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ALLOCATIVE DISTORTIONS AND THE REGULATORY TRANSITION OF THE U.S. AIRLINE INDUSTRY*

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Our paper develops a model of allocative distortions with which we analyze departures of the U.S. airline industry from efficient resource allocation during the period 1970–1981. Airline technology is assumed to transform capital, labor, energy, and materials into passenger and cargo service whose characteristics are endogeneously determined. A generalized-Leontief system of distorted profit, output supply, input demand, and reduced form output characteristics expressions is estimated by FIML using a multivariate error components model with vector autoregressive disturbances. Our results tend to support the common perception that deregulation reduced both the total cost and relative level of allocative distortions.

1. Introduction

During the 1970's and early 1980's the U.S. airline industry underwent substantial change. Two important factors in this change were the rapid increase in fuel prices and passage of the Air Deregulation Act of 1978 (ADA). Supporters of deregulation argued that a new regulatory environment would enhance the ability of the airlines to adjust to price changes in both their input and output markets. The competitive environment would reduce losses from an incorrect service level/price combination. Monopolistic behavior would be mitigated by the contestibility of airline markets. Others argued that the regulated environment encouraged expense preference behavior [Gordon (1965), Eads (1972), Douglas and Miller (1974)]. Because managers could pass on inefficient costs to consumers, they pursued their own objectives (notably increasing labor and/or capital). Implicit in both sets of arguments was the assumption that deregulation would aid in reducing inefficiency.

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Our paper develops a model of allocative inefficiency with which we analyze departures from efficient allocation during the period 1970–1981. We utilize a rich panel of firm-specific quarterly data which has been partially analyzed elsewhere [Schmidt and Sickles (1984), Sickles (1985, 1986)] and has been recently updated by Good (1985). We lean heavily on the work of Lovell and Sickles (1983) in specifying and estimating allocative inefficiency in the production of passenger and cargo service, two of whose characteristics – network and service quality – are endogenously determined. Regulatory constraints are not explicitly modeled. One potential source of inefficiency is thus constrained profit-maximizing behavior due to regulated output markets. Our modeling of technology and the introduction of inefficiency directly into a system of profit-maximizing output supply and input demand equations allows us to identify the structure of efficient technology and the level of forgone profits arising out of inefficiency. Our approach can be viewed as an alternative to the traditional cost based approach to modeling technology and productivity change for an airline assumed to be in continuous equilibrium [Caves, Christensen and Tretheway (1983, 1984), Sickles (1985)].

The plan of the paper is as follows. Section 2 provides a brief historical sketch of airline regulation that led to the condition of the industry at the beginning of the study period (1970.I) and describes a highly varied and changing regulatory environment in both the regulated and transition eras. Section 3 outlines a constrained profit-maximizing model of departures from efficient allocation. The flexible form, a hybrid generalized Leontief, has arguments which include the prices of two outputs (passenger and cargo revenue service), the prices of four inputs (capital, labor, energy and materials) and two output characteristics (an index of overall service quality and stage length). Constrained profit-maximizing behavior leads to a system of constrained output supply and input demand equations. The system considered in the empirical work includes the profit equation, five of the six first-order conditions, and two reduced-form equations for the endogenous output characteristics. The data are described in section 4. Section 5 outlines the error structure and likelihood function used in obtaining our empirical results. These results and concluding remarks are contained in section 6.

2. Historical background and regulation and deregulation[1]

The Civil Aviation Act of 1938 was the cornerstone of CAB policy for forty years. The two broadly defined objectives of this legislation were promotion of an efficient air system and the maintenance of a financially viable one. In order to encourage efficiency, the CAB found that it had to increase the level of competition in the industry. On the other hand, in order to maintain viability, the CAB usually had to provide protection from that competition.

[1]For a more lengthy discussion, see Bailey, Graham and Kaplan (1985, chs. 1–4), Meyer and Oster (1981, chs. 2–3) and Good (1985, ch. 2).

Policy often changed directions during the forty years of CAB control and the level of competition was varied as the CAB attempted to strike a balance between efficiency and financial viability.

The CAB was given three main tools to influence the level of competition: entry/exit control, control over fares and the provision of subsidy. Since the CAB felt that there were natural monopoly characteristics in airline technology, they restricted entry in order to avoid unnecessary and wasteful duplications of service. Since entry was restricted the public needed protection from potentially monopolistic fares. The CAB was also given the authority to grant subsidies in order to promote growth in demand and the development of an integrated network. The CAB did not have authority to control service (flight frequency) or aircraft type.

Entry was rarely granted to carriers without proven records of reliable service and the entry of certificated carriers was virtually eliminated.[2] Even expansion by existing carriers was expensive and time-consuming. The requesting carrier had to prove that a public need for service existed which was not currently met and that other carriers would not be financially harmed. Once entry was granted, it was a permanent license to offer service. The service could only be eliminated at the carriers' request.

Profitable routes were often awarded to individual carriers in financial difficulty or in order to minimize the growing problem of subsidy with appropriateness of the choice given little thought. This led to a piecemeal rather than an integrated development of the total system and of individual airline's networks.

Price regulation in the industry was far from optimal. Fares bore little relation to the costs of providing service. During the 1950's and 1960's substantial technological innovation occurred which led to relative cost reductions on long-haul routes vis-a-vis short-haul routes. During the same period, relative fares changed very little. Keeler (1972) and Douglas and Miller (1974) among others have shown that when service quality is not regulated while fares are, competition takes the form of increasing flight frequency and costs rise to meet fares instead of fares falling to meet costs. Jordon (1970) found that the costs (and fares) of regulated trunk airlines were fully twice as high as unregulated intrastate carriers on comparable routes.

Distorted incentives also existed for the local service airlines. During the 1950's, these carriers were viewed as providers of feeder service to the trunks. They typically used small aircraft in low-density routes. Because this was not always profitable the local service airlines were subsidized. With subsidy growing out of hand in the 1960s, the CAB began offering the local service airlines higher-density medium-haul routes which were unsubsidized and often

[2] The main exception to this statement was the permanent certification of the original 29 local service airlines in 1955. These certificates were obtained, over CAB objection, through Congressional action.

denied these routes to trunk carriers. The local service airlines responded by concentrating on jet service which was more appropriate for higher-density routes. Since subsidy on the low-density routes was based on the costs incurred with the use of this large equipment, incentives were further distorted.

The beginning of the study period (1970.I) found the airline industry in financial difficulty. The economy was in a recession and the airlines, prompted by the growth in demand during the previous few years, were very overcapitalized. This signaled the CAB to limit competition. During the first half of the 1970's very little new route authority was granted. There was, however, substantial route exit particularly by the local service airlines. The number of small communities served by certificated carriers fell by more than 25 percent.

