
Analysis of Cost at FAA's En Route Centers: An Empirical Perspective
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Analysis of Cost at FAA's En Route Centers: An Empirical Perspective[1]

by Dipasis Bhadra, David Chin, Anthony Dziepak, and Kate Harback

In this paper, an empirical framework is developed using economic theories to examine the relationships between variable costs and levels of activities at the Federal Aviation Administration's (FAA) en route centers. Using data for three fiscal years and employing time-series pooled cross section econometrics, we have found that the Air Traffic Organization's (ATO) service provisions in the en route centers have some economies of scale. Furthermore, we have found that while controllers' wage is important, it is not statistically significant in unit cost measured in aircraft flight operation counts. However, it is statistically significant when unit variable cost is measured and estimated in terms of aircraft flight operation hours. We have also found that degree of complexity, a measure of service attributes, does not impact cost. These findings, combined with on-going policy discussion on users' fees, imply that ATO may be well positioned to implement average cost pricing if cost is to be fully recovered for en route services. The implementation of marginal cost pricing may require external funding, perhaps from general funds of the U.S. Treasury.

INTRODUCTION

The organizational characteristics and performance of the air traffic/air navigation service providers (ATSP/ANSP) have been changing gradually over the last decade. Under this evolving organizational perspective, an empirical framework that measures productivity and cost efficiency may prove to be useful in the United States and elsewhere. With that in mind, the following issues have been addressed in this paper: (a) to what extent, do the ATS provisions in the United States demonstrate characteristics of a natural monopoly? In other words, is there evidence of economies of scale and scope in ATS provisions in the United States? (b) Do the costs vary with respect to changes in traffic volume, complexity, weather—factors that tend to make the U.S. ATS provisions somewhat unique? (c) How do these costs compare with those in Europe? (d) Do the determinants of costs provide any guidance to collections of revenues from the system? To address these issues, cost and traffic data on U.S. en route centers for the fiscal years (October – September) 2003 – 2005 have been used.

The paper is organized as follows. The next section provides the background and reviews associated literature. The third section provides basic empirical characteristics of the U.S. en route centers and compares them with those of Europe. The purpose of this section is to identify major factors driving the cost elements. The fourth section provides a simple analytical framework of a natural monopoly and lays out the empirical model for which results are presented in section five. The final section provides policy conclusions and suggestions for future research. Following the references, an appendix, map and name identifications for the en route centers is provided.

THE BACKGROUND

During the last two years, a lively debate has ensued in the United States regarding the collection of revenue to fund the aviation system operated by the Federal Aviation Administration (FAA) (FAA 2005). The Reauthorization Act with which Congress authorizes raising revenues via the ad valorem taxes and fees expired in September, 2007.[2] Many stakeholders in the community, including the commercial airlines and the FAA, have argued that change is needed because there is no connection between the cost of services provided by the FAA (i.e., separation of aircraft, safety, and certification of air worthiness) and the revenue collected by the FAA, primarily via ticket taxes and fees on individual passengers. The concerns about the existing revenue collection mechanisms and the pending Congressional reauthorization presented a rare and pressing opportunity to review financing alternatives. Under direction from the U.S. Department of Transportation (DOT), the FAA has evaluated alternative ways to raise revenues. The FAA/Bush Administration's proposal[3] included imposing user fees as a way of connecting revenue to costs and using price signals to allocate resources more efficiently and equitably. However, both the Senate bill[4] and the Congressional bill[5] took more conservative approaches. Many other government and semi-government agencies have also evaluated financing alternatives under direction from the congressional subcommittee on aviation (GAO 2007, 2006; CBO 2006; CRS 2006; DOT/OIG 2005).

The three major proposals (i.e., FAA/Administration's; Senate Bill; and Congressional Bill) along with some other proposals (e.g., Air Transport Association 2006) are presently under consideration by the Subcommittee on Select Revenue Measures of the House Ways and Means Committee for final legislation.[6]

Among the possible alternatives (see GAO 2006 for a detailed account), user fees based on cost recovery have surfaced as a potentially viable method without changing the current governance structure of the FAA. The members of the commercial scheduled air transportation community have argued[7] that the present sharing of costs is not equitable because airlines use fewer resources in proportion to the revenues they raise. Under the present tax rates, an average effective tax rate of 16.1% on fares and trips raises more than 90% of the total tax revenues originating in commercial schedule transportation activities (Yamanaka, Karlsson, and Odoni 2006). The allocation of these revenues is often challenged on numerous grounds.

General aviation (GA), a vibrant aviation sector comprising those who routinely use the separation services under instrument flight rules (IFR) and those who primarily use visual flight rules (VFR), disagree.[8] They argue that both the present cost sharing and the collection mechanism (i.e., fuel tax) are appropriate because GA's use of the national airspace system (NAS) imposes only a marginal burden on the system.[9] According to these users, the system was essentially created to serve commercial air services and any use by GA has been at the margin, and therefore, they should only pay marginal or incremental costs. Unfortunately, however, there has not been any effort to determine the magnitude of this marginal or incremental cost on the system.

Determining marginal cost for providers, such as air traffic services, that may enjoy economies of scale and scope is a challenging task. Incremental costs decline as services are scaled up (i.e., scale economies) that are often provided over multiple scopes (e.g., multiple users over spatially-spread locations). These scale dependencies and interdependencies over usages make clear estimation or assignment of marginal cost difficult. Economic theory (Shy 2001) has long stipulated that network industries (e.g., air traffic service (ATS) provisions) are natural monopolies, and as such, enjoy economies of scale and scope. Theories of public policies have argued (Alchian and Demstez 1972; Cornes and Sandler 1996) that in absence of any regulations, these natural monopolies fail to ensure pricing conducive to maximizing consumers' (i.e., air travelers') or social welfare. Thus, government regulations have been sought for ensuring marginal or average cost pricing as opposed to pricing under unregulated natural monopoly.[10] Under these pricing schemes, commonly known as Ramsey pricing, consumers' welfare is maximized while ensuring a constant rate of return for the natural monopolist, ATS providers, for example.

In practice, however, these regulations have spread far more extensively than pricing alone. Proponents of regulations have successfully ensured governments' widespread regulatory and budgetary protections for air traffic service provisions (ATSP) in the U.S. and elsewhere. In recent times, however, many network industries globally (e.g., telecom, cable TV, power distribution) including ATSPs in countries outside the United States (S&P 2005; GAO 2005; Oster 2006) have begun experimenting with deregulation. The empirical evidence (Oster 2006) indicates that unbundling of products and services of ATSPs through regulatory reforms may, in fact, increase efficiencies (i.e., both operations and cost) by elimination of X-inefficiency (or managerial slacks). Rationalization of capital investments that leads to integration of revenue streams with that of costs encourages innovation and ensures organizational independence. Separation of regulatory authority (e.g., safety, certification) from the operations is a key to this process. Because most of the reforms have taken place outside the United States (Cordle and Poole 2005), it is not clear to what extent the experiences from elsewhere apply to the United States. In particular, sheer traffic volume and airspace complexity together with routine weather incidences, have long been cited as characteristics differentiating the United States from others. Hence, efficiency gains that have been attained elsewhere through restructuring cost, revenue and operational characteristics may not be applicable to the United States (House Subcommittee Hearing on April 4, 2005). Empirical efforts comparing and contrasting the United States with other ATSPs have been attempted (Cordle and Poole 2005; MBS Ottawa 2006) to address some of these issues.

Additionally, the aviation system users, commercial airlines in particular, have undergone a tremendous restructuring over the past five years following the events of 9/11 and continue to do so under the pressure of increasing jet fuel price (ATA 2006). The cost readjustment in the face of enhanced competition and changed marketplace has been extensive throughout the world. In their quest for further cost reduction, commercial and non-commercial aviation system users alike have repeatedly called for cost adjustments for the ATSPs.[11] Following these calls and subsequent reforms, transparencies in management structure, costs and revenues reporting have ensued in many of the ATSPs, including those in the United States. Under the European Union’s mandatory agreement, for example, almost all members of the enlarged union (34, out of 35) now share ATSP cost data.[12] The Performance Review Commission (PRC) of Eurocontrol uses these data to compare and contrast the performance of its members over time and issues annual ATM Cost Effectiveness (ACE) reports (PRU 2005). The PRU reports are available for four years covering 2001-2004.[13]

In the United States, the FAA has undergone extensive reforms in recent years as well. Public Law 106-181 (AIR-21) that was passed in April 2000 authorized the FAA to create a chief operating officer (COO) position responsible for overseeing day-to-day traffic control operations, undertaking initiatives to modernize air traffic control (ATC) systems, increasing productivity and implementing cost-saving measures, among other things. In December 2000, the President issued Executive Order 13180 authorizing the creation of the Air Traffic Organization (ATO), headed by the COO (see GAO 2005). The new office leads NAS architecture, system engineering, investment analysis and operations research. The ATO was created in February 2004 by combining FAA’s Research and Acquisitions, Air Traffic Services, and Free Flight Offices into one performance-based organization (PBO).[14] Under this new organization, cost information has become transparent, and, in fact, now plays a critical role in the trust fund debate.[15] Furthermore, cost data played a key role in the discussion surrounding the contract negotiations between the FAA and the controllers that ended in June 2006. Furthermore, many of the recent organizational decisions, for example, restructuring FAA’s nine regional offices into three, and reducing management layers from 11 to six, were influenced by cost considerations. Over the last five years, the FAA invested large amounts of resources to streamline, document, improve, and present data on the system that are accepted under the general rules of accounting practices in the United States.[16] Consequently, this information is gaining increasing credibility and may prove to be very important in comparing and contrasting performance of the U.S. ATO against those that provide similar services abroad. Just like in the PRC/Europe, this information can also be used to benchmark the U.S. ATO’s performance against others as well as itself over time.

