1.0)	Snowbelt	Type of Financial Management
L	ATL	79,087	910,398	87,095	11.29	-	Compensatory
L	BOS	22,604	381,425	26,313	5.45	Snowbelt	Compensatory
L	BWI	19,129	293,192	21,563	3.42	-	Hybrid
L	CLT	22,655	438,198	24,169	3.65	-	Hybrid
L	CVG	21,228	503,956	25,156	2.97	-	Hybrid
L	DEN	37,505	508,930	40,746	7.80	Snowbelt	Hybrid
L	DFW	52,455	759,288	59,556	7.66	-	Residual
L	DTW	32,664	487,762	33,655	5.10	Snowbelt	Residual
L	FLL	17,938	287,593	19,503	3.82	-	Residual
L	HNL	19,061	310,986	23,280	4.22	-	Residual
L	IAD	16,950	333,613	19,804	4.13	-	Hybrid
L	IAH	33,413	458,347	36,427	5.88	-	Hybrid
L	LAS	35,337	475,420	36,149	7.19	-	Hybrid
L	LAX	55,307	637,120	73,530	9.34	-	Compensatory
L	MCO	26,741	288,526	28,679	6.84	-	Residual
L	MDW	18,644	328,025	18,879	2.61	Snowbelt	Residual
L	MSP	33,200	508,813	36,372	5.66	Snowbelt	Hybrid
L	ORD	69,509	928,691	84,039	9.63	Snowbelt	Residual
L	PHL	24,114	453,833	30,011	3.60	-	Residual
L	PHX	36,613	544,572	39,560	7.12	-	Compensatory
L	PIT	14,267	355,990	15,297	2.98	Snowbelt	Residual
L	SAN	14,992	205,500	16,430	2.32	-	Residual
L	SEA	26,756	354,716	30,270	4.08	-	Residual
L	SLC	18,592	389,688	20,775	3.22	Snowbelt	Compensatory
L	STL	20,431	322,832	21,587	3.17	-	Hybrid
L	TPA	15,311	231,453	16,279	4.37	-	Compensatory
L	Mean	30,173	449,956	34,043	5.29		
M	ABQ	6,052	221,003	6,768	1.56	-	Hybrid
M	BNA	7,989	229,169	8,581	2.24	-	Hybrid
M	BUF	4,077	135,133	4,556	1.00	Snowbelt	Compensatory
M	CLE	10,555	258,460	11,513	2.06	Snowbelt	Residual
M	DAL	5,589	249,085	5,589	1.34	-	Compensatory
M	DCA	14,215	250,515	14,273	3.17	-	Hybrid
M	HOU	7,803	242,635	7,861	1.62	-	Hybrid
M	JAX	4,883	121,143	5,590	1.31	-	Hybrid
M	MCI	9,573	182,740	10,981	2.36	-	Compensatory
M	MKE	6,142	211,418	7,047	1.72	Snowbelt	Residual
M	MSY	9,276	119,127	10,084	1.29	-	Hybrid
M	OAK	13,548	342,871	19,753	2.94	-	Hybrid
M	OKC	3,260	165,415	3,594	1.87	-	Compensatory
M	PBI	6,011	171,692	6,194	1.64	-	Hybrid
M	PDX	12,225	261,495	14,611	2.97	-	Residual
M	RDU	8,344	231,388	9,342	2.19	-	Compensatory
M	RNO	4,586	139,109	5,056	1.20	-	Hybrid
M	RSW	5,892	76,614	6,048	1.40	-	Residual
M	SAT	6,536	261,751	7,700	1.70	-	Hybrid
M	SJC	10,728	200,150	11,967	2.15	-	Residual
M	SMF	8,647	159,795	9,356	2.21	-	Residual
M	TUS	3,509	246,682	3,793	1.21	-	Residual
M	Mean	7,702	203,518	8,648	1.87		

Appendix A.2 Characteristics of Sample Airports (Cont'd)