Fares during the 1960's were set quite independent of minimum cost until the Domestic Passenger Fare Investigation formally related air fares to distance through a formula called the Standard Industry Fare Level (SIFL). The SIFL fell short of optimally regulated fares since it was based in part on data which involved a fairly high level of service competition. It also did not consider cost advantages resulting from high market density. During 1970 and 1975 capacity-limiting agreements between TWA, United and American on several transcontinental routes were sanctioned by the CAB.

The Kennedy hearings in 1975 started the airline industry and the CAB thinking about reform. Meyer and Oster (1981) refer to this as the beginning of the transition to deregulation. Administrative reforms, including multiple route authorizations and the use of 'show cause' proceedings which shifted the burden of proof from the proposing carrier to the incumbents, led to dramatically reduced cost and time in obtaining certificates. While there were many new route authorizations, many more occurred after the formal passing of the ADA in October 1978.

Several changes in fare policy also took place. In 1975 and 1976, the CAB liberalized charter requirements. In 1977, the CAB made approval of new discount fares the norm and allowed rapid implementation. Air cargo regulations were almost totally eliminated by the Air Cargo Deregulation Act of 1977. In early 1978, the CAB established a suspend free zone allowing airlines to set fares up to 10 percent above or 70 percent below the SIFL without CAB approval.[3]

New route authority after the formal passing of the ADA in 1978 was quickly implemented.[4] Price wars followed and fares again fell relative to costs. Fuel prices in late 1979 began to rise rapidly. The SIFL was set only every six months and this lead to a lag between the SIFL and costs. In

[3] The ADA tightened this zone later in the year to increases of up to 5 percent above the SIFL or reductions of up to 50 percent below the SIFL.

[4] These new provisions included automatic entry into one route per year for each airline, entry into any route for which a certificate already existed but was unused, and allowed multiple authorizations from a single hearing.

response to the financial difficulty of the industry the CAB revised the SIFL every two months and increased the upward flexibility of fares. Airlines responded by raising average fares at rates in excess of rates of increase in average costs.

In summary, the way in which regulation was established, enforced and modified by the CAB must be considered a complex and changing set of constraints. How the airlines anticipated and responded to these regulations provides additional complexity. Attempting to explicitly model these regulations, expectations and responses and their effects on temporary and/or long-run equilibrium would not in our view be a viable option. Instead, we focus on a model in which the airline is allowed to deviate from profit-maximizing behavior either because it is responding to prices that are distorted by regulation and/or because it does not adjust efficiently or immediately to undistorted prices. With our model we can determine the profit-maximizing output supply and input demand schedules, their substitution possibilities and the costs of allocative distortions. Because of the changing regulatory environment we must allow these distortions to be modeled as quite general functions of time.

3. The model

The economic model is based on the work of Lovell and Sickles (1983) who introduced a parametric model of allocative inefficiency for multi-output firms. For an excellent discussion of alternative representations of inefficient production activities, see Färe, Grosskopf and Lovell (1985). We consider a production unit employing inputs $x=(x_1,\dots,x_n)\geq 0$ to produce outputs $y=(y_1,\dots,y_m)\geq 0$. The set of all technologically feasible input–output vectors is given by the production possibilities set T, which is assumed to satisfy the following regularity conditions:

(T.1) T is a non-empty subset of Ω^{m+n}, and if $(y,-x)\in T$, then $y\geq 0$, $x\geq 0$.

(T.2) T is a closed set which is bounded from above.

(T.3) T is a convex set.

(T.4) If $(y,-x)\in T$, then $(y',-x')\in T$ for all $0\leq y'\leq y$; $x'\geq x$.

We assume that the production unit takes output prices $p=(p_1,\dots,p_m)>0$ and input prices $w=(w_1,\dots,w_n)>0$ as given, and attempts to adjust outputs and inputs so as to solve

$$\sup\{\,py-wx:\,(y,-x)\in T\,\}.$$

If $(y^0, -x^0)$ solves this problem, then the production unit's profit function is $\pi(p, w) = py^0 - wx^0$, where π satisfies the following regularity conditions:

(π.1) $\pi(p, w)$ is a real-valued function defined for all $(p, w) > 0$.

(π.2) $\pi(p, w)$ is non-decreasing in p and non-increasing in w.

(π.3) $\pi(\lambda p, \lambda w) = \lambda\pi(p, w)$ for all $\lambda > 0$.

(π.4) $\pi(p, w)$ is a convex function in (p, w).

The profit function results are useful for two reasons. First, there exists a duality relationship between a production possibilities set T satisfying T.1–T.4 and a profit function π satisfying π.1–π.4, and so T and π provide equivalent representations of the technology of a profit–maximizing production unit. The profit function is discussed in Diewert (1973) and McFadden (1978). As Diewert has pointed out, if T satisfies only T.1 and T.2, the derived function π still satisfies π.1–π.4. In this case π is dual to the convex free disposal hull T^* of T. Thus, if technology is characterized by regions of increasing returns to scale or only weak disposability, these properties will not show up in the derived profit function. With respect to the airline industry, we are limited in the characteristics of technology we can describe, particularly returns to scale. White (1979) has pointed out that different measures of returns to scale will be exhibited depending on whether output is increased at the route level, the regional level or the system-wide level. More recently, Caves, Christensen and Tretheway (1984) have estimated returns to density (i.e., route level returns to scale) by controlling for network size. Since these alternative measures of returns to scale will be masked by the profit function and since our earlier work [Sickles (1985)] indicated little evidence of scale economies at the system level for airlines in our sample, no attempt is made to measure them.

Second, with the aid of Hotelling's Lemma, we can obtain the output supply and input demand functions by

$$\nabla_p\pi(p, w) = y(p, w), \qquad \nabla_w\pi(p, w) = -x(p, w),$$

at all $(p, w) > 0$ for which $\pi(p, w)$ is differentiable. The supply and demand equations inherit their properties directly from properties π.1–π.4 of the profit function.

We now incorporate allocative distortions into the model. The production unit is said to be allocatively inefficient if it operates at the wrong point on the boundary of its production possibilities set, given the output and input prices it faces and given its behavioral objective of profit maximization. Allocative inefficiency leads to a failure to maximize profit.

