Airport Costs and Production Technology: A Translog Cost Function Analysis with Implications for Economic Development—Update

Patrick McCarthy
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GTI-01
July 15, 2011

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16. Abstract

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Update*

Patrick McCarthy**

DRAFT FINAL REPORT

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Abstract

Based upon 50 large and medium hub airports over a 13 year period, this research estimates one and two output translog models of airport short run operating costs. Output is passengers transported on non-stop segments and pounds of cargo shipped. The number of runways is a quasi-fixed factor of production. Statistical tests reject the null hypothesis that airport production technology is homothetic and homogeneous, exhibits constant returns to scale, or reflects a Cobb-Douglas production technology. From the analysis, airports operate under increasing returns to runways utilization and increasing ray economies of scale for the two output model. Airport operating costs were 2% higher after the September 1, 2001 terrorist attacks. The input demand for general airport operations is price elastic and Morishima substitution elasticities indicate that Personnel, Repair-Maintenance-Contractual services, and General Airport Operations are substitutes in production. Based upon a one output passenger cost function model, an exploratory analysis identifies a relationship between the marginal cost of airport operations and indicators economic development. All else constant, a decrease in an airport's real average operating costs is associated with increasing metropolitan employment, the number of establishments, and real gross metropolitan and state products.

Keywords: airport capacity, airport infrastructure, airport costs, economic development, panel data, runway, translog cost function, flexible form models

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I. Introduction

Passenger air travel and air freight have grown substantially over the past fifteen years. Between January 1995 and November 2009, passenger enplanements have increased 31.6% from 41.7 million to 54.9 million. At 572 million miles in November 2009, revenue freight miles have increased 33.6% during the same period, a bit less than the 40.9% increase in revenue passenger miles between January 1996 and November 2009.[1] During this same period, the total number of runways needed to support the traffic increased 3.3%. If one focuses only upon those airports with significant activity where the infrastructure needs are the greatest, the number of runways only increased 14.8%.[2] Without the necessary infrastructure to support the increasing demand for air passenger travel and air freight, there will be continuing problems with system delays, airport congestion, safety, and deteriorating services that airports provide to the traveling public and businesses. Airports are drivers of economic development and there is an increasing literature on the positive effects that airports have on metropolitan and, more broadly, regional economic development.

This study focuses on airports, their costs, and their productivity. Similar to any large enterprise, airports manage a significant amount of resources in providing the necessary infrastructure for air travel and air freight. By allocating its resources more efficiently, an airport reduces time and out-of-pocket costs of individuals and businesses and provides an infrastructure for the metropolitan area and region to strengthen its economic base and develop faster. This analysis develops and estimates single and multiple output translog models for airport operating costs. Translog models are flexible form models which allow one to test alternative hypotheses on production technology, including homotheticity, homogeneity, returns to scale, and elasticity of substitution.[3] From the results, cost estimates are used to explore the relationship between airport costs and metropolitan development.

II. Review of Literature

During the past two decades, there have been numerous studies on cost and production in the transportation and public capital literatures using flexible form models, including Caves,

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[1] Department of Transportation, Bureau of Transportation Statistics, http://www.bts.gov/data_and_statistics/.

[2] The Federal Aviation Administration identifies these as Operational Evolutionary Partnership (OEP) airports.

[3] By the principle of duality, well-behaved cost functions embody all of the economically relevant attributes of the underlying production technology (Varian, 2nd Edition, 1984).

Christensen, and Swanson (1981), Deno (1988), Duffy-Deno and Eberts (1991), Keeler and Ying (1988), Lynde and Richmond (1992), Morrison and Schwartz (1996). Among the more widely used approaches are the translog single and multi-product cost functions and generalized Leontief cost functions.

Caves, Christensen, and Swanson (1981) develop and estimate multiproduct variable or short run cost functions on a pooled cross section of railroad firms in the United States for 1955, 1963, and 1974. Using ton-miles of freight, average length of freight haul, passenger-miles and average length of passenger trips as output indexes and labor, fuel, and equipment as input indexes, the study estimates average annual rates of productivity growth at 2 percent per year for the sample period. The estimated elasticities of total cost with respect to the four outputs are consistent with the hypothesis that the United States railroad systems operate with scale economies.

Keeler and Ying (1988) analyze the effects of Federal-aid highway infrastructure investments on costs and productivity of U.S. firms in the motor freight transport industry.[4] Based on a translog cost specification of regional trucking firms, the study finds that the rapid growth of highway infrastructure that occurred between 1950 and 1973 produced a strong and positive effect on productivity growth in trucking. Furthermore, the results support the position that the benefits of these investments, narrowly defined as benefits to the trucking industry, fall between one-third and one-half of the cost of the Federal Aid highway system over this period.

Using a translog specification, Deno (1988) analyzed the impact of public capital on manufacturing firms' variable input demands and output supplies.[5] Deno found that public capital was an important factor in manufacturing input demand and output supplies. And in terms of differential effects, Deno found that water public capital had the largest effect on growing regions whereas highway capital had a larger effect on declining regions.

Duffy-Deno and Eberts (1991) estimates the effect of public capital stock on regional per capita personal income using a two-stage-least-squares regression model. For a sample of metropolitan areas, the study measures the quantity and quality of public capital stock using the perpetual inventory technique. The authors find that public capital has a positive and significant impact on per capita income, suggesting that investments in public capital enhances economic

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[4] Keeler and Ying, 1988, p. 69.

[5] Rather than estimating a cost function, Deno (1988) estimated a translog profit function. Deno's measure of public capital included roads and highways, sewers and sewage disposal and water and water treatment plants.

development and, conversely, allowing public capital to deteriorate hinders metropolitan development.

Lynde and Richmond (1992) use a translog cost function approach using annual observations for the U.S. nonfinancial corporate sector from 1958 to 1989 to estimate the impact of public capital (state and local and federal nonmilitary public capital) on the costs of production in the private sector. The authors find support for the productivity of public capital and find that public and private capital are complements rather than substitutes in production.

Morrison and Schwartz (1996) use a cost function framework to analyze the role of state infrastructure, defined as publicly owned highway, water, or sewer material, on productivity using a panel of the contiguous 48 states from 1970-1987. The measure of productivity growth decomposes the traditional productivity growth "measure of our ignorance" into the impacts of technical change, scale economies, fixity of private capital, and the availability of public infrastructure capital.[6] The authors' approach estimates shadow values that reflect the potential cost savings from a decline in variable inputs required to produce a given amount of output when infrastructure investment occurs.[7] The positive shadow value for public capital supports the inference that the return to infrastructure investment is economically significant which suggests that slowdowns in public infrastructure investment reduce productivity growth.

Brox and Fader (2005) exam the relationship between Canadian public infrastructure and private output using a constant elasticity of substitution translog cost model. Brox and Fader find that Canadian infrastructure, as measured by the accumulated stock of public infrastructure, is a substitute for private capital and that during the period of the study, 1961-1997, economies of scale characterized manufacturing costs.[8]

Although many of the above flexible form studies focus upon the development effects of transportation and other forms of public capital, none of these analyze the effect of airport infrastructure upon economic development. However, there are a number of studies that have analyzed the impact that airports have upon metropolitan development, using enplaned passengers as a measure for airport output.

Goetz (1992) tests the hypothesis that the growth of air passenger travel affects the urban system and its development. Consistent with this hypothesis, Goetz finds that increases in per

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[6] Morrison and Schwartz, 1996, p. 1100.
[7] Morrison and Schwartz, 1996, p. 1095-1096.
[8] Brox and Fader, 2005, p. 1254.

capita passenger flows are positively correlated with past and future growth, consistent with the importance that air travel has for economic development. Hakfoort et al. (2001) and Brueckner (2003) explore the impact that airports have upon metropolitan employment. Using an input-output framework to trace the effects of an expansion of Amsterdam's Schiphol Airport on the Greater Amsterdam region, Hakfoort et al. find that a one job increase at Schiphol produces 1 job from indirect and induced effects. Exploring linkages between employment and air traffic in the Chicago metropolitan area, Brueckner (2003) finds that a 1% increase in passenger enplanements increases employment in service related industries 0.1%. An important implication from Brueckner's analysis is that an airport expansion at Chicago's O'Hare Airport would have strong economic development effects, generating 185,000 service related jobs.

Rather than looking only at enplanements, Green (2007) uses various measures of airport passenger and cargo activity to analyze the effects of airports on population and employment metropolitan growth. Green finds that, after controlling for various factors and for reverse causality, passenger activity is a strong predictor of population and employment growth.

Two recent studies on airports have addressed questions of governance and airport efficiency and network effects. Based upon a set of airports worldwide, Oum et al. (2007) uses a stochastic frontier approach to analyze airport efficiency and implications this may have for airport governance. Generally, the authors find that privatizing airports will enhance airport efficiency, and by inference, economic development. An exception to this is mixed ownership structures, with government majority, which the authors find to be less efficient than 100% publicly owned airports. Oum et al. also found that metropolitan areas with multiple airports would also gain from privatization, presumably because of synergies that could be exploited by the privatized firm.

Cohen and Paul (2003) explore the extent to which changes in airport infrastructure have network-associated development effects. Based upon a generalized Leontif model, the authors not only find that airport infrastructure investment lowers manufacturing costs in an airport's own state but also generates lower manufacturing labor and material savings in neighboring states. The authors attribute these benefits to increases in traffic and system reliability.

