

ESTIMATING AIRLINE DEMAND WITH QUALITY OF SERVICE VARIABLES

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INTRODUCTION

Recent models of regulation suggest that quality of service may represent an important, hitherto ignored, variable in the price-setting calculus of the regulator (for example, see Spence, 1975). Such models have been applied extensively to the regulated airline (DeVany, 1975; Douglas and Miller, 1974; Schmalensee, 1977; White, 1972).

Notwithstanding the theoretical interest in level of service variables, empirical models of air passenger service have typically assumed that demand is insensitive to levels of quality (see for example DeVany, 1974; Gronau, 1970; Jung and Fujii, 1976; Thompson, 1974; Verleger, 1972). DeVany (1975) is an exception. His econometric model is novel in incorporating flight frequency as a quality of service variable affecting demand, but his empirical results rest on an extremely small sample size (five degrees of freedom); hence, his estimates are generally characterised by large standard errors.

The purpose of this paper is to estimate a model of airline demand that incorporates a measure of service. The findings confirm the longstanding presumption that demand is sensitive to flight frequency and availability of "excess" seats, and that the quantity of seats offered is positively and significantly affected by regulated price. Moreover, the estimates confirm recent findings that the price elasticity of demand increases with flight distance.

The choice of sample can be important to success in estimating the relevant parameters in this model. Therefore the flight segments included in our analysis were carefully chosen to exclude numerous sources of potential problems. For example, the study is confined to monopoly flight segments. It will be shown that this restriction does not introduce any systematic bias into the estimated elasticity parameters in our model. But the concentration on monopoly routes ensures that the results will not be sensitive to an arbitrary specification of oligopoly models to characterise competitive response among a few competitors.

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Moreover, since 1974 regulated fares have been set as a function of distance only.¹ "Local" carriers (as opposed to "trunk" carriers) could charge premiums (up to 30%) above the CAB distance fare formula. When competing with trunks they were in effect forced to match the trunks' CAB price. But on monopoly routes they sometimes departed from the formula. Hence our sample, in which approximately half is composed of local carrier monopolies, does not show the severe collinearity generally found between distance and fare.

To ensure that decisions on the routes are not dominated by "network" considerations—that is, to be consistent with a simplified portrayal of maximisation of profits on particular observed flight segments—the routes were further restricted to those that were more or less insulated. In particular, the routes satisfy the criterion that passengers enplaned at either end of the segment comprised at least 80% of passengers flown between these points. It is thus presumed that on these segments seats are offered primarily in response to economic considerations that apply to these segments alone. Routes were further restricted to include at least 80% nonstop flights, so that it was not necessary to compare the value of nonstop and multiple-stop flights. During the year 1976, from which our sample is drawn, 105 flight segments satisfied these criteria.

SPECIFICATION OF DEMAND

Two types of passengers enplane at either end of a flight segment: those whose origin *and* destination coincide with the origin-destination points of the segment (O&D passengers) and those who travel the segment as part of a longer flight plan ("through" passengers). Demand studies properly concentrate on O&D demand, because characteristics of the observed segments are presumably more important factors in determining O&D demand than in determining demand for "through" traffic. In this section price and quality demand relations are derived. A particular form of the demand relation $Q = Q(F, Z)$ is developed, where Q is O&D demand, F is fare and Z is a vector of quality variables.

The simplest form of demand specification accounts for fare, income and population as independent variables. Verleger (1972) discusses these models in detail and provides several variants. In essence, however, the specification takes the form

$$\text{O\&D} = A + b \text{FARE} + c \text{INC} + d \text{POP}$$

where O&D is the log of O&D passengers that fly between points i and j per period, FARE is the log of the fare, INC is the log of the average income of population centres i and j , and POP is the sum of the logs of total population in centres i and j .

More sophisticated models accommodate the implications of "mode choice". When individuals contemplate a trip, presumably they consider what is the most efficient mode by which the trip can be taken. The longer the trip distance, the greater the

¹ CAB regulated price = $a_0 + a_1 D_1 + a_2 D_2 + a_3 D_3$ where $a_0 > 0$, $a_1 > a_2 > a_3 > 0$ and D_1 is flight distance for the first 500 miles of flight distance, D_2 is flight distance in excess of 500 miles but not exceeding 1000 additional miles, and D_3 is flight distance in excess of 1,500 miles. From 1978 onwards some flexibility was introduced into the formula (particularly in a downward direction), and in 1982 price will no longer be regulated.

savings in time and out-of-pocket costs offered by the air mode in comparison with the driving mode (Gronau, 1970).

To account for mode choice, distance (in logs) is added to the demand specification; the expected sign is positive. Moreover, since the preference for the auto mode may be particularly strong for very short trips, zero-one dummy variables were included in our model which equalled unity when trip distance was 100 miles or less and when the trip distance was between 100 and 200 miles in length. Finally, three dummy variables were included for segments that served Florida, California or Las Vegas at one end. Presumably the attractiveness of these locations as resort areas will increase air demand on these routes, other things being equal.