EMPIRICAL CHARACTERISTICS OF THE U.S. EN ROUTE CENTERS AND EMPIRICAL ISSUES

As shown in Table 1, the 20 contiguous U.S. en route centers (or, just centers for short) handled more than 43 million operations[17] a year in 2005. Approximately 39.68 million IFR operations were handled by the 20 contiguous centers[18] in fiscal year (FY) 2003.

Table 1: Basic Traffic Data for U.S. Centers During FY 2003-2005 (in millions)

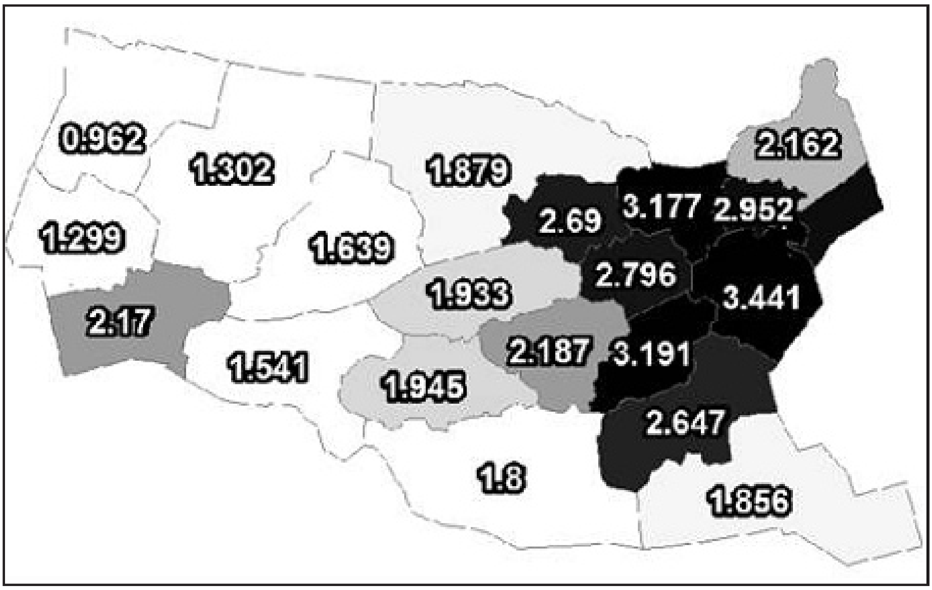
	2003		2004		2005	
	Flight Counts	Flight Hours	Flight Counts	Flight Hours	Flight Counts	Flight Hours
Commercial Carriers	30.25	17.26	32.52	17.78	33.71	18.44
IFR GA	7.48	5.28	8.01	5.43	7.96	5.36
Military	1.37	1.02	1.47	1.09	1.38	1.01
Other Traffic	0.58	0.39	0.56	0.35	0.52	0.32
Total	**39.68**	**23.95**	**42.56**	**24.65**	**43.57**	**25.13**

Source: Authors' calculation from FAA data

The commercial users that include commercial operations, commuters, air taxis and cargo had around 76-77% of the operations with a share of around 72-73% of the hours handled by the centers. IFR GAs had a share of around 18% of the flights with around 22% of the flight hours during the fiscal years 2003-2005 (Table 1).

The growth rate of IFR flight operations during 2003-2004 was 7.2% which was three percentage points higher than the annual average growth rate prior to 2001 (i.e., 1998-2000). While the events around 9/11 reduced aviation demand in the U.S. NAS somewhat (i.e., -2.7% in 2001-2000; and -0.9% in 2002-2001), U.S. aviation activities have rebounded considerably in 2003-2004 and stabilized in 2005 with annual growth rate of approximately 2.4% (authors' calculation based on ATO ETMS boundary crossing table).

Figure 1: Distribution of Operation Counts in 2005 (millions)



Source: Authors' calculation

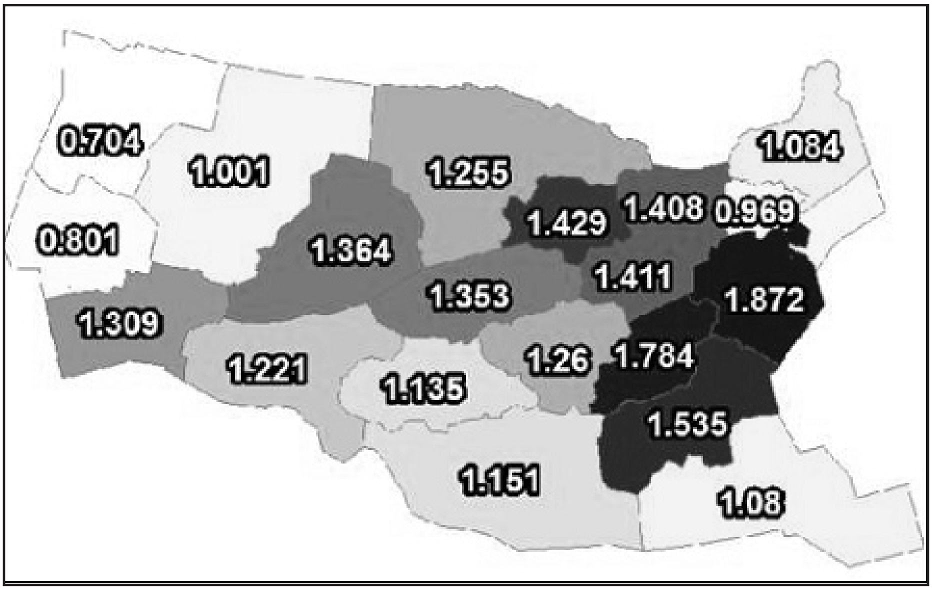
The en route centers are positioned to meet the needs of these flight operations. It is obvious that the flight patterns and their distributions are influenced by the passenger traffic demand between origin and destination cities, routes through which these demands are met, types and compositions of aircraft, and the geographic shape of the centers. Together with the convective weather, the traffic flow patterns determine the levels of complexity at the centers. As Figure 1 indicates, each center has distinct patterns with respect to use. At the high end,[19] for example, Washington (ZDC) and Atlanta

(ZTL) centers handled the most IFR operations, with Cleveland (ZOB) and New York (ZNY) right behind. At the low end of the scale, Seattle (ZSE), Salt Lake (ZLC), and Oakland (ZOA) centers handled the lowest IFR flights.[20]

The number of flight operations is indeed an important metric to determine the levels of activities within the center. However, the workload at the centers is determined by the operation occurrence as well as the intensity of uses as measured by time (i.e., hours spent), complexity and sector characteristics (e.g., upper vs. lower sectors). Total flight operation hours under each center's control is a derived demand, derived from the flight operation counts (see Bhadra, Hogan and Schaufele 2006 for this approach).[21] Thus, total flight operation hours track very well, as expected, with the operation counts. Approximately, 25.13 million IFR operation hours were generated by 43.57 million operation counts in the U.S. NAS in 2005 (see Table 1 and Figure 2).

Given the close relationship between flight operation counts and flight operation hours, it is interesting to observe, however, while flight operation hours had a growth rate of around 3% during the period 2003-2004, operation counts experienced 7.2% growth. This is perhaps indicative of shorter flight lengths. During 2004-2005, operation hours grew (2%) closely with that of operations counts (2.5%).