The generalized Leontief profit function [Diewert (1971)] and its corresponding system of output supply and input demand equations can be modified to incorporate allocative inefficiency. Following Toda (1976) and Atkinson and Halvorsen (1980), we assume that firms adjust output supplies and input demands to the wrong price ratios. These incorrect price ratios can occur for three main reasons: regulatory distortions caused by the CAB,[5] the pursuit of non-profit-maximizing behavior by managers (i.e., expense preference behavior),[6] or because firms cannot adjust immediately to price changes.[7]

Our hybrid generalized Leontief profit expression includes service output characteristics and is written as

$$\pi(\boldsymbol{q},\boldsymbol{c},t;\boldsymbol{\theta}) = \sum_{i=1}^{6} \beta_{ii} q_i + \sum_{i=1}^{5} \sum_{\substack{j=2 \\ j>i}}^{6} \cdot \beta_{ij}\left(\theta_{ij}^{-1/2} + \theta_{ij}^{1/2}\right) q_i^{1/2} q_j^{1/2}$$

$$+ \sum_{i=1}^{6} \beta_{it} q_i t + \sum_{i=1}^{6} \sum_{j=1}^{2} \sum_{k=1}^{2} \delta_{ijk} q_i c_j^{1/2} c_k^{1/2}, \tag{3.1}$$

$$\delta_{ijk} = \delta_{ikj}, \quad \forall i,\ j \neq k,$$

where $\boldsymbol{q} \equiv (p_1, p_2, w_1, w_2, w_3, w_4)$ and $\boldsymbol{c} \equiv (c_1, c_2)$ is the vector of service output characteristics. We model distortions by the ratio of perceived to actual price ratios with $\theta_{ij} = (1 + \phi_{ij} + \xi_{ij} t)^2$ where t is a time index. When $\theta_{ij} = 1$, $\forall ij$, (3.1) becomes the (maximum) profit function. The two output quantities are passenger and cargo revenue ton miles, the four inputs are capital, labor, energy, and materials, and the two output characteristics are service quality and stage length. Thus $\{\boldsymbol{q},\boldsymbol{c}\} = \{q_p, q_C, q_K, q_L, q_E, q_M, Q, S\}$. The output

[5] These distortions arose primarily because output prices were held artificially high which would tend to distort the ratios of output prices relative to input prices. For an excellent discussion of the potential distortions caused by entry deterence, see Strassmann (1985).

[6] In the most commonly cited form of the expense preference behavior model, managers gain the rough equivalent of promotion by increasing the size of their staffs. Some debate exists over the appropriateness of calling this inefficiency. Jensen and Meckling (1976) would call such managerial discretion a component of managerial compensation.

[7] An alternative would be to model airline behavior using the variable profit function [McFadden (1978)]. Dual approaches to modeling sluggist adjustments can be found in Morrison and Berndt (1981) and Morrison (1985). With this method, no matter how far out of adjustment the capital stock was, it would be called efficient. We did attempt to model the portion of capital stock not fungible as a fixed factor. The part of capital whose stock would be the least adjustable in the short-run is ground equipment and structures. We were unsuccessful in this endeavor, possibly due to the small variability in the price for flight equipment and landing fees around the time trend. To the extent that airlines' expectations are grossly incorrect, however, their capital stock will be quite different from the optimal level. The closer their expectations are to the future reality, the lower this inefficiency would be.

supply and (negative) input demand equations from which (3.1) is derived are given by

$$d_i(\boldsymbol{q}, \boldsymbol{c}, t; \boldsymbol{\theta}) = \beta_{ii} + \sum_{j \neq i} \beta_{ij}\left[\theta_{ij} q_i / q_j\right]^{1/2} + \beta_{it} t$$

$$+ \sum_{j=1}^{2} \sum_{k=1}^{2} \delta_{ijk} c_j^{1/2} c_k^{1/2}, \qquad i = 1, \ldots, 6, \tag{3.2}$$

where

$$\boldsymbol{d} = (\, y, -\boldsymbol{x}).$$

When $\theta_{ij} = 1$, $\forall ij$, i.e., (3.1) is the profit function, (3.2) represent the net supply functions based on the application of Hotelling's Lemma ($\nabla_q \pi(\boldsymbol{q}, \boldsymbol{c}, t; \boldsymbol{\theta}) = \boldsymbol{d}$). When $\theta_{ij} \neq 1$ for any $i \neq j$, (3.2) simply represent the net supply functions which imply the profit expression (3.1) ($\pi = \boldsymbol{q} \cdot \boldsymbol{d}$).

The reduced-form equations for the output characteristics (homogeneous of degree zero in prices) are assumed to be adequately approximated by

$$c_i(\boldsymbol{q}, t) = \sum_{j=1}^{6} \sum_{k>j}^{6} \gamma_{ijk} q_j^{1/2} q_k^{-1/2}$$

$$+ \sum_{j=1}^{6} \sum_{k>j} \gamma_{ijkt} q_j^{1/2} q_k^{-1/2} t + \gamma_{it} t + \gamma_i. \tag{3.3}$$

The effect of allocative distortions on profit is given by the difference

$$\pi(\boldsymbol{q}, \boldsymbol{c}, t) - \pi(\boldsymbol{q}, \boldsymbol{c}, t; \boldsymbol{\theta}) = \sum_{i=1}^{5} \sum_{j>i}^{6} \beta_{ij} q_i^{1/2} q_j^{1/2}$$

$$\cdot \left[2 - \left(\theta_{ij}^{-1/2} + \theta_{ij}^{1/2}\right)\right], \tag{3.4}$$

which is zero if all $\theta_{ij} = 1$. If any $\theta_{ij} \neq 1$, then (3.4) is non-negative by virtue of the convexity property $\pi.4$ endowed on the undistorted technology [eq. (3.1) with $\theta_{ij} = 1$, $\forall ij$] with equality holding if and only if the corresponding $\beta_{ij} = 0$.

Thus far we have ignored the fact that the production unit faces only six market prices and only five independent market price ratios, although we have used fifteen independent θ_{ij}'s to model allocative inefficiency. Clearly the market price ratios can be expected to be consistent, in the sense that any five independent price ratios can be used to determine the remaining ten price ratios. Inconsistent inefficiency requires thirty free parameters, while consistent inefficiency requires only ten since two parameters are used for each θ_{ij}. We assume that the perceived price ratios as modeled by $[\theta_{ij}(q_i/q_j)]$ are also consistent.[8] This means that the perceived price ratios must satisfy

$$\left[\theta_{ij}(q_i/q_j)\right]\cdot\left[\theta_{jk}(q_j/q_k)\right]=\theta_{ik}(q_i/q_k),\qquad i<j<k, \tag{3.5}$$

which, given consistency of market price ratios, requires that

$$\theta_{ik}=\theta_{ij}\cdot\theta_{jk},\qquad i<j<k, \tag{3.6}$$

which reduces the number of independent $\bar{\theta}_{ij}$ from fifteen to five. Writing the constrained vector as $\bar{\theta}$, it remains the case that lost profits $\pi(\boldsymbol{q},\boldsymbol{c},t)-\pi(\boldsymbol{q},\boldsymbol{c},t,\boldsymbol{\theta})$ are zero if $\bar{\boldsymbol{\theta}}=1$ and non-negative if any $\bar{\theta}_{ij}\neq 1$ by virtue of the convexity property π.4. The only real effect of forcing allocative inefficiency to be consistent is to blur the distinctions among output mix, input mix, and scale types of allocative inefficiency. While allocative inefficiency cannot be attributed to individual inputs or outputs, allocative inefficiency resulting from an over- or under-use (production) of individual quantities can be determined.