III. Empirical Methodology

Minimizing an airport's operating costs subject to an output constraint generates an airport cost function that enables a researcher to obtain insights on technical aspects of an airport's production function. In particular, a general specification for an airport's variable or operating costs is:

$$C_{it} = C(q_{it};\, p_{itj}\, ;\, k_{it},\, \tau)$$

where, for airport i at time t, C_{it} is total operating costs, q_{it} is an airport's operational output, p_{itk} is the price of variable input j, k_{it} is the level of fixed capital, and τ is the state of technology. Inputs include such factors as labor, outsourced services, repairs and maintenance, and airport capital. Depending upon specification for the empirical model, estimating this cost function can provide information on scale economies, factor demands and their prices, and elasticities of substitution. In addition, marginal and average costs of production are straightforward outputs from the analysis.

III.1 Translog Cost Function for MSA Airports

A commonly employed flexible form cost function is the translog function whose general form for total operating costs is

$$(2)\quad \ln VC_{it} = \beta_0 + \beta_q(\ln q_{it} - \ln \bar{q}_i) + \beta_k(\ln k_{it} - \ln \bar{k}_i) + \beta_\tau(\ln \tau_{it} - \ln \bar{\tau}_i) + \sum_{j=1}^{J} \beta_j(\ln p_{itj} - \ln \bar{p}_{ij})$$
$$+\frac{1}{2}\beta_{qq}(\ln q_{it} - \ln \bar{q}_i)^2 + \frac{1}{2}\beta_{kk}(\ln k_{it} - \ln \bar{k}_i)^2 + \frac{1}{2}\sum_{j=1}^{J}\beta_{jm}(\ln p_{itj} - \ln \bar{p}_{ij})(\ln p_{itm} - \ln \bar{p}_{im})$$
$$+\sum_{j=1}^{J}\beta_{jq}(\ln p_{itj} - \ln \bar{p}_{ij})(\ln q_{it} - \ln \bar{q}_i) + \sum_{j=1}^{J}\beta_{jk}(\ln p_{itj} - \ln \bar{p}_{ij})(\ln k_{it} - \ln \bar{k}_i) + \beta_{qk}(\ln q - \ln \bar{q}_i)(\ln k_{it} - \ln \bar{k}_i)$$

VC_{it} is the airport's total operating cost, q_{it} is output, p_{itj} ($i = 1, \ldots , J$) is the price of the j^{th} input, and k_{it} is the level of quasi-fixed capital, and τ_{it} is the state of technology for airport i at time t,. τ_{it} captures shifts in the cost function due to technological progress in the industry. The bar indicates a variable's mean value.

A well-behaved cost function with a quasi-fixed factor must satisfy several conditions: (a) linear homogeneity in factor prices and (b) symmetry in factor prices, (c) monotonicity and (d) concavity.[9] The following restrictions ensure that the cost function satisfies these properties:

$$(3) \qquad \sum_{j=1}^{J} \beta_j = 1, \ \sum_{m=1}^{J} \beta_{jm} = \sum_{j=1}^{J} \beta_{jm} = \sum_{j=1}^{J} \sum_{m=1}^{J} \beta_{jm} = 0$$

$$\sum_{j=1}^{J} \beta_{jq} = 0; \ \sum_{j=1}^{J} \beta_{jm} = 0; \ \sum_{j=1}^{J} \beta_{j\tau} = 0.$$

The symmetry restriction requires that $\beta_{ij} = \beta_{ji}$. If the cost function satisfies monotonicity and concavity, then input shares have positive signs at all observations and the matrix of substitution elasticities is negative semidefinite for any combination of cost shares, respectively.[10]

The translog cost function imposes no a priori restrictions on input substitution possibilities or scale economies. Further, differentiating the cost function with respect to factor prices (Shephard, 1970) yields cost share equations S_i's for each of the *j* variable inputs. In particular,

$$(4) \qquad S_i = \beta_i + \frac{1}{2} \sum_{j=1}^{n} \beta_{ij} (\ln p_{ijt} - \ln \bar{p}_{ij}) + \beta_{iq} (\ln q_{it} - \ln \bar{q}_i) + \beta_{ik} (\ln k_{it} - \ln \bar{k}_i)$$

Consistent with other analyses, Morishima partial substitution elasticities σ_{ij}^{M} provide measures of substitution between factor inputs and specifically measures the impact on the input ratio from a factor price increase as:[11] :

$$(5) \qquad \sigma_{ij}^{M} = \eta_{ij} - \eta_{jj} = \frac{\partial \ln(x_i / x_j)}{\partial p_j}$$

where p_j is the price of factor *j* (Chambers, 1988) and η_{ij} is the elasticity of input i with respect to price of input j.

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[9] Christensen, Jorgenson, and Lau (1975) and Berndt and Wood (1975).

[10] A cost function is homogenous of degree one in prices when prices and total costs move proportionately, all else equal. A cost function that is non-decreasing in factor prices satisfies monotonicity. A symmetric matrix is negative semidefinite if all characteristic roots are nonpositive (Greene, 2000, p. 47).

[11] An alternative measure for substitution effects is the Allen-Uzawa measure which is a one factor-one price measure. Morishima's measure is a two factor-one price measure which better reflects substitutability between inputs. Chamber (1988) demonstrates that Allen-Uzawa substitutes are Morishima substitutes but two factors may be Allen-Uzawa complements but Morishima substitutes. That is, in contrast to Allen-Uzawa, Morishima's measure is not sign symmetric.

In the presence of quasi-fixed and other factors of production that are difficult to adjust, Caves et al. (2002) demonstrate that for the single output case, economies of capital stock utilization (i.e. the returns to scale given the quasi-fixed factor) are:

$$(6) \qquad \mathrm{ECU}_{it} = \frac{\left(1 - \dfrac{\partial \ln VC_{it}}{\partial \ln K_{it}}\right)}{\dfrac{\partial \ln VC_{it}}{\partial \ln Q_{it}}} = \frac{1 - \left(\beta_k + \beta_{kk}(\ln k_{it} - \ln \bar{k}_i) + \beta_{qk}(\ln q_{it} - \ln \bar{q}_i) + \sum_j^J \beta_j (\ln p_{itj} - \ln \bar{p}_{ij})\right)}{(\beta_q + \beta_{qq}(\ln q_{it} - \ln \bar{q}_i) + \beta_{qk}(\ln k_{it} - \ln \bar{k}_i) + \sum_j^J \beta_j (\ln p_{itj} - \ln \bar{p}_{ij})}.$$

At mean values of production, input prices, and quasi-fixed capital, ECU_{it} is $(1/\beta_q)$. Finally, through the introduction of time variables, one can explore the effects of technological change on costs.

III.2 Translog Cost Function – Estimation Considerations

For the translog model identified in equation (2), there are two sets of restrictions. First, and summarized in equation (3), are restrictions to ensure that the cost function is well-behaved. These restrictions are imposed on the model before estimation. Second, as a flexible functional form, the translog model is a specification under which simpler models are nested. In particular, we can test for homotheticity, homogeneity, Cobb-Douglas, and constant returns to scale:

a) If $\beta_{lq} = \beta_{eq} =$ then the underlying production function is homothetic, i.e. the input ratio is a function of the input price ratio;[12]

b) If a) is true and $\beta_{qq} = 0$, then the underlying production function is homothetic and homogeneous, i.e. if there is a proportionate (e.g. doubling) increase in all variable inputs, then output increases by some power r of the proportionate increase;[13]

c) If a) and b) are true and $\beta_q = 1$, then we have constant returns to scale;

d) If a) and b) are true and $\beta_{le} = \beta_{ll} = \beta_{ee} = 0$, then the underlying production function is Cobb-Douglas with elasticities of substitution equal to 1. In addition, if $\beta_q = 1$, then the Cobb-Douglas production technology also has constant returns to scale.

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[12] Also, for homothetic production functions, slopes of the level curves (i.e. isoquants) are equal for any given input ratio and the dual cost function is separable in output and prices (Silberberg, 2nd Edition, 1990).

[13] A further implication is that that the elasticity of cost function with respect to output is constant (Christensen and Greene, 1976).

Because the data include a panel of 50 airports from 1996 – 2008, we also estimate a full set of fixed effects, α_i (i = 1, …., 49), where the constant term β_0 reflects Florida's Tampa International Airport, the reference airport.

In order to increase the efficiency of the parameter estimates, the cost function (equation 2) and the share equations (equation 4) are estimated jointly as a system. In particular,

$$\begin{aligned}(7)\ \ln VC_{it} &= \beta_0 + \sum_{i=1}^{34}\alpha_i + \beta_q(\ln q_{it} - \ln\bar{q}_i) + \beta_k(\ln k_{it} - \ln\bar{k}_i) + \beta_\tau(\ln\tau_i - \ln\bar{\tau}_i) + \sum_{j=1}^{J}\beta_j(\ln p_{itj} - \ln\bar{p}_{ij}) \\ &+ \frac{1}{2}\beta_{qq}(\ln q_{it} - \ln\bar{q}_i)^2 + \frac{1}{2}\beta_{kk}(\ln k_{it} - \ln\bar{k}_i)^2 + \frac{1}{2}\sum_{j=1}^{J}\beta_{jm}(\ln p_{itj} - \ln\bar{p}_{ij})(\ln p_{itm} - \ln\bar{p}_{im}) \\ &+ \sum_{j=1}^{J}\beta_{jq}(\ln p_{itj} - \ln\bar{p}_{ij})(\ln q_{it} - \ln\bar{q}_i) + \sum_{j=1}^{J}\beta_{jk}(\ln p_{itj} - \ln\bar{p}_{ij})(\ln k_{it} - \ln\bar{k}_i) + \beta_{qk}(\ln q_{it} - \ln\bar{q}_i)(\ln k_{it} - \ln\bar{k}_i)\end{aligned}$$

$$S_i = \beta_i + \frac{1}{2}\sum_{j=1}^{J}\beta_j(\ln p_{itj} - \ln\bar{p}_{ij}) + \beta_q(\ln q_{it} - \ln\bar{q}_i) + \beta_k(\ln k_{it} - \ln\bar{k}_i) \qquad j = 1,\ldots,J$$

where α_i (i = 1, …, 34) is the fixed effect for MSA i, J is the number of inputs, and the bar over a variable reflects the temporal mean over cross section i. Technological progress τ_i for MSA i is assumed to move with time so that τ_i = year for each cross section. Also, because the shares S_i (i = 1,…, J) sum to one, one input share must be dropped in order to identify the parameters. Parameter estimates in a system of equations are invariant to the share equation dropped when using maximum likelihood estimation procedures (Berndt (1991)).