Figure 2: Distribution of Flight Operation Hours in 2005 (millions)

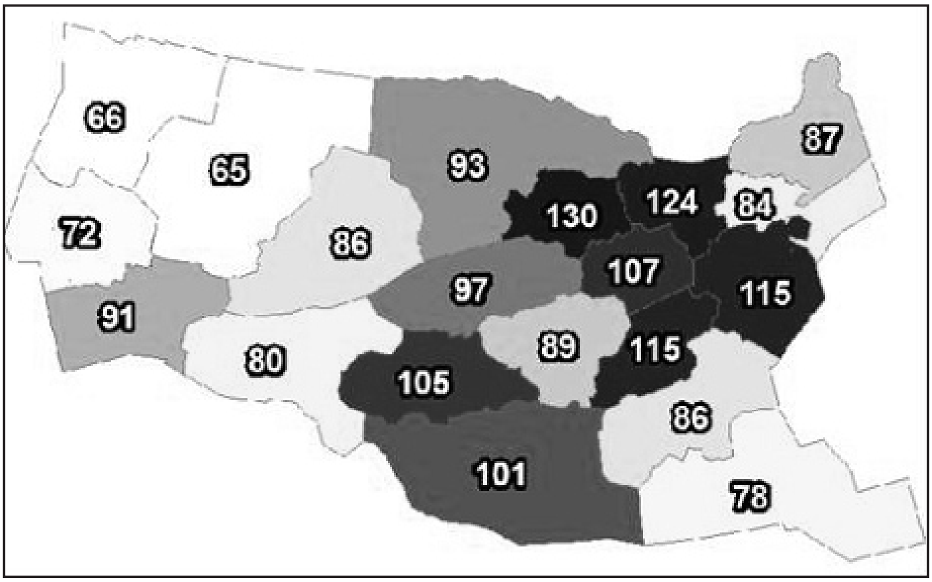


Source: Authors' calculation

The en route centers can be thought of, from an input-output sense, as primarily employing controllers to produce flight operation hours. The mix of the flight operations[22] and the time they spend are important in determining workload, the center's performance, and cost. For example, almost three out of every four flights (72%) en route are commercial in nature (i.e., commercial operations, air taxi, and cargo) requiring different treatment than the one in five (22%) which are IFR GAs and around 4% military and other flights. Presently, the ATC facilities are organized and planned for around the aggregate workload hours.[23]

The visual evidence that aircraft counts (Figure 1) and number of operation hours (Figure 2) track well indicates that output metrics (i.e., operation hours or operation counts) may correlate with the cost[24] of providing these services. More demand for services, keeping all else constant or ceteris paribus, may also lead to higher costs and vice versa. Figure 3 shows that there may be some positive correlations between output and costs; locations with darker shades in Figure 2 are also associated with similar locations and shading in Figures 1 and 3.

Figure 3: En Route Center Variable Cost of Service in 2005 (U.S. millions $)



Source: Authors' calculation

Notice, however, that this correspondence is not perfect. Beyond the obvious positive association between aircraft hours/flight operation counts and cost, spatial spread and determinants of these costs need to be explained as well. Finding these determinants is necessary to determine the incremental cost of providing the services while adequately controlling for all other factors that may be influencing cost.

Table 2: Basic Data for European ANSPs

Key Data for the European ANS system	2003
ANSPs	34
Area Control Centres (ACCs)	68
En-route sectors at maximum configuration	599
Approach Units (APPs)	190
Towers (TWRs)	417
AFIS units	91
Flight-hours controlled (M)	11.2
IFR airport movements (M)	13.7
Total Air Navigation Services (ANS) staff	54,339
Air Traffic Controller in Operation (ATCOs in OPS)	15,672
Gate-to-gate ANS costs (€ M)	6,741
Gate-to-gate ANS revenues (€ M)	6,794
Gate-to-gate ATM/CNS capital employed (€ M)	7,299

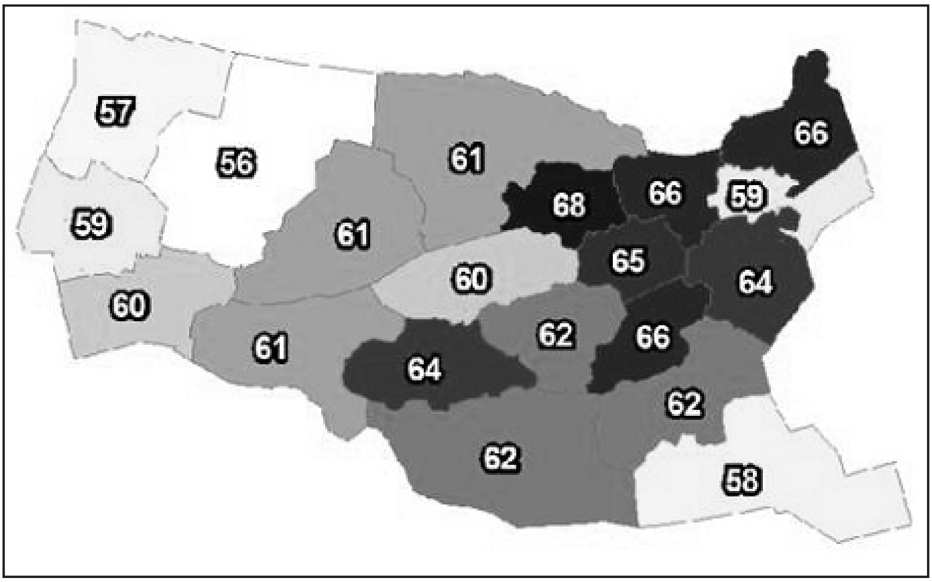
Source: http://www.eurocontrol.int/prc/ (2007)

In comparison, European airspace consists of 34 ANSPs with 68 area control centers that are roughly equivalent to 20 contiguous U.S. en route centers in terms of geographical size. Notice that for traffic levels that were almost three and a half times less than the levels U.S. centers' handled in

2003, costs of providing these services were largely similar (see Table 2). Compared to the United States, the effective tax rate is slightly lower in the European Union: 12.5% in the EU-15 compared to 16.1% in the United States (see Yamanaka, Karlsson and Odoni 2006).

Much of the costs at the U.S. centers is labor cost. However, there is a considerable variation in the share labor costs represented in the total cost across the centers. For example, Minneapolis has the lowest, at about 56%, while Chicago had the highest at about 68%. This distribution can be seen in Figure 4.

Figure 4: Percent of Labor in Total Cost in 2005



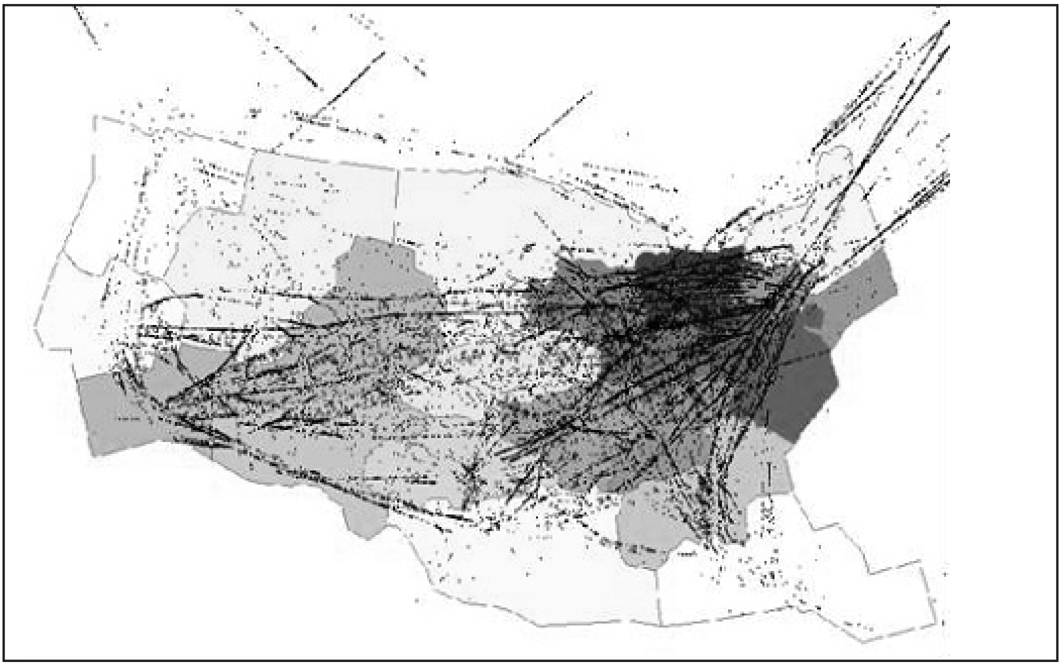
Source: Authors' calculation

While labor accounted for 48% of the costs of the entire en route service, the centers for the contiguous United States make up only 76% of the total en route costs reported in the cost of services table in cost accounting system (or CAS) of the ATO. The remaining en route centers include Anchorage, San Juan, and Guam (not included in the map), all of which have labor costs that have a lower share of their total costs than is the case for the contiguous centers (32%, 41%, 44% respectively; authors' analysis of CAS data). These three centers, however, only represent about 4% of the overall en route costs, meaning that about 20% of the costs reflected in the overall air traffic service cost of services report are not explicitly traceable to en route centers in the CAS system.

Finally, the U.S. airspace is complex. It is likely, therefore, that centers bear higher costs depending upon the degrees of complexity. There are many measures of complexity, ranging from simple volume of traffic to intricate details on how the traffic interacts with other features of the airspace. In this analysis, we consider intersection density, a tool (Glover 2004) that takes into account both flight operation counts and interactions between traffic (see Figure 5).

The key point of Figure 5 is that the higher the complexities (darker shade), the higher the intersections of traffic (dots). These appear to be somewhat correlated with costs as well, an assumption that will be empirically tested below.