4. Data

The data follow 13 firms with quarterly observations between 1970 and the end of 1981. These firms are the set of former certificated carriers that existed throughout the study period and account for over 90 percent of the domestic air traffic. There are three notable exceptions. Pan American and Trans World were excluded because a very large part of their traffic is generated in international markets with a different set of regulations, often established by treaty. Northwest experienced a number of strikes over the period and provided non-systematic reporting of personnel and aircraft assigned to service. When firms merged, only one firm (the largest) was kept in the sample prior to the merger. Consequently, Mohawk, Northeast, Southern, National and Hughes Airwest were dropped in order to maintain a balanced panel. Mergers are viewed as acquisitions by the dominant firm of additional resources: labor, equipment, materials and routes. The remaining airlines are American, Allegheny (U.S. Air), Braniff, Continental, Delta, Eastern, Frontier, North Central (Republic), Ozark, Piedmont, Texas International, United and Western.

Information on prices and quantities for these airlines was obtained through the CAB Form-41 reports for over 250 separate categories of expenditures and

[8] Because of the highly non-linear way in which the θ_{ij}'s are modeled, the inconsistently inefficient parameterization resulted in quite unstable and unreasonable estimates of the underlying technology. If managers correctly perceive prices that are distorted by the regulator, then their perceptions about these fifteen price ratios will be consistent.

inputs. These were aggregated into four broad input indices and two broad output indices. The input aggregates are capital, labor, fuel and a residual incorporating materials and outside services. The output aggregates are passenger and cargo revenue ton miles. A more detailed discussion of the index number procedure and the individual aggregates is contained in the appendix.

The characteristics of output were measured by two variables. Average stage length (revenue aircraft miles/take-offs) was calculated using information from the CAB Form-41 reports. Overall service quality was measured by the number of complaints received by the CAB's Office of Consumer Affairs (this ranged from a low of 12 to over 600 in a single quarter). In order to make these complaints comparable across firms, they were divided by passenger enplanements for that quarter. This is a very general measure of service quality. The bulk of the complaints are for late and cancelled flights, bumped passengers, and complaints about flight frequency. Much smaller components include complaints about lost baggage, cargo, fare levels and employee rudeness.

5. Estimation

The statistical model is discussed in Magnus (1982) and allows for firm heterogeneity in production [Mundlak (1978)].[9] Let N be the number of firms and T be the number of time periods. Stack the profit function (3.1), five of the six output supply and input demand equations (3.2), and the two unrestricted reduced-form output characteristics equations (3.3) into the p-vector $\boldsymbol{Z}_{it}^*$ and write the system of non-linear simultaneous equations as

$$\boldsymbol{Z}_{it}^* = f(\boldsymbol{Z}_{it}^*, \boldsymbol{q}_{it}; \Lambda) + \boldsymbol{u}_{it}^*, \qquad i=1,\dots,N, \quad t=1,\dots,T, \tag{5.1}$$

where Λ is the parameter space which is assumed to be continuous and compact. The error vectors $\boldsymbol{u}_{it}^*$ decompose as

$$\boldsymbol{u}_{it}^* = \boldsymbol{e}_i^* + \boldsymbol{\varepsilon}_{it}^*, \tag{5.2}$$

where $\boldsymbol{e}_i^*$ is NID$(0, \Gamma^*)$ and $\boldsymbol{\varepsilon}_{it}^* \sim \mathrm{N}(0, \Delta)$. Let $\boldsymbol{\varepsilon}_{it}^*$ be represented by a vector

[9] We chose this approach to modeling firm effects for several reasons. First, it is clear from the work by Sickles (1985) that firm effects dominate time effects and thus a decomposition of error into firm and time effects is unwarranted. Second, our parametric as opposed to stochastic modeling of allocative inefficiency is designed to reduce the amount of firm-specific heterogeneity due to changes in relative prices. Since this would be the most compelling reason to question the independence of the firm effects and the regressors, our parametric specification should circumvent this criticism. Third, Schmidt and Sickles (1984), in their estimation of the airline production function using a shortened version of this data set, found no evidence of the misspecification caused by the correlation of firm effects and input quantities.

AR(1) process where $\boldsymbol{\varepsilon}_{it}^{*} = R\boldsymbol{\varepsilon}_{i,t-1}^{*} + \boldsymbol{\varepsilon}_{it}$,

$$R = \begin{matrix} r^1 & & 0 \\ & \ddots & \\ 0 & & r^p \end{matrix}, \qquad \|r^i\| < 1,$$

and let

$$\mathrm{E}[\varepsilon_{i\cdot}^{*}\varepsilon_{i\cdot}^{*\prime}]^{-1} = P_i P_i'.$$

Transform the errors in (5.2) by P_i so that the transformed disturbance vector is $\boldsymbol{u}_{it} = \boldsymbol{e}_i + \boldsymbol{\varepsilon}_{it}$ with $\boldsymbol{e}_i \sim \mathrm{NID}(0, \Gamma)$ and $\boldsymbol{\varepsilon}_{it} \sim \mathrm{NID}(0, \Delta)$ with Γ positive semi-definite and Δ positive definite, both of order p. The covariance structure of $\boldsymbol{u}_{it}$ is then

$$\begin{aligned} \mathrm{E}\boldsymbol{u}_{it}\boldsymbol{u}_{js}' &= \Gamma + \Delta \quad \text{if} \quad i=j, \quad t=s, \\ &= \Gamma \quad \text{if} \quad i=j, \quad t\neq s, \\ &= 0 \quad \text{if} \quad i\neq j. \end{aligned} \tag{5.3}$$

Define the (p, T) matrices and $(pT, 1)$ vectors

$$V_i = (\boldsymbol{u}_{1i}, \boldsymbol{u}_{2i}, \ldots, \boldsymbol{u}_{Ti}) \quad \text{and} \quad \boldsymbol{u}_i = \operatorname{vec} V_i, \qquad i = 1, \ldots, N.$$

Then

$$\begin{aligned} \mathrm{E}[V_i V_j'] &= \sum_{t=1}^{T} \mathrm{E}\boldsymbol{u}_{it}\boldsymbol{u}_{jt}' = T(\Gamma + \Delta) \quad \text{if} \quad i=j, \\ &= 0 \quad \text{if} \quad i\neq j. \end{aligned} \tag{5.4}$$