IV. Data Sources and Descriptive Analysis

The measure of output for this analysis is the number of non-stop segment passengers transported and is available from the Bureau of Transportation Statistics (BTS).[14] Operating and financial data for (1996 – 2008) are available from FAA's Compliance Activity Tracking System (CATS, http://cats.airports.faa.gov) which includes operating expenses. For this study, we include all medium and large hub airports.

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[14] Data were available from the BTS website, (http://www.transtats.bts.gov/Fields.asp?Table_ID=293).

The analysis included data on airport operating (i.e. short run) expenses and three airport inputs: 1) personnel and benefits (p); contracting, maintenance, and repair (m), and airport operations (e).[15]

Often in cost analyses, personnel expenses divided by the number of employees provides an estimate of the (average) cost of labor. However, CATS does not request information on the number of employees which requires an alternative measure for airport wage costs. At the MSA level, there do not exist income or wage indices for airport personnel. Although there is income information on airport personnel at the national level, the data series are incomplete for the period 1996 – 2008.[16] The procedure followed here was to use annual average pay information in the Quarterly Census of Earnings and Wages. These data are not specific to airport personnel but are specific to MSAs.[17] These data were normalized to 1996.

MSA price indices for contracting, maintenance, and repair are not available but there exist related series at the national level. Because this category reflects, among other activities, major and minor repair activities, a price index for material and supply inputs to nonresidential building construction was used to estimate prices for this category.[18] In order to capture price differences across metropolitan areas, the national index was multiplied by a MSA regional price index and normalized to 1996.

A similar procedure was followed to obtain a price index for general airport operations. For the period 1996-2008, a national price index for ‘Other Airport Operations, adjusted for

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[15] Salaries and benefits are the salaries, wages, benefit and pension outlays for personnel that the airport employees. Contracting, maintenance, and repair includes supplies and materials, repairs and maintenance, and contractual services (including costs to commercial enterprise for diverse services that include management, financial, engineering, architectural, firefighting, and related). Airport operations include utilities and communication expenses, insurance costs and claims, small miscellaneous expenses, and other not reported elsewhere. For a definition of these categories, see U.S. DOT, FAA, Advisory Circular AC No: 150/5100-19C, April 19, 2004. Repairs and maintenance and contractual services were combined because many airports reported $0 under repairs and maintenance but large costs under contractual services, suggesting that many repairs and maintenance activities (if not all), including runways, were subcontracted to third parties. Included among general airport operations were those categories of expenses that individually were relatively small.

[16] An initial strategy was to obtain wage information from the Bureau of Labor Statistics, U.S. Department of Labor, Occupational Employment Statistics (www.bls.gov/oes), categories 48-49 (Transportation and Warehousing), 488 (Support Activities for Transportation), 4881 (Support Activities for Air Transportation)' and '48811' (Airport Operations).

[17] Bureau of Labor Statistics, U.S. Department of Labor, Occupational Employment Statistics (http://www.bls.gov/cew/data.htm). Data for this analysis is NAICS based annual data, aggregate level 40 (Total MSA Covered).

[18] Bureau of Labor Statistics, U.S. Department of Labor, Consumer Price Index, CPI Databases, http://www.bls.gov/cpi/data.htm (series BBLD--, Material and supply inputs to nonresidential building construction).

MSA price differences and normalized to 1996, was used to reflect prices for general airport operations.[19]

Tables 1 and 2 provide descriptive statistics for airport cost categories and price indices used for the cost analysis. Over the entire sample, Table 1 indicates that airports spend, on average, $38.2 million on personnel (36.4%), $42.0 million on maintenance and repair (40.0%, including Contractual), and $24.9 million (23.7%) on general airport operations. As expected,

Table 1

MSA Airports Output and Nominal Operating Costs
Panel of 50 Airports, 1996 - 2008

Group	Variable	# Obs	Mean	Std Dev
Full Sample	Contractural Services/Repairs and Maintenance ($)	650	42,002,127	62,204,985
	General Airport Operations ($)	650	24,919,411	42,778,270
	Personnel compensation and benefits ($)	650	38,233,191	38,340,527
	Operating Expenses, Total ($)	650	105,154,729	106,049,390
	Non Aero Operating Revenue, Land and Non-Terminal Facilities ($)	650	5,775,584	11,993,192
	Non Aero Operating Revenue, Parking ($)	650	30,953,354	23,296,475
	Non Aero Operating Revenue, Rental Cars ($)	650	14,393,518	10,739,802
	Airport, Domestic Passengers by U.S. and Foreign Air Carriers	650	9,405,722	7,253,000
Over Airports	Contractural Services/Repairs and Maintenance ($)	650	42,002,127	187,801,559
	General Airport Operations ($)	50	24,919,411	138,649,596
	Personnel compensation and benefits ($)	50	38,233,191	130,107,858
	Operating Expenses, Total ($)	50	105,154,729	363,494,817
	Non Aero Operating Revenue, Land and Non-Terminal Facilities ($)	50	5,775,584	33,878,724
	Non Aero Operating Revenue, Parking ($)	50	30,953,354	76,569,509
	Non Aero Operating Revenue, Rental Cars ($)	50	14,393,518	35,248,937
	Airport, Domestic Passengers by U.S. and Foreign Air Carriers	50	9,405,722	25,907,585
Over Years	Contractural Services/Repairs and Maintenance ($)	13	42,002,127	120,134,081
	General Airport Operations ($)	13	24,919,411	45,567,868
	Personnel compensation and benefits ($)	13	38,233,191	63,247,402
	Operating Expenses, Total ($)	13	105,154,729	175,979,018
	Non Aero Operating Revenue, Land and Non-Terminal Facilities ($)	13	5,775,584	11,993,192
	Non Aero Operating Revenue, Parking ($)	13	5,775,584	5,000,110
	Non Aero Operating Revenue, Rental Cars ($)	13	30,953,354	55,706,131
	Airport, Domestic Passengers by U.S. and Foreign Air Carriers	13	14,393,518	21,664,453

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[19] Bureau of Labor Statistics, U.S. Department of Labor, Consumer Price Index, CPI Databases, http://www.bls.gov/cpi/data.htm (series 488119P, Other airport operations as the primary activity, which includes operating airports and supporting airport operations. Price indices for series 48811 (Support Activities for Airport Operations) and 48811 (Airport Operations) were not available for 1996-2002.

variation in average expenses across time is smaller than the variation across airports. For example, average variation in personnel expenses over the 13 year period (1996 – 2008) is $63.2 million in comparison with $130.1 million average variation over the 50 airports.

For the full sample, airports on average transported 9.2 million passengers transported on non-stop segments with a 7.2 million standard deviation. When summed over years, the standard deviation across airports is 25.9 million passengers. California's Burbank Bob Hope Airport served the least and Atlanta served the largest number of passengers, averaging 2.56 and 35.9 million, respectively, over the 13 year period.

Reflecting airport operating characteristics of airports, Table 1 also presents revenues that airports receive from its land and terminal facilities, parking, and rental cars. For the full sample, airport physical facilities generated $5.7 million (7.5%), parking revenues were $30.9 million (40.0%), and revenues from car rentals were $14.4 million (18.6%).

Table 2 reports price indices for the three inputs where each index equals 100 for 1996. Over the entire sample, personnel expenses in MSAs have on average risen 29% in comparison with a comparable 34% average increase non-residential building materials and a 43% average increase in airport operations. In contrast to airport expenses, Table 2 also reports that the average variance in prices was much higher across time than across airports (e.g. 228 vs. 16 standard deviation for personnel).

Table 2

Input Price Indices (1996 = 100)
Panel of 50 Airports, 1996 – 2008

Group	Variable	# Obs	Mean	Std Dev
Full Sample	Price Index, Contractural Services/Repairs and Maintenance	650	143	31
	Price Index, General Airport Operations	650	129	18
	Price Index, Personnel compensation and benefits	650	134	31
Over Airports	Price Index, Contractural Services/Repairs and Maintenance	50	143	17
	Price Index, General Airport Operations	50	129	12
	Price Index, Personnel compensation and benefits	50	134	16
Over Years	Price Index, Contractural Services/Repairs and Maintenance	13	143	224
	Price Index, General Airport Operations	13	129	130
	Price Index, Personnel compensation and benefits	13	134	228

V. Estimation Results

V.1 Preliminary Estimation

Initially, the translog model in equation (8) was estimated with a time trend whose coefficient was statistically insignificant. Also included in the preliminary model was an interaction between output and a dummy variable term if the airport is located in a MSA that has more than one commercial airport. This was significant and included in the final model.

The model was re-specified with the following changes. A September 11, 2001 variable, t911, replaced the time trend, where t911 = 0 if year < 2000 and equal to 1 if year $\geq$ 2001. In addition, in order to explore whether the September 11, 2001 terrorist attack had a disproportionate effect on one of the world's busiest airports, t911 was interacted with a new variable, 'ATL', which equals 1 for Hartsfield-Jackson International Airport and 0 otherwise. In addition, 'ATL' was interacted with the fixed capital variable, number of runways, in order to explore whether there was also a differential effect of the number of runways on airport operating expenses for Hartsfield-Jackson International Airport.