Hub Size	Airport	Passengers (000's)	Movement	WLU (000's)	Output Index (BUF=1.0)	Snowbelt	Type of Financial Management
S	ACY	1,002	116,255	1,002	0.23	-	Compensatory
S	BTR	715	103,763	719	0.29	-	Residual
S	CHS	1,616	120,188	1,669	0.52	-	Residual
S	CID	922	71,625	1,147	0.33	Snowbelt	Compensatory
S	COS	2,018	202,568	2,188	0.74	Snowbelt	Hybrid
S	DSM	1,822	116,363	2,708	0.62	Snowbelt	Hybrid
S	FAI	833	136,283	1,151	0.23	Snowbelt	Residual
S	GEG	2,790	106,100	3,282	0.70	Snowbelt	Residual
S	GPT	858	109,295	858	0.30	-	Hybrid
S	GRR	1,977	110,128	2,312	0.63	Snowbelt	Compensatory
S	HPN	869	170,782	869	0.34	-	Other
S	HSV	1,052	65,192	1,613	0.59	-	Other
S	ICT	1,432	184,015	1,738	0.66	-	Hybrid
S	JAN	1,215	79,377	1,325	0.47	-	Hybrid
S	LEX	1,142	90,377	1,145	0.41	-	Hybrid
S	MDT	1,330	65,154	1,765	0.44	-	Hybrid
S	MHT	3,601	98,060	4,330	1.25	Snowbelt	Hybrid
S	MLI	812	65,354	832	0.29	Snowbelt	Compensatory
S	MSN	1,598	131,490	1,717	0.56	Snowbelt	Compensatory
S	MYR	1,335	50,152	1,357	0.34	-	Hybrid
S	ORF	3,436	121,373	3,759	1.12	-	Hybrid
S	PNS	1,362	127,197	1,407	0.46	-	Residual
S	SBA	753	152,485	781	0.39	-	Compensatory
S	SBN	802	65,100	939	0.25	Snowbelt	Other
S	SFB	1,254	385,303	1,330	0.33	-	Other
S	SRQ	1,062	137,193	1,066	0.42	-	Residual
S	SYR	1,895	119,071	2,094	0.62	Snowbelt	Hybrid
S	TLH	1,113	102,946	1,205	0.35	-	Residual
S	TUL	2,747	175,221	3,231	0.73	-	Hybrid
S	TYS	1,428	139,639	1,776	0.66	-	Hybrid
S	Mean	1,493	123,935	1,710	0.51		
N	ABI	115	84,094	122	0.06	-	Compensatory
N	BGR	551	98,041	567	0.25	Snowbelt	Compensatory
N	BIS	282	50,370	285	0.10	Snowbelt	Hybrid
N	BMI	420	31,373	439	0.09	Snowbelt	Residual
N	CPR	121	48,303	202	0.08	Snowbelt	Compensatory
N	DAB	566	337,615	567	0.35	-	Residual
N	LAN	535	193,809	761	0.25	Snowbelt	Compensatory
N	LFT	318	71,329	345	0.19	-	Residual
N	LNK	420	92,480	420	0.35	-	Other
N	MFR	482	63,060	514	0.18	-	Hybrid
N	PAH	66	27,381	66	0.04	-	Compensatory
N	PFN	372	86,611	384	0.14	-	Hybrid
N	PIE	998	210,846	1,182	0.50	-	Other
N	ROA	622	82,968	743	0.25	-	Hybrid
N	SGF	653	89,140	757	0.25	-	Other
N	TRI	391	87,698	403	0.22	-	Hybrid
N	Mean	432	103,445	485	0.21		
Total	Mean	10,698	229,249	12,069	2.10		

Appendix A.3 Data Sources

Data for the analysis can be categorized into three groups:

1) Traffic Statistics
    A. Passengers
       : Total number of passengers and percentage of international passengers
    B. Cargo: Percentage of cargo volume of WLU
    C. Aircraft movements

The main sources are:	Airport Council International-North America (ACI-NA) (http://www.aci-na.com)
	American Association of Airport Executives Survey (2000)
	Annual reports and websites

2) Financial Data
    A. Cost: Total operating cost, labor cost, softcost, contractual services cost, etc
    B. Revenue: Aviation and non-aviation revenue, etc

The main sources are:	Annual reports/financial reports and websites
	US Federal Aviation Administration Form 5100-127 (http://cats.crownci.com/reports/reports.cfm)

3) Other Data
    A. Number of employees
    B. Types of financial management: compensatory, residual, hybrid, other
    C. Capacity constraints: % of delays
    D. Snowbelt: Days with snowfall
    E. Input factor price: Cost-of-living index

The main sources are:	American Association of Airport Executives Survey (2000)
	American Chamber of Commerce Researchers Association (ACCRA) (http://www.coli.org)
	Annual reports and websites
	US DOT Air Travel Consumer Report
	US National Climatic Data Center (NCDC)