In specifying the form of the fare variable, it is useful to account for the possibility of varying fare elasticities over different trip distances. In particular, because the auto mode is a more viable substitute for air travel on shorter trips, the fare elasticity might be expected to be stronger on shorter than on longer trips. On the other hand, if the probability of making a trip is negatively and, say, linearly related to the fare level, a given percentage change in fare would be expected to exert a stronger impact on the likelihood of taking a trip, the higher the fare (the greater the distance). On balance, then, the fare elasticity may increase, decrease or remain roughly constant with trip distance.

To accommodate the possibility of a varying fare elasticity, an interaction term between fare and distance can be added to the demand specification (see DeVany, 1974). But in our relatively small sample the correlation between this variable and the fare and distance variables precludes a successful estimate of all three parameters. Since distance is a major contributor to the level of fare, however, an alternative approach is to vary the form of the fare variable to reflect an increasing, decreasing or constant elasticity over all fare levels (hence, over varying distances).

In our model, the square of the fare in natural units provided the best fit to the data. This specification exhibits increasing fare elasticities with higher fares. The characteristic is shared by linear demand curves and is consistent with results reported by DeVany (1974) and Verlager (1972). Since longer flights typically exhibit higher fares, the implication is that demand is more price-elastic on longer flights.

Flight frequency and load factors

The quality of air service may depend upon numerous factors, but writers have generally concentrated on the relevance of flight frequency. That is, there is a presumption that consumers attach benefit to the availability of a wider choice of flight times. Moreover, given demand and plane size, more flights generate lower load factors, which in turn generate higher probabilities of obtaining tickets for first-choice flights at or near departure times.

Douglas and Miller (1974) indexed this dimension of quality by

$$T = K_1 T_1 + K_2 d T_2$$

where T_1 is the average time between a passenger's desired time of departure and the nearest available scheduled flight, d is the probability that the typical passenger's first-choice flight will be booked when he calls, T_2 is the "wait" time to the next

available flight, and $K_1 = K_2$ is the average wage. But this measure is not useful for empirical work.²

DeVany (1975) measures quality of service by flight frequency. In so doing, he assumes that the wait times, T_1 and T_2 , are proportional to flight frequency. He does not, however, incorporate the probability of obtaining a seat on a first-choice flight, a service dimension that is presumably dependent upon the load factor.

To correct for this omission, we include flight frequency and load factor as quality of service variables. In particular, letting Q represent O&D demand and Y represent through demand, we specify that³

$$Q = A \exp(bF^2) N^\beta [(Q + Y)/S]^\alpha \quad \beta > 0, b < 0, \alpha < 0 \quad S = N\bar{S} \quad (1)$$

where N is flight frequency, $(Q + Y)/S$ is segment load factor, \bar{S} is average plane size, S is total segment seats flown and A depends upon a vector of other variables. Since Q appears on both sides of the equation and N is also a function of Q , equation (1) will be estimated below using two stage least squares; flight frequency and load factor are taken to be endogenous variables.

Following Douglas and Miller (1974), it is generally assumed that plane size can be taken as given with regard to any particular segment; therefore flight frequency is the carrier's control variable in the context of our problem. An exogenous increase in flight frequency acts to increase airline demand in two ways: directly, by increasing flight choice to consumers; and indirectly, by decreasing the load factor, thereby increasing the probability of obtaining seats on desired flights.

Recall that, in addition to O&D demand, "through" travellers also fly over the segments. In our sample, these individuals typically enplane at one end of the segment but continue on past the other end.⁴ While we do not attempt to explain their level of demand for air service, an assumption must be made concerning through passengers' sensitivity to changes in quality of service. In this regard, it is assumed that through demand is sensitive to seat availability on this segment in a similar way to O&D demand: that is,

$$(\partial Y/\partial N)/(\partial Q/\partial N) = Y/Q \quad (2)$$

Differentiating (1) with respect to N , converting to elasticity form, and using (2), it is easily verified that the elasticity of O&D demand with respect to flight frequency is

$$\chi = (\beta - \alpha)/(1 - \alpha) \quad (3)$$

Diminishing returns to increasing flight frequency is assured if

$$\chi < 1 \quad (4)$$

² T_1 cannot be computed in fact because the distribution of desired flight times is not observed. The derivation of T_2 requires large numbers of calculations using flight schedules, and d depends upon the type of distribution of passenger calls and requires measures of variance of these calls from day to day and week to week for each route. Moreover, there is no reason to believe either that K_1 is equal to K_2 or that the wage is an adequate measure of K_1 or K_2 .