The re-specified model was estimated where Contractual and Repair/Maintenance was the input share equation dropped. Estimated by iterative seemingly unrelated regression equations (ITSUR) method, the model fit the data well, much less so for the share equations.[20] A priori, the model satisfies linear homogeneity in prices and factor price symmetry. In addition, estimated shares are all positive, consistent with monotonicity, and the concavity conditions are satisfied at all points.

Given a well behaved cost function, Table 3 below reports the results of specification tests that identify whether the underlying production function exhibits homotheticity, homogeneity, Cobb-Douglas, and constant returns to scale. From the results in Table 3, we reject the null hypothesis that the underlying production technology is homothetic and homogenous. In addition, we reject, at lease at the .02 level, the null hypothesis that airport short run production technology exhibits constant returns to capital utilization. And we also strongly reject the hypothesis that short run production occurs with a Cobb-Douglas technology.

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[20] At convergence, the ITSUR method (also known as the Zellner method (Zellner (1962)) produces maximum likelihood estimates (Kmenta and Gilbert (1968)). All models were estimated in SAS. These results are available from the author upon request.

Table 3
Base Translog Model - Wald Specification Tests

	Restrictions (parameters set equal to 0)	Restrictions (parameters set equal to 1)	Test Statistic	p-value
Homothecity	β_{lq}, β_{eq}	-	9.97	0.0068
Homothecity and homogeneous	β_{lq}, β_{eq} , β_{qq}	-	25.93	<.0001
Homothetic, homogeneous, and constant returns to scale	β_{lq}, β_{eq} , β_{qq}	β_q	216.77	<.0001
Cobb-Douglas, nonconstant returns to scale	β_{lq}, β_{eq} , β_{qq}, β_{le}, β_{ll}, β_{ee}	-	72.78	<.0001
Cobb-Douglas, constant returns to scale	β_{lq}, β_{eq} , β_{qq}, β_{le}, β_{ll}, β_{ee}	β_q	270.63	<.0001

V.2 Final Estimation Results

Given these preliminary results, the following cost and share equation model is estimated

(8)

$$\ln VC_{it} = \beta_0 + \sum_{i=1}^{34} \alpha_i + \beta_q (\ln q_{it} - \ln \bar{q}_i) + \beta_k (\ln k_{it} - \ln \bar{k}_i) + \beta_\tau (\ln \tau_i - \ln \bar{\tau}_i) + \sum_{j=1}^{J} \beta_j (\ln p_{itj} - \ln \bar{p}_{ij})$$

$$+ \frac{1}{2} \beta_{qq} (\ln q_{it} - \ln \bar{q}_i)^2 + \frac{1}{2} \beta_{kk} (\ln k_{it} - \ln \bar{k}_i)^2 + \frac{1}{2} \sum_{j=1}^{J} \beta_{jm} (\ln p_{itj} - \ln \bar{p}_{ij})(\ln p_{itm} - \ln \bar{p}_{im})$$

$$+ \sum_{j=1}^{J} \beta_{jq} (\ln p_{itj} - \ln \bar{p}_{ij})(\ln q_{it} - \ln \bar{q}_i) + \sum_{j=1}^{J} \beta_{jk} (\ln p_{itj} - \ln \bar{p}_{ij})(\ln k_{it} - \ln \bar{k}_i) + \beta_{qk} (\ln q_{it} - \ln \bar{q}_i)(\ln k_{it} - \ln \bar{k}_i)$$

$$+ (\beta_k \cdot \mathrm{ATL}) \cdot (\ln k_{it} - \ln \bar{k}_i) + \; + \beta_{t911} \cdot t911 + \beta_{atl911} \cdot t911 \cdot \mathrm{ATL} +$$

$$+ \beta_{MA} \; (\mathrm{MAirport}) \cdot (\ln_{it} - \ln \bar{q}_t) \cdot$$

$$S_i = \beta_i + \frac{1}{2} \sum_{j=1}^{J} \beta_j (\ln p_{itj} - \ln \bar{p}_{ij}) + \beta_q (\ln q_{it} - \ln \bar{q}_i) + \beta_k (\ln k_{it} - \ln \bar{k}_i) \qquad j = \text{Personnel, General, Airport, Operation}$$

(8)

The cost function includes two interaction terms that are specific to Atlanta’s Hartsfield-Jackson International Airport, t911*ATL and ($\beta_k \cdot$ ATL), which tests the hypothesis that the September 11, 2001 terrorist attack and the number of runways have differential effects on Atlanta’s operating costs. And the model includes an interaction term between output and MAirport, a dummy variable that equals 1 if the MSA has more than one commercial airport, and 0 otherwise.

Table 4 reports the estimation results for the translog cost function including a full set of airport fixed effects. Relative to a general technology with no fixed effects, the Wald test statistic, at 27,783, soundly rejects the null hypothesis. In addition, estimated input shares are positive at all points and concavity conditions are satisfied at all points, both of which are consistent with well behaved cost functions.

V.2.1 Economies of Airport Runway Utilization

The results reported in Table 4 indicate that airports experience significant returns given runway capacity. At the sample mean, a 1% increase in passengers transported on non-stop segments increases costs 0.72%. Alternatively, the inverse of β_q, gives short run returns to runway utilization at the sample mean, indicating that a proportionate increase in variable inputs increases output 1.40%.[21] However, there is quite a bit of variation in passengers (i.e. output) across airports. For the entire sample, airports handled, on average, 9 million passengers with a 6.7 million standard deviation. Rather than evaluating at the mean, an alternative measure of returns to runway utilization is to calculate each of these measures for each observation and then take the average over all observations.[22] This produces slightly higher returns equal to 1.64. Disaggregating the sample by hub size found little difference in returns, 1.69 and 1.61 and for medium and large hubs, respectively.

V.2.2 September 11, 2001 Terrorist Attack

In preliminary analyses, a time trend did not have a significant effect on airport short run costs so that there is an apparent absence of appreciable change in production technology over the sample period. However, the multi-sited terrorist attack on September 11, 2001 and the subsequent and significant disruption of air travel did have an effect on airport operating costs.

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[21] From equation (6), the cost elasticity and returns to runway capacity also depend upon β_k. However, we cannot reject the null hypothesis that $\beta_k = 0$ at the .05 level of significance (p-value = 0.702).

[22] Although we cannot reject the null hypothesis $\beta_k = 0$, the cost elasticity for each airport in general depends upon multiple factors, β_l and β_e, which are statistically different from 0.

Table 4

Translog Airport Cost Estimation Results, 1996 -2008
Output – Passengers
No Operating Characteristics

Parameter	Estimate	Approx StdErr	p-Value
β_0	18.077	0.031	0.0000
β_q	0.716	0.085	0.0000
β_{qq}	1.323	0.347	0.0002
β_k	-0.073	0.191	0.7024
β_{ka}	0.020	0.405	0.9603
β_{kk}	2.862	1.185	0.0160
β_{qk}	-1.670	0.669	0.0128
β_l	0.384	0.005	0.0000
β_e	0.217	0.005	0.0000
β_{ll}	-0.090	0.040	0.0230
β_{ee}	-0.601	0.092	0.0000
β_{le}	0.299	0.052	0.0000
β_{lq}	-0.102	0.032	0.0017
β_{eq}	0.037	0.034	0.2831
β_{lk}	-0.054	0.076	0.4773
β_{ek}	-0.003	0.081	0.9660
β_{t911}	0.025	0.017	0.1509
β_{atl911}	0.142	0.076	0.0628
map1	-0.451	0.069	0.0000

observations: 617
Wald Test:

H_0: α_i (i = 1,…,49)
H_A: not all α_i coefficients = 0

Test statistic: 27,783, p-value < 0.001

<u>Homothetic, Homogeneous, Cobb-Douglas, Constant Returns to Scale</u>

H_0: $\beta_{ij} = 0$ ($i, j = q_1, q_2$, pl, pe)
H_A: not all coefficients = 0

Test statistic: 270.6, p-value < 0.001

Notes: For model with full set of airport fixed effects, Tampa International Airport is the reference airport. Contractual and Repair/Maintenance is the omitted input share. Output is passenger on non-stop segment passengers transported.

From Table 8 the ‘911’ attacks enter the equation through a dummy variable that equals zero if year is less than 2001 and one otherwise and an interaction term with a second dummy variable for Atlanta’s Hartsfield International Airport to test the hypothesis that the terrorist attacks affected Atlanta’s costs more than that of other airports. Reflected in the coefficients β_{t911} and $\beta_{tAtl911}$, Table 8 confirms that the ‘911’ attacks did increase airport short run operating costs. Relative to the pre-911 environment, annual airport operating costs were 2.5% higher. Moreover, the ‘911’ attack led to an additional 14.2%% annual increase in short run operating cost at Atlanta’s Hartsfield-Jackson International Airport, an effect that was much higher. Although a significant increase relative to the average effect, the average yearly number of passengers is also nearly four times the average for the sample, 35.9 million versus 9.2 million.

V.2.3 Demand and Substitution Elasticities

Table 5(a) and Table 5(b) report the own and cross price elasticities of demand and the Morishima elasticities of substitution. The own price input demand elasticities η_{ii} (i = l, e, m) in Table 5(a) are negative, as expected, and their values indicate different price sensitivities. With

Table 5(a)

Input Demand Elasticities

η_{ll}	-0.851				
η_{le}	0.999	η_{ee}	-3.576		
η_{lm}	-0.148	η_{em}	4.531	η_{mm}	-0.838

Authors’ Calculations. l – Personnel; e – General Airport Operations; m – Contractual and Repair/Maintenance. η_{ij} is the elasticity of input i with respect to a change in price of input j.