Figure 5: Airspace Complexity (June 1, 2005)



A SIMPLE ANALYTICAL AND EMPIRICAL FRAMEWORK

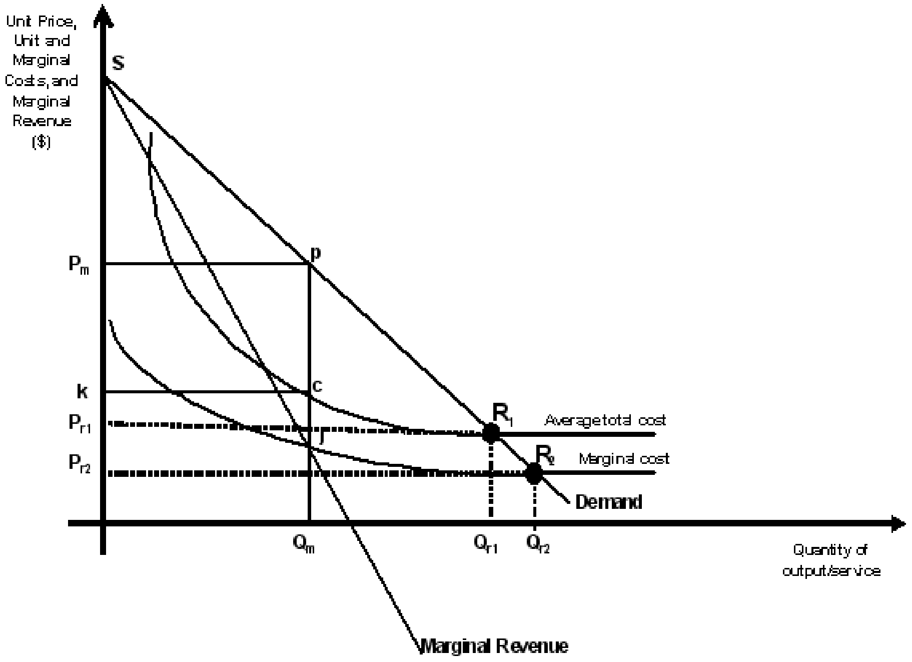
Economic theory states that a natural monopoly is characterized by declining unit costs over all ranges of output. This acts as a natural barrier against the entry of competitors, making the monopoly *natural*. Following rules of profit-maximization, an unregulated natural monopoly would produce Q_m service and charge P_m price (see Figure 6). Under this equilibrium, SpP_m is the surplus that consumers receive while the rectangle $P_m pck$ represents unregulated monopolist's profit.

Clearly, there are economic opportunities that are not appropriated. The least cost combination of price and output would be P_{r1} and Q_{r1} where the natural monopolist is regulated to set its price equal to average total cost in order to take advantage of the declining unit cost. Under this average cost pricing, the monopolist's erstwhile profit has been transferred to consumers' surplus. Interestingly, a new triangle of benefit pR_1j,called deadweight loss, has been added to consumers' surplus. This conversion of deadweight loss under unregulated monopoly to something enhancing social welfare as consumers' surplus is considered as the benefit of average cost pricing for natural monopoly. Under this pricing, a normal rate of return (or premium) can be guaranteed to the natural monopolist by adding it to the average total cost.

Alternatively, if the regulated price were to be set equal to the marginal cost, i.e., P_{r2}, the quantity would have increased to Q_{r2}. However, the monopolist would incur a loss, per unit of output, that equals the vertical distance between the marginal and average cost, i.e., approximately ($P_{r1} - P_{r2}$). For a regulated natural monopoly, therefore, marginal cost pricing leads to a loss that will have to be paid by the government's general fund or subsidy in some form.

Two implications follow immediately from this demonstration: (a) if the industry is exhibiting economies of scale for the full range of output, the least cost structure is indeed provided by a monopoly; and (b) if the firm is to set price according to marginal cost, then, it cannot recover the full cost. Thus, full recovery of cost would require a subsidy or general funding of the amount between marginal and average total cost, i.e., roughly the difference between P_{r1} and P_{r2} (see Panzar and Willig 1977 for the original treatment of these results). However, the average cost pricing ensures both technical and allocative efficiencies.[25] It is evident that prior to arguing for one form of pricing or another, one needs to empirically establish that the average total and marginal cost are indeed falling for all observable ranges of output. In the empirical section below, this task is addressed in a generalized fashion.

Figure 6: A Simple Analytical Model of a Single Service Natural Monopoly ATS Provider



Note that the above example is for a single service provider. In reality, however, any ATSP, or FAA's ATO in particular, provides more than one service. Although service provisions can be classified into numerous categories (Bhadra, Hogan and Schaufele 2006), it is assumed in this paper given the task at hand, that the ATO serves only the following two users: commercial operations including air taxis and cargo. IFR GA, i.e., military and other users are excluded. Given the earlier discussion, we consider some of the other factors influencing the costs in a direct or indirect way:

(1) $TC = f(wl, sq; Q_i, Q_j)$

where TC is the total cost; *wl* is the wage payment to labor; sq is the variable representing service attributes (i.e., complexity, weather, and traffic restrictions); and Q_i, and Q_j, represent commercial operations and IFR GA, respectively. Variations of (1) are empirically tested for the existence of natural monopoly in U.S. ATS provision[26] followed by determining the marginal cost for different services. In the section below, the data and variables used for this empirical analysis are discussed.

DATA

With the passing of the Federal Aviation Reauthorization Act of 1996, the FAA was required to "develop a cost accounting system that adequately and accurately reflects the investments, operating and overhead costs, revenues, and other financial measurement and reporting aspects of its operations."[27] The 2000 Wendell H. Ford Aviation Investment and Reform Act for the 21st Century

(AIR-21, 2000) required the U.S. Department of Transportation Office of the Inspector General (OIG) to conduct annual assessments of the FAA's CAS.

In February of 2001, the OIG (2001) reported that implementation of the CAS was four years behind schedule. The OIG also found that FAA had a lot of room for improvement in the quality of tracking labor cost, overhead, and assets. By January of 2002 in the report assessing the CAS for 2001, OIG (2002) was able to report that the FAA had made significant progress, though it still lagged behind schedule and faced many challenges. Subsequent reports assessing years 2002 and 2003 (covering some events in 2004) completed in June of 2003 (OIG 2003) and November of 2004 (OIG 2004) respectively, read similarly. They cite both accomplishments and shortfalls. The overall picture of the trend that emerges is one of gradual but consistent improvement, with significant obstacles still in place.

One setback occurred at the beginning of fiscal year 2004 when the FAA began connecting the CAS to the new Delphi financial management system. These problems stopped the ongoing processing of cost data and created a backlog which left FY 2004 CAS data unavailable until 2005. During the time period over which the backlog was processed through the present, more sweeping improvements are reported to have been made to the system, though these have not yet been documented in an OIG assessment. FAA regards the FY 2005 data as the cleanest and most thorough cost accounting data to date. A move is being made to make the data available on a quarterly basis. With these cautions in place, CAS data for fiscal years 2003-2005 with the corresponding traffic data was combined for the same years.

Accessing the most recent CAS data requires accessing the FAA's Report Analysis and Distribution System (RADS). The historic data is, however, available in the CAS reports archive[28] on the FAA's public website. Presently, the CAS accounting reports archive contains annual cost of service data for fiscal years 1999 through 2003, classified by five lines of businesses (or, service delivery points, SDP): (1) Air traffic service; (2) En route SDPs; (3) Oceanic SDPs; (4) Flight services SDPs; and (5) Terminal services SDPs.

Table 3: Data Characteristics by Fiscal Years

FY	TYPE	ATC	W	Sq	Q_i	Scale: Q_i	Q_j	Scale: Q_j	Scope
2003	MEAN	$44.88	$162,595	2859	1,512,568	2.5E+12	374,029	1.604E+11	6.18E+11
2003	STD	$9.09	$11,262	1773	480,012	1.6E+12	146,823	1.13E+11	3.8E+11
2003	N	20	20	20	20	20	20	20	20
2004	MEAN	$45.51	$171,313	3134	1,625,763	2.9E+12	400,354	1.832E+11	7.11E+11
2004	STD	$9.82	$11,310	1822	529,397	1.8E+12	155,179	1.275E+11	4.38E+11
2004	N	20	20	20	20	20	20	20	20
2005	MEAN	$45.45	$181,294	1830	1,685,414	3.1E+12	398,105	1.801E+11	7.33E+11
2005	STD	$9.83	$12,262	1091	564,827	2.1E+12	150,864	1.265E+11	4.53E+11
2005	N	20	20	20	20	20	20	20	20

Source: Authors' calculation

For information on traffic (i.e., output measures) handled by the centers, the Enhanced Traffic Management System (ETMS) data was used.[29,30] The ETMS data contains records of flight operation counts operated under IFR that were processed by the host computer system and worked by FAA controllers. The ETMS flight operation counts and hours are based on the RADAR data thus eliminating some potential bias in the reporting procedures that may perhaps be present in air traffic activities data system (or, ATADS) data. In addition, the finance division of the FAA's Air Traffic Organization (ATO-F) uses ETMS flight operation hours as the measure of the output or services that the FAA provides to users of the system. Using the position data of a flight operation (i.e., departure, arrival, and route messages), ATO (AIM Lab) prepares a table of boundary crossing. The boundary crossing data contains one record for each piece of airspace that a flight traverses. As opposed to the flight track (TZ) data which in general contains one record a minute, the boundary crossing table is summarized to contain the entry and exit positions and times for the pieces of airspace traversed. The aggregate nature and the efficiency of the boundary crossing table makes it possible to align the data to the monthly statistics of flight operation counts and time in facility (flight operation hours) that are necessary for this study. The boundary crossing data was used to measure the aggregate output metrics annually. In the table below, the basic characteristics of the data that are used in this empirical analysis are provided. Variables represented in columns of Table 3 are defined in the next section.