Further, the $(pT, 1)$ vectors u_i $(i = 1, \ldots, N)$ are distributed NID$(0, \Omega)$ with

$$\Omega = \begin{bmatrix} \Gamma+\Delta & & & & & \\ \Gamma & \Gamma+\Delta & \cdot & & & \\ \vdots & \vdots & & \cdot & & \\ \vdots & \vdots & & & \cdot & \\ \Gamma & \Gamma & \cdot & \cdot & \cdot & \Gamma+\Delta \end{bmatrix} = s_T s_T' \otimes \Gamma + I_t \otimes \Delta, \tag{5.5}$$

where s_T is a $(T, 1)$ vector of ones. Let

$$M = \frac{1}{T} s_T s_T' \quad \text{and} \quad W = \Delta + T\Gamma.$$

Then Ω can be written alternatively as $\Omega = M \otimes W + (I_T - M) \otimes \Delta$ which leads us to the log-likelihood function for cross-section i,

$$\log L_i = \text{constant} - \tfrac{1}{2}\log|W| - \tfrac{1}{2}(T-1)\log|\Delta| - \tfrac{1}{2}\operatorname{tr} V_i M V_i' W^{-1}$$

$$- \tfrac{1}{2}\operatorname{tr} V_i (I - M) V_i' \Delta^{-1} + \sum_{t=1}^{T} \log|J_t|, \tag{5.6}$$

where J_t is the Jacobian of the transformation from $\boldsymbol{u}_{it}$ to $\boldsymbol{Z}_{it}$. The log-likelihood function for the full sample is thus

$$\log L = \sum_{i=1}^{N} \log L_i. \tag{5.7}$$

The results in the next section were generated by maximizing (5.7) using the Davidon-Fletcher-Powell algorithm.

6. Estimation results and concluding remarks

The eight-equation system consisted of the profit expression, cargo output, capital, labor, energy, materials, service quality and stage length equations. Estimates of the parameters from the profit system (3.1) and (3.2) are given in table 1. The derived inefficiency parameters, $\bar{\theta}_{ij}$, and curvature properties (profit elasticities), $\eta_{\pi_{ij}}$, are presented in table 2. The relative magnitude of unobserved heterogeneity is identified by the error component matrices in table 3. Input and output quantities have been scaled by 10^6, quality by 10^1 and stage length by 10^2 to keep the variances in roughly the same order of magnitude. The time path of allocative distortions, measured as lost profits relative to total industry revenues, is given in fig. 1. Because this measure attaches substantially larger weight to larger firms, an average of firm-specific lost profits relative to firm revenues is also presented in fig. 2.

A sufficient condition for the non-negativity of lost profits is the convexity of the profit function. These regularity conditions were satisfied at 92 percent of the 624 observations in the sample. As can be seen from the profit elasticity matrix in table 2, all own elasticities have the correct sign. They represent slightly inelastic responses to prices for all inputs except labor. This suggests that unions were quite effective in maintaining employment levels despite wage increases. Input substitutability was quite limited with materials showing the largest substitutability with other inputs. This is quite sensible as materials is a residual category including outside services as well as food and other supplies. The largest elasticity of substitution was between labor and materials (0.541),

Table 1

Coefficient estimates.[a]

Parameter	Estimate	t-statistic	Parameter	Estimate	t-statistic
β_{PP}	255.7	20.3	δ_{CSS}	−12.1	−4.19
β_{PC}	−19.3	−3.72	δ_{KQQ}	59.8	32.4
β_{PK}	−4.91	−7.74	δ_{KQS}	−45.9	−26.7
β_{PL}	−10.9	−12.8	δ_{KSS}	98.8	54.7
β_{PE}	−15.5	−18.1	δ_{LQQ}	−6.70	−3.04
β_{PM}	2.31	4.56	δ_{LQS}	31.4	24.0
β_{CC}	40.6	3.68	δ_{LSS}	12.7	11.1
β_{CK}	−6.59	−1.92	δ_{EQQ}	1.54	1.19
β_{CL}	24.2	30.4	δ_{EQS}	17.6	6.96
β_{CE}	−1.56	−8.39	δ_{ESS}	−21.9	−7.22
β_{CM}	−2.51	−8.23	δ_{MQQ}	5.68	16.1
β_{KK}	−0.633	−1.51	δ_{MQS}	−5.12	−21.2
β_{KL}	−6.29	−2.41	δ_{MSS}	−5.23	−9.05
β_{KE}	−0.886	−2.03	ϕ_{PC}	0.0432	2.51
β_{KM}	−3.55	−3.39	ξ_{PC}	0.0139	7.11
β_{LL}	−56.1	−6.11	ϕ_{CK}	0.00568	1.20
β_{LE}	1.02	1.02	ξ_{CK}	−0.00420	−3.21
β_{LM}	−23.5	−27.1	ϕ_{KL}	0.223	3.91
β_{EE}	−11.7	−3.02	ξ_{KL}	−0.0256	−8.33
β_{EM}	−6.33	−2.82	ϕ_{LE}	−0.363	−6.96
β_{MM}	−8.94	−1.41	ξ_{LE}	0.0122	11.1
β_{PT}	1.07	6.18	ϕ_{EM}	0.0466	−1.55
β_{CT}	0.378	7.44	ξ_{EM}	−0.00547	−6.14
β_{KT}	−0.230	−7.41	γ_{QPC}	4.10	1.19
β_{LT}	−0.669	−7.75	γ_{QPK}	11.4	1.83
β_{ET}	−0.350	−10.1	γ_{QPL}	5.72	0.54
β_{MT}	−0.343	−9.2	γ_{QPE}	17.4	2.85
δ_{PQQ}	−66.3	−34.2	γ_{QPM}	−39.3	−2.23
δ_{PQS}	−1.63	−1.08	γ_{QCK}	−5.25	−0.95
δ_{PSS}	−63.3	−55.5	γ_{QCL}	−7.01	−0.81
δ_{CQQ}	15.1	10.5	γ_{QCE}	−12.4	−2.66
δ_{CQS}	−46.8	−18.1	γ_{QCM}	31.0	2.06

suggesting that variations in the labor force were accomplished in part by purchasing outside services rather than by increasing firm employment levels.

The error component matrices in table 3 suggest that firm-specific heterogeneity dominates total noise in all equations. The ratio of firm-specific variation to total variation ranged between 97 and 85 percent for input demand and output supply equations, between 87 and 81 percent for the characteristic equations, and more than 98 percent for the profit equation.

Profit-maximizing input levels increased over time at average annualized rates in 1975.IV of 2.85% for capital, 3.07% for labor, 3.41% for energy and 3.22% for materials. Technical change was output augmenting for passenger service (2.15%) and cargo service (1.89%).