Table 5(b)

Morishima Elasticities of Substitution

σ_{ll}	-	σ_{el}	2.626	σ_{ml}	0.706
σ_{le}	4.575	σ_{ee}	-	σ_{me}	4.559
σ_{lm}	0.690	σ_{em}	2.639	σ_{mm}	-

Authors’ Calculations. See note under Table 5(a) for definition of categories.

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an own price elasticity equal to -0.85 and -0.84, Personnel and Contractual/Repair and Maintenance are relatively in sensitive to price changes. On the other hand, General Airport Operations, which reflects many and varied types of airport activities, is most sensitive to price. A 1% increase in the price of airport operations leads to a 3.6% decrease in demand, all else constant. Looking at the cross price elasticities, the positive signs on η_{le} and η_{em} indicate that General Airport Operations is a substitute for Personnel and Contractual/Repair and Maintenance. A 1% increase, for example, in the price of Contractual/Repair and Maintenance activities increases the demand for general airport operations 4.5%. On the other hand, the negative sign for the cross price elasticity between Contractual/Repair and Maintenance and Personnel indicates that the two inputs are complements but the low value indicates little relationship between the two inputs.

Table 5(b) reports Morishima elasticities of substitution.[23] The Morishima substitution elasticities indicate that in producing passenger trips, General Airport Operations is more easily substitutable for Personnel and Contractual/Repair and Maintenance activities. A 1% increase in the price of labor increases the (airport operations/labor) input ratio 2.6%; conversely, a 1% increase in the price of airport operations increases the (labor/airport operations) 4.6%. Similarly, there is relative ease substituting airport operations for Contractual/Repair and Maintenance (cmr) activities. A 1% increase in the price of airport operations (cmr) leads to a 4.6% (2.6%) increase in the cmr/operations (operations/cmr) input ratio, respectively. In contrast, the ability of an airport to substitute labor for cmr is more limited. A 1% increase in the price of labor (cmr) increases the cmr/labor (labor/cmr) input ratio 0.81% (0.69%), respectively.

Blackorby and Russell (1989) demonstrate that when the price of input i increases, the relative share of input i increases if the Morishima elasticity of substitution is less than 1 and decreases if greater than 1. From the calculated elasticities in Table 5(b), this implies that:

1. an increase in the price of labor increases the relative share of General Airport operations and decreases the relative share of Contractual/Repair and Maintenance;

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[23] Blackorby and Russell (1989) demonstrate that the Allen-Uzawa measure neither reflects the ease of substitutability between inputs in production nor is informative about relative factor shares. In contrast, the Morishima measures are asymmetric, reflect ease of substitutability between inputs, and provide information on relative shares. Both measures are conditioned on compensated or constant output input demands. This is not a restrictive assumption when production technology is homothetic, as in this case, since elasticities and optimal output input ratios are independent of output (Blackorby, Primont, and Russell (2007)).

2. an increase in the price of airport operations increases the relative shares of Personnel and Contractual/Repair and Maintenance, respectively;
3. an increase in the price of cmr decreases the relative share of and increases the relative share of General Airport Operations.

V.2.4 Average and Marginal Production Costs

For the entire sample and disaggregated by hub size, Table 6 provides average and marginal cost estimates for a 1 million increase in annual passengers. The estimated short run average and marginal cost for an additional million passengers is $11.35 million and $8.04 million, respectively. For large (medium) hubs, the costs are higher (lower). In addition, and reflecting the estimated returns to runway capacity, marginal costs are lower than average costs indicating that, all else constant, airports on average are operating on the downward portion of their average cost curves.

Table 6

Average and Marginal Cost

$ Million per million passengers

	Average Cost	Marginal Cost
Full Sample	11.35	8.04
Large Hubs	12.79	3.72
Medium Hubs	9.72	2.68

Authors' Calculations. From Table 1, average actual cost per million passengers over the entire sample is $11.98 million.

For each of the 50 airports included in this analysis, Table 7 reports estimated average and marginal costs of production per passenger. The airports are listed by hub size and the number of annual passengers served. The shaded numbers denote that an airport's cost measure is at least 1 standard deviation away from the hub size (large, medium) mean.

Table 7

Average and Marginal Cost for Large and Medium Hub Airports

Airport	Mean # PAX	Mean Average Cost	Mean Marginal Cost	Mean # Runways	Mean Average Cost per Runway	Mean Marginal Cost per Runway
Hartsfield-Jackson International, ATL	35.85	3.09	2.20	4.23	0.73	0.52
Chicago O'Hare International, ORD	29.45	11.72	8.34	6.08	1.92	1.38
Dallas/Forth Worth International, DFW	25.37	10.85	7.76	7.00	1.55	1.11
Los Angeles International, LAX	21.92	15.07	11.30	3.00	5.02	3.77
Denver International, DEN	18.78	11.55	8.27	5.46	2.11	1.51
Phoenix Sky Harbor International, PHX	18.28	5.83	4.22	2.69	2.20	1.68
McCarran International, LAS	17.41	7.98	5.81	4.00	2.00	1.45
Detroit Metro Wayne, DTW	15.50	12.43	8.85	7.00	1.78	1.26
Minneapolis-St. Paul International, MSP	14.72	7.58	5.38	3.31	2.29	1.67
Orlando International, MCO	13.60	8.37	5.98	3.46	2.42	1.76
Seattle-Tacoma International, SEA	12.93	11.36	8.16	2.08	5.47	4.02
Newark International, EWR	12.15	18.82	13.47	3.00	6.27	4.49
Charlotte Douglas International, CLT	11.82	2.68	1.95	4.00	0.67	0.49
Lambert St.Louis International, STL	11.28	7.55	3.51	5.23	1.42	0.71
Philadelphia International, PHL	11.19	9.81	7.05	3.77	2.61	1.89
Laguardia International, LGA	10.84	13.32	9.68	3.00	4.44	3.23
General Edward Lawrence Logan, BOS	10.51	17.07	12.10	5.23	3.25	2.32
Salt Lake City International, SLC	9.46	7.57	5.44	4.00	1.89	1.36
Baltimore-Washington International, BWI	9.08	8.03	5.74	4.00	2.01	1.44
John F. Kennedy International, JFK	8.94	33.69	24.23	4.00	8.42	6.06
San Diego International, SAN	8.37	7.41	6.03	1.00	7.41	6.03
Miami International, MIA	8.06	49.73	34.48	3.46	14.34	10.42
Tampa International, TPA	7.84	9.29	6.77	3.00	3.10	2.26
Fort Lauderdale/Hollywood International, FLL	7.49	6.68	4.47	3.00	2.23	1.49
Ronald Reagan Washington National, DCA	7.47	14.01	10.22	4.00	3.50	2.55
Washington Dulles International, IAD	7.44	9.78	6.40	5.00	1.96	1.28
Chicago Midway International, MDW	6.74	20.45	14.12	3.08	6.65	4.61
Cincinnati/Northern Kentucky, CVG	8.52	7.04	4.57	3.31	2.11	1.46
Pittsburgh International, PIT	7.19	10.38	5.83	4.00	2.59	1.46
Portland International, PDX	6.43	9.98	7.21	3.00	3.33	2.40
Kansas City International, MCI	5.87	8.79	6.25	3.00	2.93	2.08
Cleveland-Hopkins International, CLE	5.45	9.61	6.55	4.58	2.09	1.48
Memphis International, MEM	4.91	8.67	6.28	3.92	2.21	1.61
Nashville International, BNA	4.65	8.88	6.44	4.00	2.22	1.61
John Wayne Airport Orange County, SNA	4.57	8.76	7.44	3.00	2.92	2.48
New Orleans International, MSY	4.55	6.88	4.59	3.00	2.29	1.53
Sacramento Metro, SMF	4.36	12.53	9.15	2.00	6.26	4.58
Raleigh-Durham International, RDU	4.15	6.93	4.98	3.00	2.31	1.66
Indianapolis International, IND	3.78	14.73	10.70	3.00	4.91	3.57
Dallas Love Field, DAL	3.70	4.92	3.45	3.00	1.64	1.15
Austin-Bergstrom International, AUS	3.67	10.15	7.41	2.00	5.08	3.70
San Antonio International, SAT	3.59	12.05	8.73	3.00	4.02	2.91
Albuquerque International, ABQ	3.45	8.29	5.94	4.00	2.07	1.48
Port Columbus International, CMH	3.26	13.94	9.99	2.00	6.97	4.99
Bradley International Airport, BDL	3.08	9.49	6.84	3.00	3.16	2.28
General Mitchell International, MKE	3.02	10.42	7.57	5.00	2.08	1.51
Palm Beach International, PBI	2.98	8.40	6.12	3.00	2.80	2.04
Southwest Florida International, RSW	2.83	15.02	10.78	1.00	15.02	10.78
Jacksonville International, JAX	2.61	12.41	8.99	2.00	6.21	4.50
Burbank Bob Hope , BUR	2.56	4.16	3.02	2.00	2.08	1.51

Authors' calculations. For large hubs, the mean (standard deviation) for average and marginal cost is \$12.7 (\$9.6) and \$8.9 (\$6.8) respectively. For medium hubs, the mean (standard deviation) is \$9.7 (\$2.8) and \$6.9 (\$2.1) respectively. The shaded positive (negative) numbers indicate a cost measure is at least 1 standard deviation above (below) the sample mean.

the mean. For large hubs, there is negative correlation between the number of passengers served and average operating costs (-0.27) and marginal costs (-0.26), another reflection of economies of utilization. A comparable correlation (-0.28) exists between passengers and marginal costs for medium hubs but a weaker correlation at medium hubs for average costs (-0.19). Relatively few large hubs have costs that are more than one standard deviation from the mean but there are some standouts. As the largest airport, Atlanta has the second lowest marginal ($2.20) and average ($3.09) cost, with Charlotte Douglas International Airport having the lowest marginal and average costs ($1.95 and $2.68). By comparison, Chicago, Dallas/Fort Worth and Los Angeles have costs that are at least three times higher. The highest costs among the large hub airports are John F. Kennedy and Miami International airports, with (average, marginal) costs equal to ($33.69, $24.23) and ($49.73, $34.48) respectively.