EMPIRICAL MODEL AND FINDINGS

Following the underlying relationships between cost and production of services, also known as Shephard's duality lemma (Varian 1999), equation (1) can be written in terms of unit cost function (ATC) for multi-service provisions as follows:

$$\text{(2)} \qquad \text{ATC} = f\,(w, \text{sq}; \text{Q}_\text{i}, \text{Q}_\text{j})$$

where ATC, or short-run average total cost, is defined as total variable cost divided by total flight operation counts (or hours) that each center serves; and *w* is the average wage paid to controllers. Notice that (2) is a pseudo dual cost function because it does not have the price of outputs or services. Lack of information about other resources and consideration of exogenous factors (e.g., service attributes measures) make the above cost function short run.

Using the earlier discussion as a guide, equation (2) can be specified as follows:[31]

$$\text{(3)} \qquad \begin{aligned} \text{ATC} &= \alpha + \beta{*}w + \chi{*}\,\text{Q}_\text{i} + \delta{*}\,\text{Q}_\text{j} + \phi{*}\text{sq} \\ &\quad + \gamma{*}\text{scale} + \eta{*}\text{scope} \end{aligned}$$

where sq is represented by total counts of interactions density for a busy representative day in different years (as measured by intersection density tools); scale is represented by the square of the total number of IFR flight operation counts (i.e., commercial and IFR GA flights) that the center handles and scope is defined by the multiplicative interactions between IFR GA and commercial flights. All other variables in (3) have been defined earlier.

Before the empirical results are presented with supporting analysis, it is important to address issues involving the data and estimation procedure. The number of observations in the dataset is limited essentially by number of years (i.e., 20 centers over three years equaling 60). In situations like this, analysts often pool cross sections of data over time and use ordinary least squares (OLS) regressions. While this is routinely done, there are some obvious problems with this procedure. For example, variables in cross section units may be correlated over time; one activity (e.g., commercial operations) may be too closely correlated to another (e.g., IFR GA) across centers and over time. In addition, unobserved or omitted variables are often present (either in a systematic or random manner) that are lumped together under OLS procedure and treated as errors with assumption of normality. Due to pooling data together, good information is lost that, instead of increasing the efficiency of estimation, is treated as errors or nuisance.

To understand the general structure of relationships among variables in a cross-section pooled time series dataset, a test for multicollinearity among all exogenous variables in the sample is conducted. When explanatory variables are correlated, the estimated coefficients could potentially be less precise. This is caused by the fact that the degrees of correlations among explanatory variables may, in fact, be larger than their corresponding association with the explained variable, in this case, ATC. Associations among explanatory variables always exist, the degrees of which differ depending on the data and variables. Interestingly, however, if those dependencies remain stable over time (three years in our case), estimated parameters are expected to yield relatively low standard errors in terms of their units and thus can be used for i empirical relationships as well as to forecast (if there is a need) the underlying relationship.

Nonetheless, a formal test of multicollinearity among the explanatory variables is performed. Examining these test results estimated over the entire sample (60 observations),[32] the standard errors associated with the proposed explanatory variables are small and stable.[33] The condition indices,[34] however, appear to be larger for two variables than what is usually suggested and those are scale economies for IFR GA, and scope economies (i.e., interactions between commercial and IFR GA).

In a cross-section pooled time series dataset, these are expected outcomes. In fact, multicollinearity in time series data are common and typically arise because the information content of the sample is not generally rich enough to meet the information requirements specified by the model (Hsiao 2003). Given this, it is evident that the use of OLS is not appropriate for the data and types of models being considered in this research.

To overcome the limitations of OLS, we categorize data as panel data. Generally speaking, econometric procedures analyze a class of linear econometric models that are more applicable when time series (i.e., fiscal years) and cross sectional (i.e., centers) data are combined to form time series cross section (or, TSCS) or panel data. This procedure is particularly useful for situations where it is important to (a) identify models to discern knowledge regarding competing hypotheses (e.g., testing of natural monopoly); (b) minimize or eliminate estimation bias that often arises under standard OLS procedure; and (c) finally and most importantly, reduce problems of multicollinearity (Hsiao 2003). In addition, data attributes observed on a cross section of centers representing individuality of centers over time (i.e., intertemporal dynamics) allow us to have greater degrees of freedom thus reducing the gap between information of a model and those provided by the data (Hsiao 2003). Time stable characteristics of the units of analysis (i.e., centers) are better understood by applying TSCS procedure.

The TSCS regression equation can be generally specified as follows:

$$(4) \qquad y_{it} = \sum_{k=1}^{K} X_{itk}\beta_k + u_{it} \quad i = 1,\ldots, N; \quad t = 1,\ldots, T$$

ATC = y_{it} is a function of a host of factors that are represented by X_{itk}, where i = 1, …, N are the units of observations or number of cross sections (i.e., centers); t = 1, …., T are the length of time periods (i.e., fiscal years 2003-2005) for each cross section; and k = 1…, K are the number of explanatory or exogenous variables.

The composite error term (u_{it}) can be specified as follows:

$$(5) \qquad u_{it} = v_i + e_t + \varepsilon_{it}$$

When the error depends only on cross sections (v_i), the specification is called a one-way fixed effect model. Alternatively, this can be captured by unit or center-specific dummy variables. However, when the error depends on both cross sections (v_i) and time (e_t), a two-way fixed effect model is more appropriate. Finally, ε_{it} is the classical error with zero mean and constant variance.

Cross sections could be different among themselves (e.g., Seattle is different than New York) or they could be different over time (i.e., two-way fixed effect). Furthermore, these effects can be nonrandom (e.g., coastal en route centers may be systematically different than those that are located inland) or completely random. Finally, when errors (both across cross sections and over time) are correlated, serial autocorrelation is present.

If cross sectional or over time effects are fixed (i.e., both one- and two-way fixed effect models), the regression models can be used with dummy variables (i.e., year and cross section units) by using OLS which is the best linear unbiased estimator (BLUE). Given the earlier observations on limitations of OLS and the relatively small size of the sample, this severely limits the degrees of freedom and limits the efficiency of OLS estimators. Alternatively, if the effects are not fixed (or assumed to be), then empirical specification requires that the effects are independent of the regressors (or, X_{itk}). These classes of models are called random effect (RE) models. For RE models, the estimation method is feasible estimated generalized least squares (EGLS) procedure. This involves estimating the variance components first and then using the estimated variance-covariance matrix for applying the generalized least squares (GLS) model to the data. Given the assumption of RE and thus use of the variance component model, we use the Fuller-Battese method to estimate the regression parameters of the generalized model.[35] The aggregate estimated features of the model are reported in Table 4A.

Table 4A: TSCS Estimation Results for 20 Centers: Aggregate Features

Dependent Variable: UnitAVC (Counts: Measured by Number of Flights)

Model Description

Estimation Method	Fuller
Number of Cross Sections	20
Time Series Length	3

Fit Statistics

SSE	69.2006	DFE	52
MSE	1.3308	Root MSE	1.1536
R-Square	0.6567		

Variance Component Estimates

Variance Component for Cross Sections	13.4864
Variance Component for Time Series	1.350907
Variance Component for Error	1.104113

Hausman Test for Random Effects

DF	m Value	Pr > m
7	19.04	0.0081

There are 20 cross sections which are the centers over a period of three years that have been estimated by Battise-Fuller method in SAS 9.1 environment. Given 60 observations and eight explanatory variables in the specified model, there are 52 degrees of freedom (DFE). Low mean squared error (MSE) and root mean squared errors (RMSE) in the magnitude of $1.33 and $1.15, respectively, represent relatively close fit of the estimation to the data. The R^2 signifies almost 2/3 of the variation in the data has been explained by the model specification.[36] Despite the high variability in variance across cross sections, variance components for time series and errors are relatively small. Finally, Hausman *m*-test for random effects represents the appropriateness of the random-effects specification as opposed to OLS specification. This test is based on the assumption that under no correlation, the null hypothesis between the effect variables (u_{it}) and regressors (X_{itk}), OLS and GLS are consistent. However, OLS is inefficient. Hence, the Hausman test is performed to demonstrate that the GLS estimation is more applicable.[37] The *m*-test shows that GLS estimation is indeed appropriate for the data under consideration.