Table 1 (continued)

Parameter	Estimate	t-statistic	Parameter	Estimate	t-statistic
γ_{QKL}	−7.12	−2.14	γ_{SKL}	−5.84	−6.87
γ_{QKE}	−9.23	−3.18	γ_{SKE}	−0.977	−1.28
γ_{QKM}	25.5	4.55	γ_{SKM}	6.91	4.45
γ_{QLE}	20.3	4.65	γ_{SLE}	−0.0246	−0.01
γ_{QLM}	−29.3	−4.53	γ_{SLM}	1.88	1.29
γ_{QEM}	19.3	9.46	γ_{SEM}	−0.945	2.00
γ_{QPCT}	0.00570	1.41	γ_{SPCT}	0.00775	0.89
γ_{QPKT}	1.23	4.53	γ_{SPKT}	−0.153	−1.12
γ_{QPLT}	0.0171	0.06	γ_{SPLT}	−0.00955	0.15
γ_{QPET}	−0.0482	−0.03	γ_{SPET}	0.0000643	0.46
γ_{QPMT}	−0.962	−1.67	γ_{SPMT}	0.143	1.62
γ_{QCKT}	−1.58	−5.78	γ_{SCKT}	0.0159	0.99
γ_{QCLT}	0.564	1.01	γ_{SCLT}	0.0274	0.27
γ_{QCET}	−0.0361	−0.12	γ_{SCET}	0.00393	1.60
γ_{QCMT}	0.795	1.53	γ_{SCMT}	0.0198	0.18
γ_{QKLT}	0.0450	0.83	γ_{SKLT}	0.0854	0.69
γ_{QKET}	−0.606	−4.31	γ_{SKET}	0.00484	0.26
γ_{QKMT}	0.107	0.44	γ_{SKMT}	−0.192	−3.31
γ_{QLET}	0.486	2.52	γ_{SLET}	−0.00555	−0.31
γ_{QLMT}	0.594	2.76	γ_{SLMT}	0.0067	0.19
γ_{QEMT}	−0.574	−5.30	γ_{SEMT}	0.0593	2.52
γ_{QT}	−0.0248	−0.59	γ_{ST}	−0.0288	−0.13
γ_{Q}	−24.4	−5.58	γ_{S}	0.124	0.29
γ_{SPC}	3.19	3.98	r^{π}	0.476	12.5
γ_{SPK}	11.08	6.83	r^{C}	0.476	12.5
γ_{SPL}	−4.66	−1.71	r^{K}	0.476	12.5
γ_{SPE}	1.59	1.07	r^{L}	0.476	12.5
γ_{SPM}	−13.3	−2.77	r^{E}	0.476	12.5
γ_{SCK}	−11.8	−8.07	r^{M}	0.476	12.5
γ_{SCL}	11.5	4.87	r^{Q}	0.513	13.9
γ_{SCE}	−1.68	−1.43	r^{S}	0.516	14.2
γ_{SCM}	3.99	0.89			

[a]Subscript labels are P = passenger revenue ton miles, C = cargo revenue ton miles, K = capital, L = labor, E = energy, M = materials, Q = quality, S = average stage length, T = time.

Our efficiency results corroborate some of the common perceptions about the regulatory transition of the airline industry and question a few others. The industry experienced its greatest reduction in losses during a regulated era in which administrative attempts were made to increase efficiency through an improved regulatory process. The pattern of inefficiency in fig. 1 suggests that adoption of the SIFL and a substantial reduction in allocative distortions are highly correlated events. The pattern of inefficiency in fig. 2, which is more representative of local service airlines, suggests that the elimination of service to small communities also lead to a more appropriate overall equipment type – route density match. (The spike in 1973 is the result of a strike experienced by Ozark.)

Table 2

Profit elasticities and inefficiency estimates.[a]

$$\underset{(1975.\mathrm{IV})}{\eta_{\pi}} = \begin{bmatrix} 0.430 & & & & & \\ -2.27 & 1.42 & & & & \\ -0.214 & 0.287 & -0.903 & & & \\ 0.251 & -0.539 & 0.120 & -0.390 & & \\ 0.608 & 0.0596 & 0.0285 & -0.028 & -0.936 & \\ -0.075 & 0.079 & 0.095 & 0.541 & 0.233 & -0.875 \end{bmatrix}$$

$$\underset{(1970.\mathrm{I})}{\bar{\theta}} = \begin{bmatrix} 1.0 & 0.523 & 0.635 & 2.08 & 0.264 & 0.363 \\ & 1.0 & 1.22 & 3.98 & 0.505 & 0.694 \\ & & 1.0 & 3.28 & 0.416 & 0.571 \\ & & & 1.0 & 0.127 & 0.174 \\ & & & & 1.0 & 1.37 \\ & & & & & 1.0 \end{bmatrix}$$

$$\underset{(1975.\mathrm{IV})}{\bar{\theta}} = \begin{bmatrix} 1.0 & 1.09 & 1.10 & 1.64 & 0.668 & 0.731 \\ & 1.0 & 1.01 & 1.51 & 0.614 & 0.672 \\ & & 1.0 & 1.49 & 0.607 & 0.665 \\ & & & 1.0 & 0.406 & 0.445 \\ & & & & 1.0 & 1.10 \\ & & & & & 1.0 \end{bmatrix}$$

$$\underset{(1981.\mathrm{IV})}{\bar{\theta}} = \begin{bmatrix} 1.0 & 1.89 & 1.55 & 0.576 & 0.499 & 0.418 \\ & 1.0 & 0.819 & 0.304 & 0.263 & 0.220 \\ & & 1.0 & 0.371 & 0.321 & 0.269 \\ & & & 1.0 & 0.866 & 0.725 \\ & & & & 1.0 & 0.838 \\ & & & & & 1.0 \end{bmatrix}$$

[a] The order of variables in the distorted profit elasticity matrix η_{π} is passenger ton miles, cargo ton miles, capital, labor, energy, materials. Thus the (1, 2)th entry is for the passenger–cargo pair.

The requirement that perceived prices be consistently distorted prevents us from attributing the cost of allocative distortions to individual inputs or outputs. However, we can examine patterns of over- or underproduction (input use) by comparing (3.2) with the undistorted supply (demand) schedule.