For medium hubs, the marginal cost for Cincinnati/Northern Kentucky ($5.57) is at least one standard deviation below the mean for medium hubs. And Burbank Bob Hope Airport has is a low cost provider ($3.02 marginal cost and $4.16 average cost) relative to the mean. High cost medium hub airports whose (average, marginal) costs are well above the medium hub mean include Sacramento ($12.53, $9.15), Indianapolis ($14.73, $10.70), Port Columbus International ($13.94, $9.99), and Southwest Florida International ($15.02, $10.78).

The last column in Table 7 normalizes per passenger marginal cost by runway. For large hubs, Charlotte Douglas and Atlanta have the lowest average and marginal cost per runway whereas Miami has the largest average and marginal cost per runway. Among medium hubs, Dallas Love Field has the lowest cost per runway in comparison with Southwest Florida which has the highest average and marginal cost per runway.

V.2.5 Atlanta’s Hartsfield-Jackson International Airport

The analysis above focused upon costs and production technology for a 13 year panel of 50 large and medium hub airports. Atlanta’s Hartsfield-Jackson International Airport is unique in this panel because of the significantly larger number of passengers served relative to other MSAs with only one commercial airport. From a cost perspective, do Atlanta’s costs differ significantly from other airports in the sample? Relative to the other airports included in this study, Atlanta serves 21% more passengers than next busiest airport, Chicago’s O’Hare Airport.

Atlanta's scale has potential cost implications that other airports face to a smaller degree. The translog cost results reported in Table 4 confirmed this. Interacting a dummy variable for Atlanta with the '911' dummy variable and interacting an Atlanta dummy with the runway variable yield coefficients that are statistically significant at the .10. Table 8 summarizes the cost and technological attributes for Atlanta's Hartsfield-Jackson International Airport relative to the other large hubs in the sample. There is virtually no difference between Atlanta and the other large hubs in terms of input demand or factor substitution in serving airport passengers and in the effect of an additional runway. The major differences between Atlanta and the other large hubs center on average and marginal costs, returns to capacity, and on the '911' attack, as noted above. The percentage effect of '911' is more than 6 times larger relative to other large hubs.

Table 8

Cost and Production Characteristics for Atlanta Hartsfield-Jackson Airport

	Atlanta	Other Large Hubs
Cost Function Related		
Cost Elasticity	0.718	0.704
Additional runway (% change in cost)	-0.061	-0.062
Average Cost per passenger ($)	3.091	13.188
Marginal Cost per passenger	2.202	9.320
September 11, 2001 Effect (% change in cost)	0.165	0.025
Production Related		
Returns to Runway Capacity	1.468	1.558
Own Price Elasticity		
η_{11}	-0.852	-0.850
η_{ee}	-3.555	-3.573
η_{mm}	-0.839	-0.839
Elasticities of Substitution		
σ_{le}	4.556	4.572
σ_{lm}	0.690	0.691
σ_{el}	2.617	2.625
σ_{em}	2.630	2.638
σ_{ml}	0.706	0.705
σ_{me}	4.540	4.557

There is a difference in the returns to runway capacity, 1.468 for Atlanta versus 1.558 for other large hubs.[24] The scale of Atlanta's Hartsfield-Jackson Airport is also evident from the calculated average and marginal cost per passenger. Relative to other large hubs in the sample, Atlanta's average costs and marginal costs are about 25% those of other large hubs, on average. The next lowest calculated cost per passenger was Charlotte/Douglas International Airport, with 0.23 additional runways on average (4.23 versus 4) during the period and with one-third the number of passengers served (11.8 versus 35.8 million). Atlanta airport's low cost performance will likely show up in a variety of positive ways that complement Atlanta's economic development objectives.

VI. Discussion and Potential Implications for Economic Development

Few would argue with the notion that in major metropolitan areas, airports are an important driver of economic activity. Past research on the economic development effects of airports typically explore linkages that exist between various measures of airport output and measures of metropolitan development. Exemplifying this approach, Goetz (1992) finds a positive correlation between per capita passenger flows and measures of economic development growth.

From the estimated translog cost model, estimates of the average variable cost are easily available, as reported in Table 7. With average cost estimates, one can explore whether a relationship exists between airport costs and economic development indicators, including real gross state product and real gross metropolitan product. After converting nominal marginal costs into real marginal costs estimates (using a regional price index), various economic development indicators were regressed on real average costs. The exploratory two-way fixed effects regression model includes a separate interaction term to determine whether Atlanta experienced any differential effects from the September 11, 2001 terrorist attack.[25]

Table 9 presents the estimation results which indicate that increasing airport marginal costs are related to economic development indicators. With the exception of real per capita income, in which the effect is positive, a 1% increase in an airport's real average cost of serving

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[24] From equation (6), short run returns to scale are adjusted by the cost elasticity of the fixed factor, runways in this case, which was negative but not statistically different from 0.

[25] Reported models are double-log specifications which performed better than alternative linear and other model specifications.

passengers in MSAs with only one commercial airport is associated with a 0.30% reduction in lower metropolitan employment and approximately a 0.35% decrease in metropolitan establishments. Also consistent with the notion that an airport's impact will have larger local effects, Table 9 reports the finding that an increase in real average cost is associated with reductions in real gross state product but the magnitude of the effect is lower than that that for MSA indicators, -0.24%, versus -0.30%.

Also reported in Table 9 is an interaction term between Real Average Cost and whether an airport is one of multiple airports in the MSA. Table 9 reports two findings. First, for each of the economic indicators, the sign of the interaction term is positive. Second, the magnitude of the effect is smaller than the direct effect, i.e. the effect on MSAs with one commercial airport. For example, for airports located in a multiple airport MSA, such as Los Angeles and New York, a 1% increase in average operating airport costs reduces metropolitan employment and the number of establishments by 0.28% and 0.32%. Also, the '911-Atlanta' interaction term identified a positive and significant effect upon employment, the number of establishments, gross state product for the Atlanta MSA but a decrease in real per capita income. This variable is likely

Table 9

Marginal Airport Operating Costs and Indicators of Economic Development, 1990 – 2008*

	Dependent Variable			
Explanatory Variable	*Metropolitan Employment*	*Number of Establishments*	*Real Gross State Product*	*Real Per Capita Income*
Real Average Cost	-0.305	-0.359	-0.244	0.029
p-value	<.0001	<.0001	<.0001	0.1861
Real Average Cost*	0.089	0.119	0.091	0.073
Multiple Airport MSA	0.0254	0.0364	0.0221	0.0068
911 × Atlanta	0.082	0.103	0.028	-0.07129
p-value	0.0004	0.0018	0.2214	<.0001

*Authors' Calculations. All results are based on a panel of 50 large and medium hubs, 1996 – 2008. All models contain a constant term and 49 fixed effects (Tampa International Airport is the reference airport). All models are double log models estimated in SAS.

capturing more than the terrorist attack in finding that, relative to other airports in the sample, Atlanta experienced an increase in economic activity but not per capita incomes subsequent to the attack.

Building upon these results, Table 10 reports results for the relationship between real average airport operating costs and gross metropolitan product (GMP) and its sub-categories, which include Leisure and Hospitality, Profession and Business, Private Goods, Private Services, Finance, and Government.

Table 10

Marginal Airport Operating Costs and Gross Metropolitan Product, 2001 – 2008*

	Dependent Variable						
Explanatory Variable	*Real Gross Metropolitan Product (GMP)*	*Real GMP Leisure and Hospitality*	*Real GMP, Profession and Business*	*Real GMP, Private Goods*	*Real GMP, Private Services*	*Real GMP, Finance*	*Real GMP, Government*
Real Average Cost	-0.317	-0.259	-0.464	-0.211	-0.287	-0.464	-0.326
p-value	<.0001	<.0001	<.0001	0.0495	<.0001	<.0001	<.0001
Real Average Cost*	0.151	0.056	0.695	-0.174	0.211	0.695	-0.075
Multiple Airport MSA	0.0251	0.4575	<.0001	0.2848	0.0010	<.0001	0.2890

*Authors' Calculations. All results are based on a panel of 50 large and medium hubs, 2001 – 2008. All models contain a constant term and 49 fixed effects (Tampa International Airport is the reference airport). All models are double log models estimated in SAS.

Similar to the results in Table 9, there is a negative correlation between real GMP and real average airport cost, indicating that a 1% increase in real average cost lowers real GMP 0.31%. The effect is lower, 0.16%, for cost increases in MSAs with more than one commercial airport.

Table 10 also indicates that the impact of an increase in real average costs is negatively related to the six sub-categories of real GMP. The largest negative association (-0.464%) is for Profession and Business and Finance and the smallest association (in absolute value) is for Private Goods (-0.211%). However, for MSAs with more than one commercial airport, there are distribution effects. In particular,

- the coefficients for the interaction term is negative for the Private Goods and Government categories, reinforcing the direct effect of an increase in real average cost on real GMP for these categories;

- the interaction coefficient for Leisure and Hospitality and Private Services is positive but less than the direct effect which gives an overall negative relationship between real average airport cost and real GMP for these sub-categories;
- the interaction coefficient for Profession and Business and Finance is positive and greater than the direct effect which gives an overall positive relationship between real average airport cost and real GMP for these sub-categories. This suggests that concerns about reverse causality may be more serious for these sub-categories.