³ DeVany also used enplaned passengers as the dependent variable instead of the traditional O&D variable. It is well known that the former specification tends to lead to inefficient parameter estimates.

⁴ Recall that in our sample, the vast majority (80% in all cases, and 90% in most cases) of through travellers enplane at either end of the segment.

SPECIFICATION OF SUPPLY

To derive the supply equation, it is assumed that carriers maximise profits on each segment separately. In our sample, the number of passengers travelling over a particular segment is approximately $Q + Y$.⁵ Representing the (constant) marginal cost of serving each passenger by C and the marginal cost per seat offering by M , also assumed constant, profits can be depicted by

$$\pi = (F - C)(Q + Y) - MS \quad (5)$$

where F is the segment fare. Differentiating (5) with respect to flight frequency, and recalling (2), seat offerings are determined:

$$S = (\chi/M)(F - C)(Q + Y) \quad (6)$$

Recall that "locals" are permitted some upward flexibility in setting fares relative to the CAB formula. But it will be shown below that this modification does not require the inclusion of a second supply equation. Assuming that C is second order small, the main characterisation of seat offerings is therefore represented by the following equation:

$$\log S = b_0 + \lambda \log(Q + Y) + \varepsilon \log F + \text{other}$$

where we expect $\lambda, \varepsilon > 0$

To illustrate the implications of locals' partial freedom to choose fare level also, we partially differentiate (5) with respect to fare and set the result equal to zero: the maximum profits fare satisfies

$$\frac{\partial \pi}{\partial F} = (Q + Y) + (F - C) \left(\frac{\partial Q}{\partial F} + \frac{\partial Y}{\partial F} \right) = 0 \quad (7)$$

Making the simplifying assumption that the segment price enters into demand for through passengers in the same way as that for O&D passengers,⁶ and recalling that, in our model, $Q: A \exp(bF^2)$, (7) becomes

$$F(F - C) = \frac{-1}{2b} \quad (8)$$

which is independent of output and hence level of flights. This characteristic of our model explains why a second "price" equation is not included in our estimation to account for locals' ability to depart from the CAB price formula. In short, whether or not price is limited by regulation, availability of seats is affected by fare level (see (6)) but not vice versa.

The other variables in the supply specification are now briefly described. From (6), it is apparent that the lower the cost of the flight, the more seats are expected to be offered. Notwithstanding that segment seat offerings may partly depend on cost factors that are not segment-specific, we can nevertheless attempt to adjust for

⁵ That is, the sample was chosen so that passengers enplaned composed virtually all passengers carried over a particular segment.

⁶ In particular, if $Y: \exp(bF^2)$.

differential costs across segments. For example, costs are presumed to be positively related to average ramp-to-ramp time on any given segment (see Keeler, 1972).

Moreover, it is assumed that the numbers of carrier gates and amount of runway space do not rise proportionately with airport traffic (so lengthy queues are generated at peak hours at larger airports). Hence, other things constant, we would expect that carriers would be less willing to offer seats in high density airports. Thus, a dummy variable was set equal to unity whenever at least one end of a flight segment recorded more than 100,000 departures per year.

The proportion of O&D to enplaned passengers is included to test whether O&D demand stimulated more response than "through" demand. Other independent variables included dummies to reflect identities of individual carriers. Also, a dummy variable was set equal to one when a carrier was "local" and zero if it was a "trunk". Trunks are carriers that existed when CAB regulation began. It is commonly assumed that the routes that they serve are more profitable. Another dummy variable was set equal to one to denote segments that are eligible for subsidy if "losses" (calculated by the CAB) are experienced.⁷

While segments in the samples were served directly by a single regulated carrier, two variables were included to measure effects of indirect airline competition. First, a dummy variable was set equal to one if unregulated "commuter" carriers offered any scheduled flights on the segment (as they did in nine instances in the sample⁸). Second, the number of total carrier departures (to any destination) at either airport in the segment was divided by total aircraft departures at either airport; the log of the highest proportion was included as an independent variable. As a carrier controls more flights from a particular airport, it faces less competition from other carriers in the form of circuitous flights to the same destination, or to alternative destinations where the choice of destination is endogenous.

RESULTS

The demand and supply equations were estimated by two stage least squares, and the results are presented in Tables 1 and 2. The estimated coefficients α and β in Table 1 are consistent with the notion that airline demand is positively related to number of flights and negatively related to load factor. The demand elasticity of flight frequency which incorporates the effects of flight choice and seat availability is significantly greater than zero at the 0.01 level.⁹ It is also less than unity, thereby satisfying (4), albeit insignificantly.

At the mean fare-distance in the sample (i.e., \$50 one-way in 1976, which corresponds to a trip length of 440 miles under the CAB fare-distance formula), the

⁷ Trunk carriers are not eligible for subsidy; local carriers (post-1938 entrants) are presumed to serve less profitable routes than trunks. Certain segments that satisfy particular criteria are eligible for subsidy. Operating losses experienced on these segments enter into a complex CAB subsidy formula.