Table 4B illustrates TSCS estimation results for specified parameters.

Table 4B: TSCS Estimation Results for 20 Centers: Parameters

The TSCSREG Procedure
Fuller and Battese Method Estimation

Dependent Variable: UnitAVC (Counts: Measured by Number of Flights)

Parameter Estimates

Variable	DF	Estimate	Standard Error	t-value	Pr > |t|	Label
Intercept	1	78.08404	9.9484	7.85	<.0001	Intercept
w	1	0.000069	0.000059	1.17	0.247	Average Annual Wage ($) of Center Controllers (PC&B)
sq	1	-0.00001	0.000359	-0.04	0.971	Complexity Measure by Interaction Density
Q_i	1	-0.00004	0.00001	-3.55	8E-04	Number of Commercial Flights
Scale: Q_i	1	3.94E-13	3.11E-12	0.13	0.9	Scale Effect in Commercial Operations
Q_j	1	-9.44E-06	0.000028	-0.34	0.738	Number of IFR GA Flights
Scale: Q_j	1	-9.06E-11	6.39E-11	-1.42	0.163	Scale Effect in IFR GA Operations
Scope	1	4.82E-11	2.52E-11	1.92	0.061	Scope Measure as captured by Interactions between Commercial and IFR GA Flights

Notice that the estimated intercept is statistically significant at a 99% level of significance. This signifies that centers are indeed different and those differences persist over time. In RE specification, a significant intercept captures those differences.

Average wage of controllers appears to have the right sign but is not statistically significant. That is, higher average wage tends to increase the average unit total cost. While the estimated parameter has the right sign, statistical insignificance may be reflective of the fact that labor costs are part of fixed cost due to contractual arrangements and terms of long-term employment. Empirical evidence (Oster 2006) indicates that is the case in other countries as well. Interestingly, however, complexity reduces cost, as opposed to the expected increases in unit total variable cost controlling for output and other measures. However, it is insignificant and thus may be dropped in re-specification. This result does not particularly make sense. Either the data construction or the metric may need to be looked at further.

The output or service measures, as represented by commercial, and IFR GA flight operation counts have been estimated to have negative coefficients. While they are statistically significant (99%) for commercial flight operation counts, they are insignificant for IFR GA flight operation counts. This is an interesting finding, for as services increase, unit variable cost declines for commercial operations confirming the earlier empirical hypothesis of natural monopoly of the centers for this group of users. However, this is not the case for IFR GA users.

The underlying nature of the scale economies in providing specified services is not confirmed by the scale economies as measured by the total flight activities for respective services (i.e., scale: Q_i and scale: Q_j). Notice further that increased scope (i.e., mixing services of commercial and IFR GA flight operation counts within a center) may increase unit variable cost, a result that is statistically significant (90%) and may make intuitive sense. The nature of composite services provided by centers, given the types of aircraft flown by IFR GA and commercial operators, could be different leading to scope diseconomies and increasing unit variable cost.

Given the findings of Table 4B, a new model was re-specified dropping the complexity measure. The results are provided in Table 5A and 5B.

Table 5A: TSCS Estimation Results for 20 Centers: Aggregate Features of Respecified Model

Dependent Variable: UnitAVC (Counts: Measured by Number of Flights)

Model Description

Estimation Method	Fuller
Number of Cross Sections	20
Time Series Length	3

Fit Statistics

SSE	70.2005	DFE	53
MSE	1.3245	Root MSE	1.1509
R-Square	0.6570		

Variance Component Estimates

Variance Component for Cross Sections	13.02866
Variance Component for Time Series	1.068327
Variance Component for Error	1.090801

Hausman Test for Random Effects

DF	m Value	Pr > m
6	248.82	< 0.0001

Interestingly, exclusion of complexity measures has increased the relevance of the choice of RE specification and the EGLS estimation. Estimated parameters of the re-specified model (Table 5B) behave the same way as the generalized model (Table 4B).

Table 5B: Re-Specified TSCS Estimation Results for 20 Centers: Parameters

The TSCSREG Procedure
Fuller and Battese Method Estimation

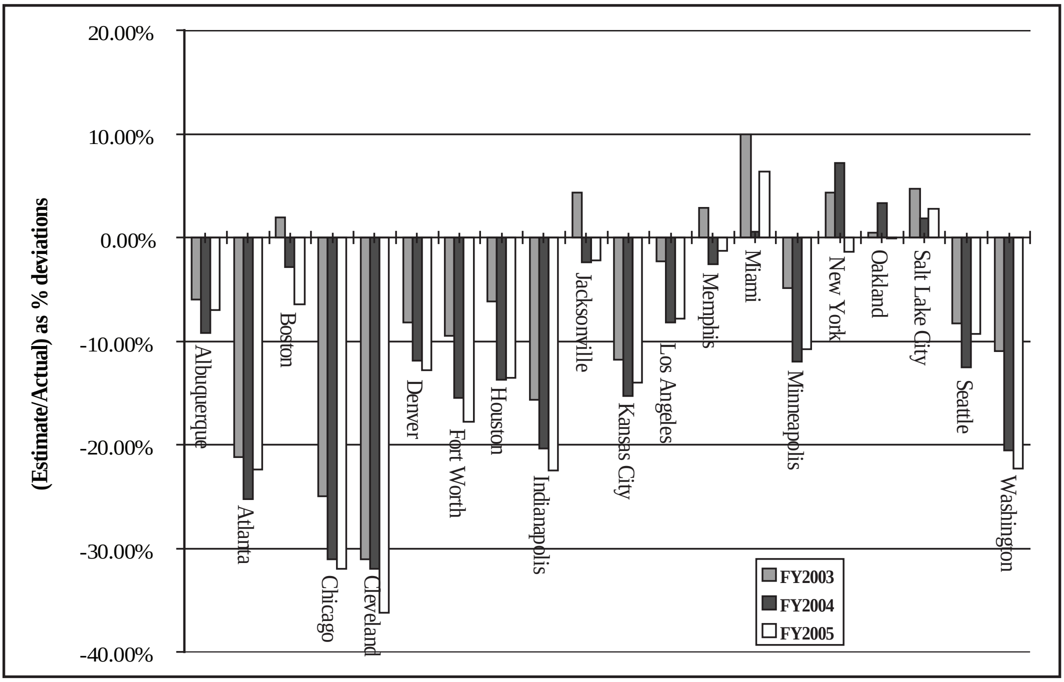
Dependent Variable: UnitAVC (Counts: Measured by Number of Flights)

Parameter Estimates

Variable	DF	Estimate	Standard Error	t-value	Pr > |t|	Label
Intercept	1	77.22322	9.628	8.02	<.0001	Intercept
w	1	0.000076	5.6E-05	1.35	0.1828	Average Annual Wage ($) of Center Controllers (PC&B)
Q_i	1	-0.00004	9.65E-06	-3.9	0.0003	Number of Commercial Flights
Scale: Q_i	1	3.90E-13	2.94E-12	0.13	0.8949	Scale Effect in Commercial Operations
Q_j	1	-9.55E-06	2.8E-05	-0.3	0.7324	Number of IFR GA Flights
Scale:Q_j	1	-9.15E-11	6.34E-11	-1.4	0.1549	Scale Effect in IFR GA Operations
Scope	1	4.88E-11	2.50E-11	1.95	0.0559	Scope Measure as captured by Interactions between Commercial and IFR GA Flights

Often it is instructive to compare estimated model results to the actual data. Figure 7 shows the fit of the re-specified model to the data.

Figure 7: Deviations of Estimate from Actual Unit Variable Cost by Centers Over Time



The deviation measured by estimated results divided by actual data as percentage (vertical axis) over three fiscal years clearly demonstrates that the estimates, generally speaking, underestimated the actual data. Overall, these deviations are calculated to be -6.6% for FY03, -11% for FY04, and -12% for FY05, on average. Estimates underestimated almost half the sample by over 10%.[38]

In the specification above, aircraft flight operation counts was categorized as the measures of center's output and services. It is argued elsewhere (Bhadra, Hogan and Schaufele 2006) that centers are better characterized by the amount of time that each aircraft spends within the center boundaries. Aircraft flight operation hours have been shown to be derived from aircraft that fly within the center's geographical space. This measure therefore captures the essence of the flights: both the aircraft operation counts (i.e., occurrence) and the intensity of its use (i.e., hours).

Considering the aircraft flight operation hours as the output metric as opposed to counts, unit variable cost was re-specified and equation (3) re-estimated. Results are shown in Tables 6A and 6B.