VII. Extensions

a. Airport Operating Characteristics

Airports do not generate revenues solely from airline operations but also generate revenues from complementary services and activities that airports provide to their customers The extent to which airports offer these services can be seen as airport operating characteristics that differentiate one airport’s cost structure from another. Table 1 provided descriptive statistics for three services that airports provide – land and non-terminal facilities, parking, and rental cars – which account for 7.5%, 40.0%, and 18.6% of the non-aeronautical related revenues. Two other major services offered are Retail Stores and Food and Beverage, which account for 13.1% and 5.6% of non-aeronautical revenues.

To account for differences in non-aeronautical characteristics across airports, the translog cost function was re-specified to include three additional variables, the share of non-aeronautical revenues generated from land and non-terminal facilities, parking, and rental cars. Due to large amounts of missing revenue data for Food and Beverage and Retail Store, the model did not include these categories. Also, because it is not known whether a reported $0 figure for a service was a true $0 or simply unreported data, the sample for this analysis only included observations with positive revenue data for land and non-terminal facilities, parking, and rental cars.

The re-specified model included level terms for each of the non-aeronautical operating characteristics and interaction terms between each characteristic and interactions between each characteristic and output (passengers), input prices (personnel, general airport operations, and contractual and repair/maintenance), and the quasi-fixed input (runways).

Table 11 reports the estimation results and Tables 12a,b and 13 report input demand elasticities, Morishima elasticities of substitution, and estimated measures of average and

Table 11

Translog Airport Cost Estimation Results, 1996 -2008
Output – Passengers
No Operating Characteristics

Parameter	Estimate	StdErr	p-Value
β_0	17.956357	0.0371927	0.0000
β_q	0.7574285	0.0952311	0.0000
β_{qq}	0.7141082	0.3784213	0.0597
β_k	-0.0713821	0.2150299	0.7400
β_{kk}	0.7485138	1.2557044	0.5514
β_{qk}	-0.4081955	0.753292	0.5881
β_l	0.384677	0.004913	0.0000
β_e	0.2147712	0.0050978	0.0000
β_{ll}	-0.1051465	0.0371711	0.0048
β_{ee}	-0.6185277	0.0914802	0.0000
β_{le}	0.3074722	0.049969	0.0000
βlq	-0.1113182	0.0323958	0.0006
βeq	0.0418563	0.0342984	0.2228
β_{lk}	-0.066672	0.076592	0.3844
β_{ek}	0.0058381	0.0808744	0.9425
β_{t911}	0.0187529	0.0179615	0.2969
β_{atl911}	0.1678299	0.0755637	0.0268
bka	-0.5298648	0.4237143	0.2117
bs2	-0.0272363	0.0192692	0.1581
bs3	-0.1028133	0.1000647	0.3047
bs4	-0.0134352	0.0491922	0.7849
bs2s2	-0.0048787	0.0089485	0.5858
bs3s3	0.9451615	0.4060724	0.0203
bs4s4	-0.0441453	0.0395329	0.2646
bs2s3	-0.0896792	0.0654922	0.1715
bs2s4	-0.0377804	0.0234418	0.1076
bs3s4	-0.0622419	0.145739	0.6695
bs2q1	0.0083726	0.0511099	0.8699
bs3q1	-0.2935564	0.2890838	0.3103
bs4q1	0.1940109	0.1294111	0.1344
bs2pl	0.0046866	0.0060849	0.4415
bs3pl	0.0548473	0.0344974	0.1124
bs4pl	-0.0186224	0.0146825	0.2052
bs2pe	-0.008669	0.0063205	0.1707
bs3pe	-0.055512	0.0359418	0.1230
bs4pe	0.0141771	0.0152698	0.3536
bs2k1	-0.5019598	0.140363	0.0004
bs3k1	-0.7984726	0.825705	0.3340
bs4k1	-0.4167425	0.3163067	0.1882
map1	-0.5084811	0.0695464	0.0000

observations: 617
Wald Test:

H_0: α_i (i = 1,…,49)
H_A: not all α_i coefficients = 0

Test statistic: 25,890, p-value < 0.001

<u>Homothetic, Homogeneous, Cobb-Douglas, Constant Returns to Scale</u>
H_0: $\beta_{ij} = 0$ ($i, j = q_1, q_2$, pl, pe)
H_A: not all coefficients = 0

Test statistic: 238.2, p-value < 0.001

Notes: For model with full set of airport fixed effects, Tampa International Airport is the reference airport. Contractual and Repair/Maintenance is the omitted input share. Output is passenger on non-stop segment passengers transported.

Table 12(a)

Input Demand Elasticities

η_{ll}	-0.889				
η_{le}	1.018	η_{ee}	-3.687		
η_{lm}	-0.129	η_{em}	4.663	η_{mm}	-0.877

Authors' Calculations. l – Personnel; e – General Airport Operations; m – Contractual and Repair/Maintenance. η_{ij} is the elasticity of input i with respect to a change in price of input j.

Table 12(b)

Morishima Elasticities of Substitution

σ_{ll}	-	σ_{el}	2.717	σ_{ml}	0.763
σ_{le}	4.704	σ_{ee}	-	σ_{me}	4.689
σ_{lm}	0.748	σ_{em}	2.735	σ_{mm}	-

Authors' Calculations. l – Personnel; e – General Airport Operations; m – Contractual and Repair/Maintenance. σ_{ij} is the elasticity of substitution between inputs i and j due to a change in factor price j.

Table 13

Average and Marginal Cost
With Non-Aero Operating Characteristics
$ Million per million passengers

	Average Cost	Marginal Cost
Full Sample	11.37	8.53
Large Hubs	12.76	3.73
Medium Hut	9.80	2.81

Authors' Calculations. From Table 1, average actual cost per million passengers over the entire sample is $11.98 million.

marginal cost of serving additional passengers. In comparison with the cost model that did not include non-aeronautical airport operating characteristics, salient points from Tables 11-13 are:

- The parameter estimates for variables in the original model are robust in sign and magnitude;
- The estimated coefficient for output is slightly higher, 0.75, which implies economies of runway utilization equal to 1.34, a bit lower than the 1.40 in the original model;
- At the mean, non-aeronautical revenue generating operations reduce airport operating costs. A 1% increase in the revenue share of land and non-terminal facilities, parking, and rental car revenues reduces airport operating cost .03%, .10%, and .01% respectively;
- Input demand elasticities and elasticities of input substitution are robust;
- Estimated average operating costs and estimated marginal costs are robust in comparison with the original model.

Overall, including non-aeronautical operating characteristics in the model controls for differences across airports but does not change the main results reported in Tables 4 – 6.

b. Two Output Model with Operating Characteristics

A second extension to the original model recognizes that airports not only move passengers from an origin to a destination but also freight. Table 14 reports the amount of freight shipped over the sample period. In total, airports shipped 191 million pounds of freight with much larger variation in shipments across airports rather than across time, again reflecting the heterogeneity in airports. There are also significant differences by hub size. Large hub

Table 14

Freight Shipped, 1996 - 2008

Group	Variable	# Obs	Mean	Std Dev
Full Sample	Freight Shipped by U.S. and Foreign Air Carriers (pounds)	650	191,698,430	424,838,357
Over Airports	Freight Shipped by U.S. and Foreign Air Carriers (pounds)	50	191,698,430	1,127,485,359
Over Years	Freight Shipped by U.S. and Foreign Air Carriers (pounds)	13	191,698,430	844,000,153

airports shipped, on average, 225.7 million pounds compared with 151.8 million pounds for medium hub airports. To put these numbers in perspective, the (approximate) maximum amount of cargo in a TEU (twenty foot equivalent unit used) in shipping is 48,000 pounds. Based on this number, the amount of air cargo shipped during the sample period was roughly equivalent to 3,993 TEUs. Large hub airports, on average, shipped the equivalent of 4,702 TEUs during the sample period.

The re-specified model included level and squared terms for the additional output, cargo freight, and cargo freight interaction terms with passengers, input prices, the quasi-fixed input, and operating characteristics.

For multi-product model, economies of capital utilization is generalized to ray economies of capital utilization which reflects the impact on short run costs from a proportional increase in all outputs. When evaluated at the mean, $\beta_1 + \beta_2$ is the impact on costs from a 1% increase in all outputs, where β_i is the first order coefficient for output i and β_k is the first order coefficient for the quasi-fixed input (runways). A measure of ray scale economies RSE of capital utilization is

$$\text{RSE} = \frac{1-\beta_k}{\beta_1+\beta_2}$$

S > (<) 1 implies ray economies (diseconomies) of capital utilization.

In providing air services to shippers and passengers, a question that arises is whether the cost of providing air cargo and passenger service jointly is more or less costly than having dedicated facilities to provide each service separately. More formally, given two outputs, q_1 and q_2, economies (diseconomies) of scope are present if $C(q_1, q_2) < (>) C(q_1, 0) + C(0, q_2)$, that is, if the cost of joint production is less (more) than the cost of separate production.

A sufficient condition for economies of scope is weak cost complementarity, which exists if an increase in one output lowers the marginal cost of a second output, that is, if $\frac{\partial^2 C}{\partial q_1 q_2} < 0$.

Panzar and Willig (1977) have shown that, at the sample mean, ($\beta_1\beta_2 + \beta_{12}$) is an approximate test of weak complementarity where β_{12} is the parameter of the interaction term.