⁸ A commuter carrier operates craft that have no greater capacity than 30 seats and are lighter than 7,500 pounds. Commuters were unregulated by the CAB.

⁹ The variance of $(\beta - \alpha)/(1 - \alpha)$ is $[1/(1 - \alpha)^2] V_{\beta - \alpha} + [(\beta - \alpha)^2/(1 - \alpha)^4] V_{1 - \alpha} - 2[(\beta - \alpha)/(1 - \alpha)^3] C_{\beta - \alpha, 1 - \alpha}$, where V_i is the variance of i and C_{ij} is the covariance between i and j . Using $V_{\beta - \alpha} = V_{\beta} + V_{\alpha} - 2C_{\beta\alpha}$ and $C_{\beta - \alpha, 1 - \alpha} = C_{\beta, 1 - \alpha} + C_{-\alpha, 1 - \alpha}$, V_x can be calculated from known parameters.

TABLE 1
TOLS Estimate of Airline Demand

<i>Variable</i>	<i>Coefficient</i>	<i>t-value</i>
Constant	-26.04	3.14
Flights ^a (β)	0.755	3.03
Load factor ^a (α)	-0.854	1.68
Elasticity of flight frequency (χ)	0.864	4.32
Fare ²	-0.105E-3	2.56
Fare elasticity ^b	-0.525	—
Distance ^a	0.733	2.35
Income ^a	2.35	2.71
Population ^a	0.336	5.05
100 miles or less	-2.09	4.17
100-200 miles	-0.258	0.99
Las Vegas	1.94	6.22
Florida	0.258	0.80
California	0.334	1.36

^a Variable is in log form. Dependent variable is log of O&D.

^b Evaluated at mean fare level in sample.

"Load factor" and "flights" were considered endogenous variables in this estimate. All other variables in this table and all independent variables listed in Table 2, except "enplaned", were considered exogenous variables.

TABLE 2
TOLS Estimate of Seat Supply

<i>Variable</i>	<i>Coefficient</i>	<i>t-value</i>
Constant	4.96	8.00
Enplaned ^a (λ)	0.803	21.20
Fare ^a (ϵ)	0.472	2.82
Ramp-to-ramp time ^a	-0.638	3.85
O&D ÷ enplaned ^a	-0.012	0.41
Carrier airport concentration ^a	-0.123	2.82
Commuter competition	0.078	0.79
Airport departures > 100,000	-0.118	1.70
Local carrier	-0.497	3.74
Subsidy eligible	0.088	1.44

^a Variable in logs. Dependent variable is log of seats.

"Enplaned" was considered an endogenous variable in this estimate. All other variables in this table and all variables in Table 1, except "load factors" and "flights", were considered exogenous variables.

price elasticity of demand is equal to -0.525 . But the specification allows variable price elasticity with distance; hence, using the same CAB formula, the results imply a price elasticity equal to unity for a trip distance equal to 830 miles. Brown and Watkins (1968) and Gronau (1970) impose constant elasticity restraints on their estimates and find elasticities in the vicinity -0.85 and -0.75 , respectively.¹⁰ DeVany (1974) allows for varying price elasticity over distance and finds an elasticity equal to -0.97 for a 440-mile trip and one equal to -1.13 for an 830-mile trip.

Turning to the supply estimates in Table 2, all the signs are as expected. The strong positive coefficient on passengers enplaned confirms the expected causation from demand to seats. The output and fare elasticities are significantly positive and are insignificantly different from each other at the 0.05 level. These results are consistent with (6) except that both coefficients are less than unity, which is not expected.

SUMMARY

Overall, the results reported in this paper are consistent with *a priori* expectations, particularly in terms of the apparent strong role played by quality of service variables in airline demand. The estimates can be utilised in theoretical studies, such as those mentioned at the beginning of this paper, which incorporate flight frequency as an important factor of demand. The results stem from a sample that is relatively small and carefully chosen to eliminate numerous potential theoretical and empirical problems. Further research might extend the analysis to broader markets. For example, it would be interesting to test the prediction of this model that the parameter estimates would not be affected by the consideration of competitive routes. In addition, since monopoly routes tend to be relatively small and short in distance, it would be useful to determine how significant these factors may be to our estimates. Further tests along these lines, however, may involve considerably more complex models and estimation techniques.

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¹⁰ The Brown and Watkins estimate pertains to trips shorter than 1,000 miles. The Gronau estimate does not exclude trips on the basis of length and pertains to business travel only. Gronau's estimated price elasticity for personal trips is -0.30 . His estimates are made for "full price" elasticities (where price includes fare and time costs); so, for comparability, his estimates have been adjusted to simple fare elasticities.

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