The industry experienced three financially trying periods during the study period: 1970, 1975–76, and 1980–81. We find overcapitalization only in the latter period although capital is less distorted than other outputs and inputs. The pattern of energy use suggests an underutilization of the resource in 1970 which was quickly eliminated after the first oil price shock and remained at approximately the profit-maximizing level after 1976. The distortions in labor demand were as expected. There was a substantial overuse of labor at the beginning of the sample which was gradually reduced over the sample period. Materials were substantially underutilized throughout the sample period. The pattern approximately mirrored the overuse of labor and may have been caused by a failure to take advantage of the substitution possibilities between

Table 3

Error component matrices.[a]

$$\Delta = \begin{bmatrix} 109.3 & & & & & & & \\ 34.8 & 20.2 & & & & & & \\ -27.8 & -13.2 & 12.7 & & & & & \\ -46.8 & -18.3 & 18.2 & 32.5 & & & & \\ -12.3 & -5.51 & 6.23 & 9.92 & 4.47 & & & \\ -41.4 & -19.3 & 17.2 & 26.1 & 8.65 & 25.1 & & \\ 6.84 & 2.71 & 0.808 & -0.694 & 1.45 & 0.123 & 14.4 & \\ 1.39 & -3.78 & -0.416 & 2.22 & -1.16 & 2.30 & -1.76 & 54.8 \end{bmatrix}$$

$$\Gamma = \begin{bmatrix} 18048. & & & & & & & \\ 818. & 37.6 & & & & & & \\ -1205. & -53.2 & 82.3 & & & & & \\ -3315. & -147. & 226. & 619. & & & & \\ -1489. & -65.9 & 102. & 279. & 126. & & & \\ -1581. & -69.5 & 108. & 297. & 134. & 142. & & \\ 45.7 & 1.99 & -3.24 & -8.70 & -4.01 & -4.3 & 1.20 & \\ -20.6 & -6.75 & -8.99 & -17.5 & -10.4 & -12.8 & 2.56 & 68.8 \end{bmatrix}$$

[a] Order of equations is profit, cargo, capital, labor, energy, materials, quality, stage length.

inside and outside services due to union power and/or expense preference behavior of management.

Turning to the outputs, we find an underproduction of passenger ton miles in 1970 which is consistent with the service competition hypothesis. The distortion was completely eliminated by 1975. However, after 1979 underproduction returned, though not nearly at the level of the early 1970's. Cargo showed the most unexpected patterns. While there was slight underproduction prior to 1977, there was overproduction after 1979.

In summary, our results tend to support the common perception that deregulation reduced both the total cost of allocative distortions and the relative level of allocative distortions for input and outputs in the airline industry. However, the largest benefits appear to be a result of administrative change early in the 1970's rather than as a result of the ADA itself.

Appendix

The index number procedure takes desirable features from the chained Divisia index number and the multilateral index number approaches of Caves, Christensen and Diewert (1982). In both cases the price index is exact (in that it is consistent with an underlying cost function) and superlative (in that the underlying cost function is flexible, e.g., translog).

The index procedure used here, developed in Good (1985), uses the hypothetical firm approach as outlined by Caves, Christensen and Diewert, but only within each cross-section. Comparisons made over time are carried out by

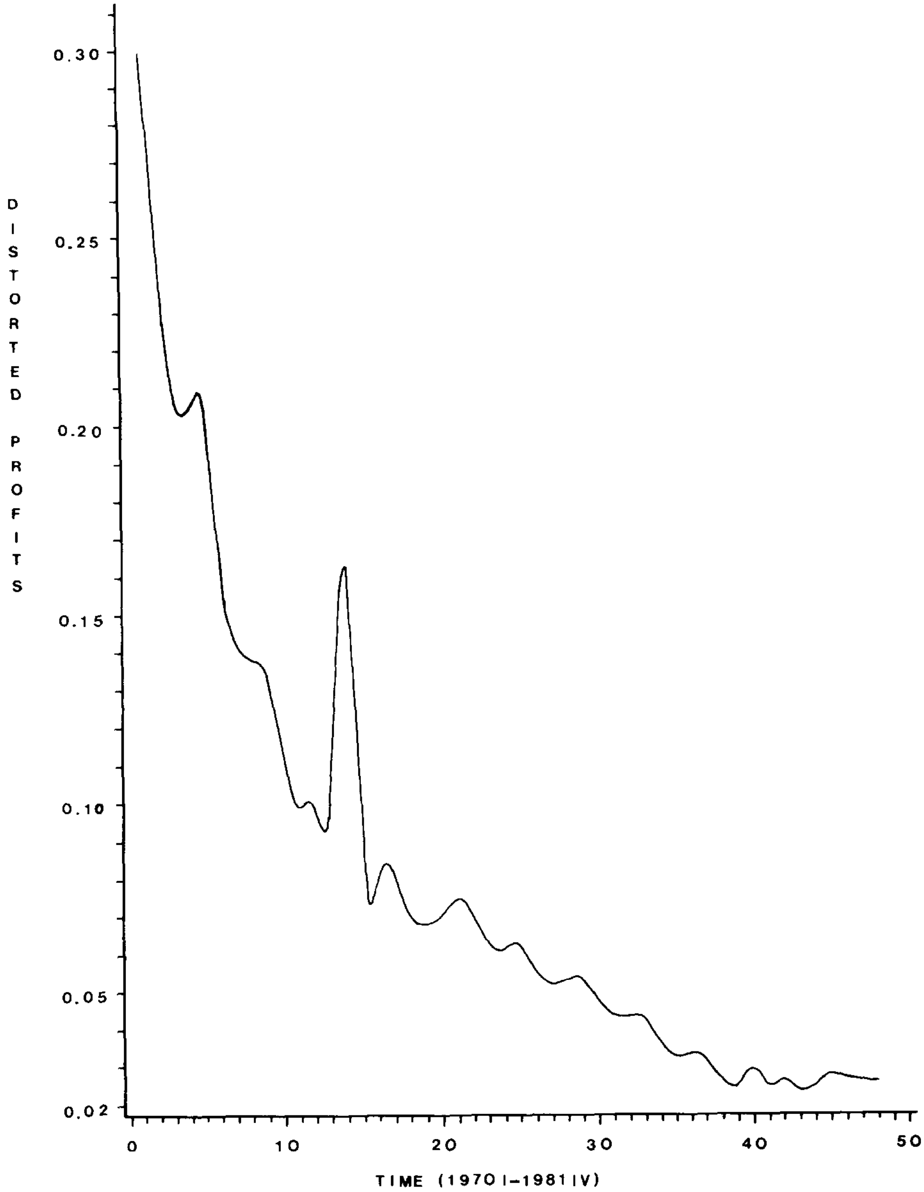

Fig. 1. Allocative distortions measured by forgone profits as a percentage of firm revenues.