Tables 15-18 report the parameter estimates, scale and scope economies, input and substitution elasticities for the two output cost function model, and cost estimates. Important findings from this model include:

- The output parameter estimate for passengers is positive and significant, reflecting passenger economies of capacity utilization. A 1% increase in passengers, all else constant, increases operating costs 0.72%;
- The output parameter estimate for freight is positive with potentially very strong freight economies of capacity utilization but the effect is not statistically significant. A 1% increase in freight shipped, all else constant, increases operating costs 0.25%;.
- The measure for ray economies of capital utilization is 1.57 which reflects production under positive economies. If all inputs are proportionately increased, passengers and freight will increase in greater proportion. Alternatively, from the cost elasticity, if passengers and freight shipped increase 1%, airport operating costs increase 0.74%, less than 1%;
- There is evidence of economies of scope, which implies that the cost joint production of passengers and cargo freight is less than the sum of separate facilities serving passengers and cargo freight, respectively, but the effect is not statistically significant;
- Estimates for input elasticity of substitution are robust relative to the single output model (with or without operating characteristics). The most sensitive substitutable input to changes in relative input prices is general airport operations;
- Input demand elasticities in the two product model were generally lower than in the single product model. In particular, for this model there is much less substitutability between ‘contractual and repair/maintenance’ inputs with personnel (from -0.148 in Table 5(a) to -0.051 in Table 17(a)) and general airport operations (from 4.531 in Table 5(a) to 1.652 in Table 17(a);
- The marginal cost of serving an additional passenger ranges between \$1.71 and \$1.75 per passenger and between \$0.25 and \$0.32 per pound of freight. These numbers are considerably lower than the average cost of product and reflect economies associated with capacity utilization.

Table 15

Translog Airport Cost Estimation Results, 1996 -2008
Output – Passengers, Freight
Operating Characteristics

Parameter	Estimate	p-Value
β_0	17.971	0.0000
β_{q1}	0.719	0.0000
β_{q2}	0.025	0.2275
β_{q1q1}	0.850	0.0433
β_{q2q2}	0.007	0.4031
β_{q1q2}	-0.060	0.3006
β_k	-0.174	0.4836
β_{kk}	2.313	0.1083
β_{q1K}	0.422	0.6393
β_{q2K}	-0.303	0.0525
β_{pl}	0.385	0.0000
β_{pe}	0.212	0.0000
β_{lplpl}	-0.069	0.0935
β_{lpepe}	-0.507	0.0000
β_{plpe}	0.243	0.0000
β_{plq1}	-0.109	0.0015
β_{peq1}	0.063	0.0766
β_{peq2}	0.002	0.7263
βeq	-0.014	0.0242
β_{plk}	-0.056	0.4698
β_{pek}	0.020	0.8094
β_{t911}	0.019	0.3980
β_{atl911}	0.149	0.0408
map1	-0.452	0.0000
map2	-0.038	0.0173
bka	-0.418	0.0986
β_{s2}	-0.010	0.6460
β_{s3}	-0.041	0.7214
β_{s4}	0.036	0.5307
β_{s2s2}	-0.001	0.9020
β_{s3s3}	1.113	0.0222
β_{s4s4}	-0.016	0.7570
β_{s2s3}	-0.028	0.6885
β_{s2s4}	-0.052	0.0460
β_{s3s4}	0.005	0.9817

Table 15 (cont'd)

Parameter	Estimate	p-Value
β_{s2q1}	-0.049	0.4093
β_{s3q1}	-0.435	0.1812
β_{s4q1}	0.223	0.1397
β_{s2q2}	0.025	0.0097
β_{s3q2}	0.013	0.8207
β_{s4q2}	0.019	0.4727
β_{s2pl}	0.005	0.4522
β_{s3pl}	0.053	0.1273
β_{s4pl}	-0.019	0.2072
β_{s2pe}	-0.007	0.2728
β_{s3pe}	-0.064	0.0774
β_{s4pe}	0.023	0.1398
β_{s2k}	-0.560	0.0004
β_{s3k}	-2.033	0.0284
β_{s4k}	-0.156	0.7229

observations: 617

Wald Test:

Fixed Effects

H_0: α_i (i = 1,…, 49)

H_A: not all α_i coefficients = 0

Test statistic: 22,902, p-value < 0.001

Homothetic, Homogeneous, Cobb-Douglas, Constant Returns to Scale

H_0: $\beta_{ij} = 0$ ($i, j = q_1, q_2$, pl, pe)

H_A: not all coefficients = 0

Test statistic: 11,717, p-value < 0.001

Notes: For model with full set of airport fixed effects, Tampa International Airport is the reference airport. Contractual and Repair/Maintenance is the omitted input share. Outputs are passengers on non-stop segment passengers transported (q_1) and pounds of freight shipped (q_2) .

Table 16
Two Output Model
Economies of Scale and Scope Measures

Measure	Estimate	p-Value
Cost Elasticity	0.74	< .0000
Economies of Capital Utilization	1.57	< .0000
Economies of Scope	-0.04	0.48

Table 17(a)
Two Output Model
Input Demand Elasticities

η_{ll}	-0.795				
η_{le}	0.846	η_{ee}	-3.187		
η_{lm}	-0.051	η_{em}	1.652	η_{mm}	-0.822

Table 17(b)
Two Output Model
Morishima Elasticities of Substitution

σ_{ll}	-	σ_{el}	2.335	σ_{ml}	0.745
σ_{le}	4.037	σ_{ee}	-	σ_{me}	4.063
σ_{lm}	0.771	σ_{em}	2.473	σ_{mm}	-

Table 18
Average and Marginal Cost
With Non-Aero Operating Characteristics

	Average Cost		Marginal Cost	
	Passenger	Freight	Passenger	Freight
Full Sample	11.43	2.44	1.75	0.29
Large Hubs	12.77	2.38	1.71	0.32
Medium Hubs	9.92	2.50	1.80	0.25

Authors' Calculations. From Table 1, average actual cost per passenger over the entire sample is $11.68. Average cost per pound of freight over the entire sample is $2.33.

The two product cost function model is a generally robust extension of the single output model and provides additional insights into airport operating characteristics. Yet the very low output coefficient associated with cargo freight calls for additional research to be sure that the model appropriately captures airport cost and production characteristics and generates cost measures that reflect airport operating environments.

VIII. Concluding Comments

Through their impacts upon regional, state, and national mobility, airports and their associated activities can significantly benefit a metropolitan area's economic development. Yet relatively little is known about airport cost functions, their operational and production characteristics.

This study's measure of airport output is annual passengers served and cargo freight shipped. Based upon a panel of 50 large and medium hub airports from 1996 – 2008, the research for this paper develops and estimates flexible form translog airport operating cost models and this paper reports the results of three increasingly complex models: 1) one-output (passengers) base model that does not account for non-aeronautical airport activities (e.g. parking); 2) a one-output (passengers) model that does account for non-aeronautical airport activities; and 3) a two-output (passengers and freight) model that accounts for non-aeronautical airport activities. In each of these models, the number of runways is a quasi-fixed factor of production.

The models generally fit the data well and lead to several findings that are common across the three models:

- At the mean, airports serve passengers under increasing returns to runway capacity. All else constant, a 1% increase in passengers served increases short run operating costs between 0.71% and 0.76%;
- Reflecting economies of capacity utilization, the cost of serving additional passengers (i.e. marginal cost) is less than the average cost of serving passengers;
- An increase in runway capacity reduces short run operating costs but the effect is not statistically significant;
- Input demands for Personnel and Contractual/Repair and Maintenance are input price inelastic. All else constant, a 1% increase in the price of Personnel and Contractual/Repair and Maintenance, respectively, reduces the amount of the input demanded by 0.8%;

- Input demand for General Airport Operations is input price elastic. All else constant, a 1% increase in the price of General Airport Operations reduces the amount demanded by over 3.2%;
- As a cost-minimizing response to an input price rise in General Airport Operations, airports can more easily substitute Personnel and Contractual/Repair and Maintenance inputs;
- As a cost-minimizing response to an input price rise in Personnel (Contractual/Repair and Maintenance), airports can less easily substitute Contractual/Repair Maintenance inputs (Personnel);
- The 911 terrorist attacks increased average airport operating costs 2% and Atlanta's Hartsfield-Jackson airport costs by at least 16%;
- Airport operating costs for airports in MSA's with more than one commercial airport (e.g. New York, Chicago, Los Angeles) were ½% lower for airports in MSAs with only one commercial airport;
- For models that included non-aeronautical activities at airports (land and terminal rentals, parking, and car rental), the mean effect was generally negative but statistically not significant.

Selected results from extensions to the base model include:

- Results from the one output model with non-aeronautical attributes were robust in comparison with the base model that did not include non-aeronautical attributes;
- For the two-output model, there are strong product economies of capacity utilization for freight shipped but the effect is not statistically significant. A 1% increase in freight shipped, all else constant, increases operating costs 0.025%.
- Airports operate under ray economies of runway capacity and economies of scope, although the measure for scope economies is not statistically significant.

How does Atlanta's Hartsfield-Jackson airport compare with other large hubs? Although Atlanta's average passenger throughput is 20% higher than the next largest airport, its average and marginal cost is at least three times less. Among the large hubs, only Charlotte Douglas International airport, with one third the passengers in Atlanta, has lower costs. A further critical difference between Atlanta and the other large hubs is that the 911 terrorist acts significantly increased the airport's operating costs.

The results also provide some evidence of an association between airport operating costs and metropolitan economic development indicators. Increases in real airport operating costs are associated with decreases in several indicators of economic development including real gross metropolitan product. A 10% decrease in real airport operating costs, for example, is associated with a 3.1% increase in real GMP. The results identify differential GMP effects depending upon the sub-category of real GMP.

There are two major directions for future work in this area. First, more work is needed on the metropolitan effects of airport operations. This analysis builds upon prior results, using a smaller number of airports, and for the one output model provides consistent implications for economic development. However, the relationship between economic development indicators and real airport average costs largely disappeared in the two-output model.

A second and related direction is to conduct additional research on the two-output model. Measures of marginal cost for passengers and freight were considerably lower than those obtained in the one-output model. Additional work is required to assess this as well as the economic development differences between this model and the one-output model.

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