Table 6A: TSCS Estimation Results for 20 Centers: Aggregate Features

Dependent Variable: UnitAVC (Hours: Measured by Hours of Flight)

Model Description

Estimation Method	Fuller
Number of Cross Sections	20
Time Series Length	3

Fit Statistics

SSE	247.4333	DFE	53
MSE	4.6686	Root MSE	2.1607
R-Square	0.7782		

Variance Component Estimates

Variance Component for Cross Sections	50.78549
Variance Component for Time Series	5.806803
Variance Component for Error	3.667545

Hausman Test for Random Effects

DF	m Value	Pr > m
6	18.56	0.0023

Looking at the aggregate features of the model, it is apparent that unit variable cost when measured and estimated in terms of aircraft flight operation hours improves statistical properties. This is supported by examining the estimated parameters in Table 6B.

Table 6B: TSCS Estimation Results for 20 Centers: Parameters

The TSCSREG Procedure
Fuller and Battese Method Estimation

Dependent Variable: UnitAVC (Hours: Measured by Hours of Flight)

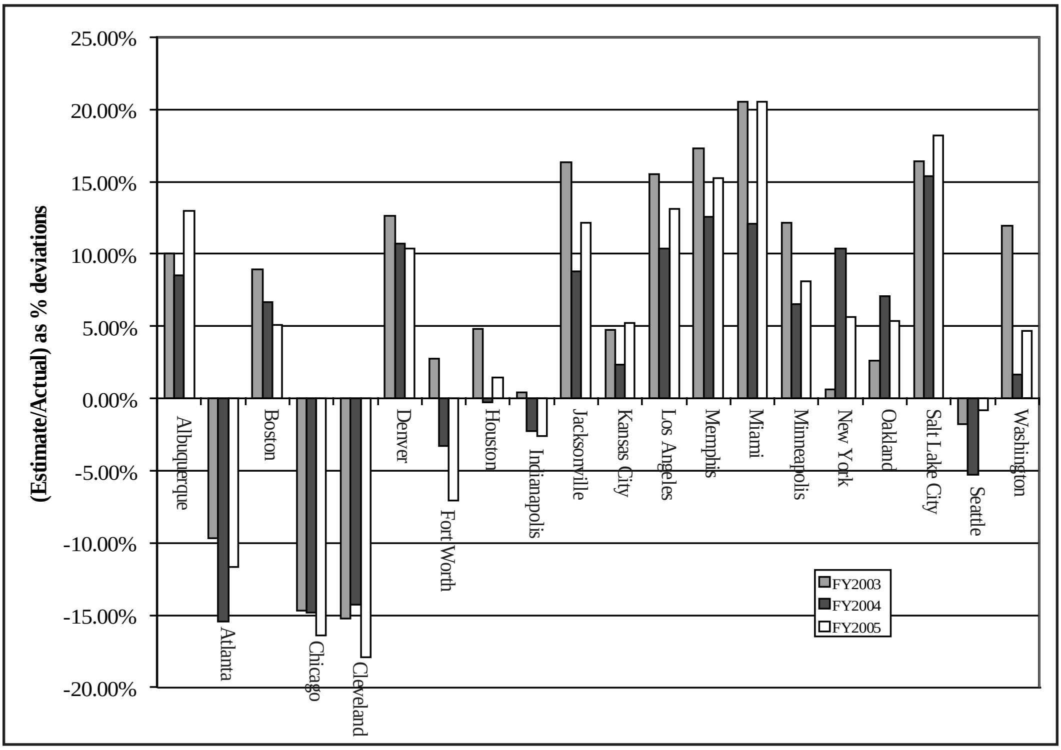
Parameter Estimates

Variable	DF	Estimate	Standard Error	t-value	Pr > |t|	Label
Intercept	1	79.47658	21.7998	3.65	<.0006	Intercept
w	1	0.000199	0.0001	1.9	0.0626	Average Annual Wage ($) of Center Controllers (PC&B)
Q_i	1	-0.00007	3.10E-05	-2.37	0.0216	Number of Commercial Flights
Scale: Q_i	1	2.06E-12	1.87E-11	0.11	0.9125	Scale Effect in Commercial Operations
Q_j	1	1.22E-04	7.7E-05	1.59	0.1172	Number of IFR GA Flights
Scale:Q_j	1	-4.07E-10	1.92E-10	-2.11	0.0393	Scale Effect in IFR GA Operations
Scope	1	9.81E-11	9.08E-11	1.08	0.2847	Scope Measure as captured by Interactions between Commercial and IFR GA Flights

Unlike the estimation reported in Table 5B, average wage appears to be statistically significant at 90% level. Unlike the earlier estimation, however, IFR GA hours tend to increase unit variable cost but its enhanced scale effects tends to reduce it. While the former is somewhat insignificant, the latter is statistically significant. The measure for scope economies, as captured by the interactions of the two users' hours, has a positive sign (and thus still signifying diseconomies), but it is statistically insignificant.

Using these estimated coefficients, the estimated results against the data is compared and reported in Figure 8.

Figure 8: Deviations of Estimate from Actual Unit Variable Cost (by hours) by Centers Over Time



The specified model (as reported in Table 6B) matches the actual unit variable cost fairly well, with half the sample having less than 10% error. However, estimated unit variable cost, on average, overestimates actual unit variable cost – a finding that is in sharp contrast with the result when unit variable cost is estimated by aircraft flight operation counts (Figure 7). On average, errors are 6% for FY03, 3% for FY04, and 4% for FY05. Miami, Memphis, Salt Lake City, Jacksonville, Los Angeles (all positive), and Cleveland, Chicago, and Atlanta (all negative) have the largest errors between estimated results and actual data.

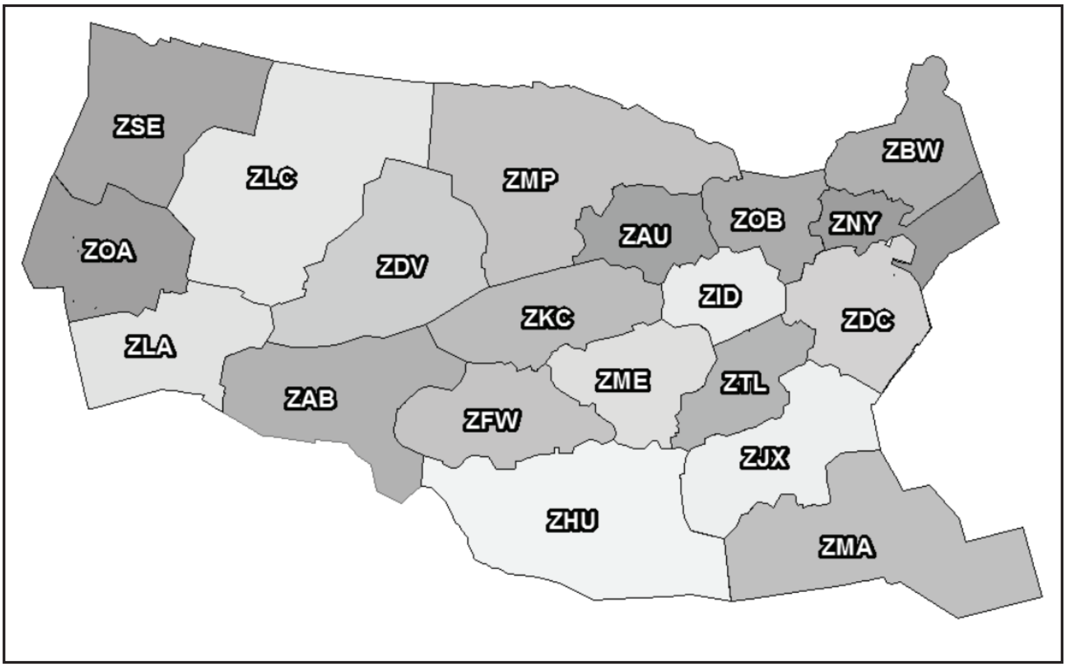
An empirical analysis using a relatively small sample, founded on sound economic theories, shows some promise for examining policies influencing performance, cost and restructuring. As evident, the U.S. ATO's en route centers that serve multiple users (i.e., commercial air carriers and IFR GA) may have considerable economic opportunities in terms of declining average total cost for ranges of services for some users. In particular, statistical results indicate that commercial air carriers enjoy increasing scale economies thus requiring special service attention. Specialization in services requiring alignment of service provisions according to scale, and not scope, may have some empirical validity. Basic economic framework also indicates that pricing under natural monopoly may require average cost pricing in absence of any external funding support. General government funding may be required in case of regulation that supports marginal cost pricing. Using the above econometric framework and data, prices (i.e., average and marginal cost) and magnitude of those external general funding can be calculated relatively easily. Furthermore, the above framework can be used for estimating center budgets using forecasted operations (i.e., commercial and IFR GA) as the basic drivers, keeping in mind the limitations of the model and underlying data.