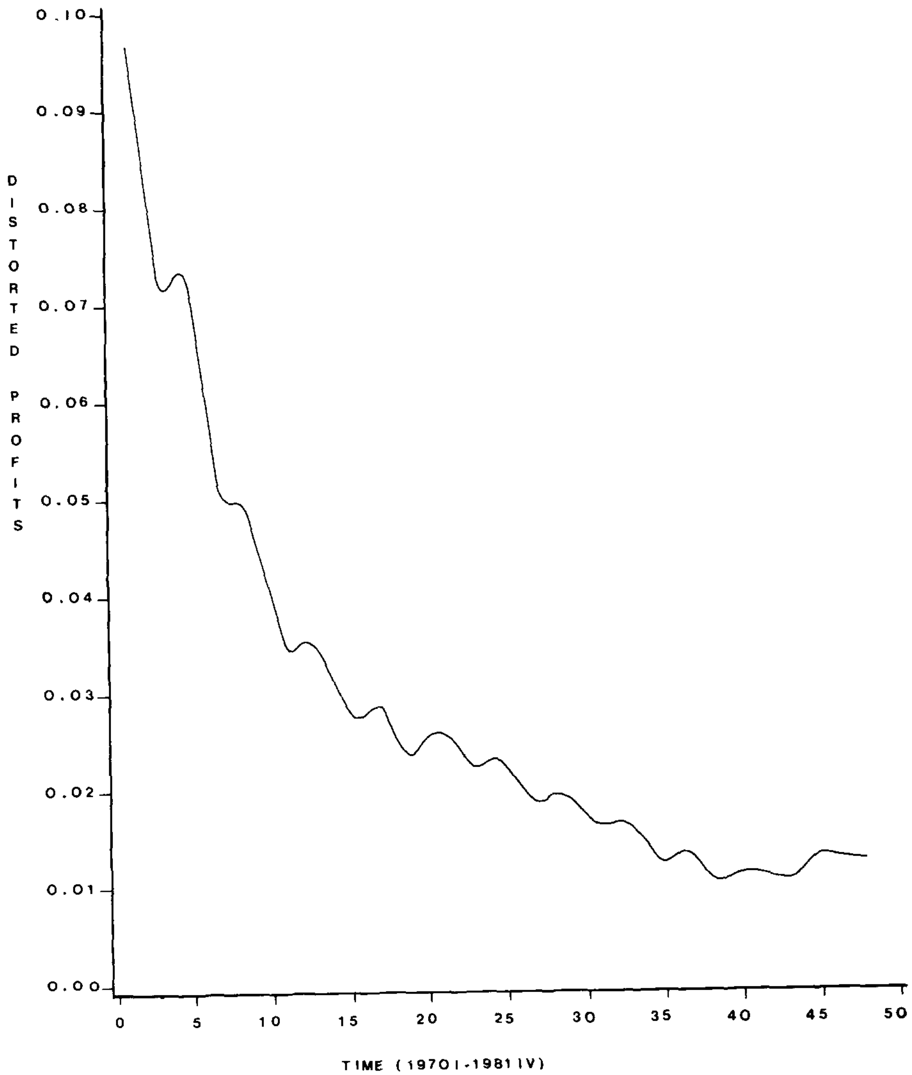

Fig. 2. Allocative distortions measured by forgone profits as a percentage of industry revenues.

chaining the indices for the hypothetical firm using the Divisia method. The resulting index which permits multilateral comparisons (through an unambiguously implied path) while at the same time has [to use Dreshler's (1974) term] a high degree of characteristicity is

$$\log w^*_{it} = \tfrac{1}{2} \sum_{j=1}^{N} \left[\left(M_{ijt} + \overline{M_{jt}} \right) \left(\log w_{ijt} - \overline{\log w_{jt}} \right) \right]$$

$$+ \sum_{s=2}^{t} \tfrac{1}{2} \sum_{j=1}^{N} \left[\left(\overline{M_{js}} + \overline{M_{m,s-1}} \right) \left(\overline{\log w_{js}} - \overline{\log w_{j,s-1}} \right) \right],$$

where w_{ijt} and M_{ijt} are the price and expenditure share, respectively, of subcomponent τ in time period t for firm i. A bar over a quantity indicates a mean within the cross-section and can be considered to be a measure of the hypothetical firm. Finally, the index for the hypothetical firm is normalized in the first time period to be 1.

The labor index is composed of 73 separate expenditure accounts and 18 quantity measures either directly or indirectly associated with employment. These are aggregated, through simple addition, into five major employment groups: pilots, flight attendants, mechanics, cargo handlers, and others (predominately administrative personnel). Indirect employment expenses such as insurance, pensions, contributions and payroll taxes are allocated to the employment groups by the percentage of direct employment expenses accounted for by each group. These five groups were then aggregated with the multilateral price index.

The energy index is designed to measure aircraft fuel only. While there is only one component in this index, the index number procedure is still used to provide a normalization of price.

The capital index is constructed from five categories which are directly associated with the physical plant of the airline industry: aircraft rented, aircraft owned, ground facilities rented, ground equipment owned, and landing fees. The two aircraft categories were further aggregated by imputing the rental price of aircraft to comparable owned equipment. While this implicitly assumes no depreciation, it is partially justifiable since FAA maintenance requirements are so stringent. Current expenses for owned ground equipment were calculated using the perpetual inventory approach, a 1955 benchmark, and the Jorgensen–Hall user price formula. The rented ground facilities utilized the implicit price deflator for nonresidential fixed investment. Finally, landing fees are considered to be a rental expense for runways. The quantity measure is assumed to be capacity tons landed.

The materials index is comprised of nine services and commodities used by the airlines. Within each of these groups quantity information is measured in

Table A.1

Subcomponents of the materials index.

Subcomponent classification	Price index[a]
Aircraft maintenance materials	PPI: Fabricated metal products
Advertising	McCann–Erickson advertising index
Communications	CPI: Telephone services
Insurance	Industry aggregate with revenue ton miles as quantity deflator
Outside business services	CPI: Miscellaneous business services
Supplies	PPI: Total manufacturing non-durables
Utilities	Electric, gas, and sewer services
Passenger food	PPI: Processed foods
Passenger and cargo commissions	CPI: Air fares

[a]PPI is the Producer Price Index series, while CPI is the Consumer Price Index series from the Bureau of Labor Statistics.

such diverse units that airline specific price information cannot be determined. Consequently, price indices are established for the entire industry for each of these subcomponents. Airline-specific information on expenditure of each of these subcomponents is used to tailor the resulting multilateral price index to the firm as much as possible. The nine subcomponents of the materials index are noted in the table above. A multilateral materials price index was then computed.

Price indices of two output classes are also constructed. These classes are an aggregate of passenger service and an aggregate of cargo and charter services. Passenger service is an aggregate of first class and coach (including all discounted travel). Cargo output is an aggregate of five categories: air freight ton miles, mail ton miles, express cargo ton miles, charter cargo ton miles, and charter passenger miles. Because charter revenues were systematically unreported by some firms, charter cargo and charter passenger miles were aggregated into a single category. All of these measures are related to services actually provided rather than the production of capacity. Quantity and expenditure data are all directly obtained from Form-41 reports.

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