CONCLUDING THOUGHTS AND FURTHER RESEARCH

In this paper, an empirical framework using sound economic theories was developed. Using this framework, it was found that the ATO's service provisions in the en route centers indeed enjoy some economies of scale. Furthermore, it was found that while controllers' wage is important, it is not statistically significant in unit cost measured in aircraft flight operation counts. However, it is statistically significant when unit variable cost is measured and estimated in terms of aircraft flight operation hours. This result should be interpreted carefully for controllers' wage is often dependent upon the centers' traffic levels and complexity. The study also found that degree of complexity, a measure of service attributes, does not impact cost. This may very well be the artifact of the complexity variable in the analysis as captured by the IDAT. These findings combined with earlier discussion on pricing imply that ATO may be well positioned to implement average cost pricing if cost is to be fully recovered for en route services. The implementation of marginal cost pricing may require exogenous funding, perhaps from general funds of the U.S. Treasury.

The paper can be improved in numerous ways. First, the sample size should be expanded to include other years (or quarterly data) with careful attention on issues relating to cost data comparability and subsequent errors. This will allow one to experiment with expanded empirical specifications. For example, while many more variables can be tried, experiments on the specification, from present linear to non-linear that are more accommodative, may also be tried. Second, the empirical specification is presently short on input variables. Consideration of other expenses, as a proxy measure of non-labor inputs, may also be tried including estimating long-term unit costs. Third, the framework can be improved by incorporating spatial-econometrics since activities and cost at en route centers is often contiguous and thus spatially dependent. Adjacent centers may exhibit costs that may not be aggregated. Fourth, a very brief comparison against the European ANSPs has been made in the paper. This analysis can be further expanded to include data from other ATSPs more rigorously.

Appendix A: FAA's En Route Centers in the Contiguous U.S.



Key to Center IDs:

ZAB	Albuquerque	ZLA	Los Angeles
ZAU	Chicago	ZLC	Salt Lake City
ZBW	Boston	ZMA	Miami
ZDC	Washington	ZME	Memphis
ZDV	Denver	ZMP	Minneapolis
ZFW	Fort Worth	ZNY	New York
ZHU	Houston	ZOA	Oakland
ZID	Indianapolis	ZOB	Cleveland
ZJX	Jacksonville	ZSE	Seattle
ZKC	Kansas City	ZTL	Atlanta

Endnotes

1. Paper presented at the 7th ATIO/AIOO conference in Belfast, September, 2007. Authors would like to thank those who participated in the session and for their comments and suggestions.

2. For a summary of these issues including FAA's options, legislative processes, and timeframe, see http://www faa.gov/airports_airtraffic/trust_fund/media/Trust_Fund.pdf; retrieved August 9, 2007.

3. See http://www faa.gov/regulations_policies/reauthorization; retrieved July 10, 2007.

4. See http://www.govtrack.us/congress/billtext.xpd? bill=s110-1300; introduced May 3, 2007 and retrieved July 10, 2007.

5. See http://www.govtrack.us/congress/billtext.xpd?bill =h110-2881; introduced June 27, 2007; retrieved July 10, 2007.

6. For more details, see http://waysandmeans.house.gov/hearings.asp?formmode=detail&hearing =582&comm=6; retrieved August 3, 2007.

7. See Smart Skies Initiatives: www.smartskies.org

8. For a discussion of these issues see http://web nbaa.org/public/govt/issues/.

9. A recent GAO report (2006) sums up this point most succinctly: "Representatives of GA, on the other hand, state that the system exists at its present size to serve the needs of the commercial aviation industry and that GA should be assigned only the incremental costs of serving GA, i.e., those costs that would not otherwise exist." (p. 19 of the GAO Report #06-973: Aviation Finance: Observations on Potential FAA Funding Options", September 2006).

10. It is noteworthy to mention, however, that with the significant expansion of technologies, many of the industries once thought to be natural monopolies, are proving to have very few "natural" barriers. Telecommunications, utilities, and railroads are all examples in the United States. However, it is unlikely that the U.S. air transport service provisions will experience deregulations promoting similar competition in the short run.

11. For example, Giovanni Bisignani, the Director General and CEO of the International Air Transport Association (IATA), has noted recently "Airlines achieved amazing results in the last four years. Non-fuel unit costs decreased by 13%, Labour unit costs decreased by 33%, and distribution costs were slashed by 10%. Airlines will absorb US$21 billion in additional fuel costs without an erosion of profitability." He congratulated the ATSPs for handling the productivity and efficiency issues effectively but noted that still much work needs to be done to improve efficiency in cost. Noting some interests towards privatization of the ATSPs, especially in Europe, Bisignani cautioned: "Privatization must be focused on efficiency—not making a quick buck for government coffers….Privatization needs a strong regulatory framework. The goal must be to constantly improve efficiency, drive down costs—and maintain safe operations. That is exactly what the airlines have done. And our partners must achieve the same," [speech delivered at the "Partnership for Change with Air Navigation Service Providers - Cost Efficiency, Environment and Liberalisation:" http://www.iata.org/pressroom/pr/2006-08-18-01 at the Gold Coast, Australia, retrieved on November 24, 2006.

12. See http://www.eurocontrol.int/prc/; retrieved August 8, 2007.

13. See http://www.eurocontrol.int/prc/public/standard_page/doc_ace_reports.html;retrieved August 8, 2007.

14. For more information, see http://www.ato faa.gov/.

15. GAO (2006) sums up the role of Cost Accounting System (CAS) data in this debate as following: "...assessing the extent to which the current approach (i.e., excise tax based trust fund revenue collection) or any other approach (six proposed approaches) aligns costs with revenues would require completing an analysis of costs, using either a cost accounting system or cost finding techniques to distribute costs to the various NAS users..(p. 11)...."our point is that this capability (i.e., cost assignment or estimation) would be needed to operate under a cost-based user charge system". (p 40).

16. See http://atofinance faa.gov/.

17. Note that the traffic data are measured in terms of the aircraft crossing the boundaries of centers. Thus, a long-haul flight is typically expected to cross more than one center, and hence, will be counted by multiple centers as an operation.

18. See Appendix A for the en route center boundaries together with their names.

19. Shades of colors arbitrarily represent different volumes of operations throughout the paper.

20. It should be noted that we make these rankings using domestic traffic only. Thus, international, over flying, and oceanic traffic are not accounted for here.

21. The term derived demand is used in the input-output context. That is, demand for operation hours are derived through its functional relationship with operation counts.

22. The composition of flights may loosely represent altitudinal characteristics, another dimension in determination of workload.

23. See www.atofinance.gov for basic performance metrics that the ATO tracks for centers.

24. Throughout this analysis, we consider only variable cost and not total cost. Variable costs are defined as operations and maintenance costs and do not take into account fixed costs.

25. Technical efficiency ensures that the representative firm operates at the lowest point of the average total cost while allocative efficiency is ensured when price is equal to marginal cost.

26. Economies of scale and scope are, generally speaking, long-term concepts. However, data requirements are often numerous for constructing such long-term empirical functions. In order to avoid these, we keep our empirical framework short-run with an explicit acknowledgement that this framework should be ideally estimated for long-term data.

27. Federal Aviation Reauthorization Act of 1996, Public Law 104-264, 104th Congress.

28. Last accessed June 29, 2006: http://www.faa.gov/about/plans_reports/costarchive /

29. For more details, see http://www.apo.data faa.gov/faaETMSCall.htm.

30. Please note that accessing these data may require special permission from the FAA.

31. To understand the empirical nature of the relationships, numerous other specifications and other variables were tried as well. Those specifications, results, and the entire dataset are available from the authors, upon request.

32. Due to the space limitations, we do not report these results in this paper. These and all other results reported in the paper are available from the authors upon request.

33. Generally speaking, when multicollinearity exists, affected estimates tend to have high standard errors and are usually unstable.

34. Condition indices can be generated via regression procedure (i.e., Proc Reg) in SAS. This is performed as follows: first, the X'X matrix (i.e., matrix containing explanatory variables) is scaled to have 1s as the diagonal elements. Following this transformation, the eigenvalues and eigenvectors are calculated. The condition indices are the square roots of the ratio of the largest eigenvalue to each individual eigenvalue. The largest condition index is the condition number of the scaled X matrix and when this number is around 10, weak dependencies may begin to impact the regression parameters. When the index is larger than 100, a considerable number of numerical errors may exist. (see SAS (9.1).

35. In addition to fixed and random effect models (both one and two ways), Parks method can be used while specifying an autoregressive model and the Da Silva method can be used for mixed variance component moving-average model for testing and understanding specifications.

36. Notice, however, the conventional R2 is inappropriate for all models that the TSCS procedure estimates using GLS. Hence, a generalization of the R-squared measure is reported in Table 4A. This is called Buse R2 method. This number is interpreted as a measure of the proportion of the transformed sum of squares of the dependent variable that is attributable to the influence of the independent variables. In the case of OLS estimation, the Buse R2 is the same as the usual R2.

37. That is, covariance of an efficient GLS estimator with its difference from an inefficient OLS estimator is not zero.

38. Given these apparent systematic results (i.e., greater underestimating over time), we formulate the deviation scores as function of time in order to evaluate the effect of time. We did not find any statistically useful results from this exercise.

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