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Economics of Technological Change: A Joint Model for the Aircraft and Airline Industries

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The principal focus of this econometric model is on the process of technological change in the U.S. aircraft manufacturing and airline industries. The problem of predicting the rate of introduction of current technology aircraft into an airline's fleet during the period of research, development, and construction for new technology aircraft arises in planning aeronautical research investments. The approach in this model is a statistical one. It attempts to identify major factors that influence transport aircraft manufacturers and airlines, and to correlate them with the patterns of delivery of new aircraft to the domestic trunk carriers. The functional form of the model has been derived from several earlier econometric models on the economics of innovation, acquisition, and technological change.

Nomenclature

C_i = liquidity measure: debt-equity ratio of the ith airline at the time when the airline began to use aircraft type j

I = interest rate, long-term corporate bond rate as denoted by the Federal Reserve Board

P_{ij} = a smoothed estimate of the proportion of aircraft of type j in airline i's fleet

R_{Mj} = revenues of the manufacturer producing aircraft type j

T_{ij} = number of new aircraft of type j delivered to airline i at time t

ADV_i = annual advertising expenditures by airline i

AVCOST_i = average cost per available ton-mile for airline i

FRPMS = a three-year forecast of revenue passenger miles (RPMS) for airline i based upon previous five-year trend

LFA_i = annual load factor, revenue ton-miles/available ton-miles

RPMNS_i = nonscheduled revenue passenger miles for airline i

RPMS_i = annual revenue passenger miles for airline i

YLD_i = yield or average revenue, dollars per revenue passenger mile

$\hat{\pi}_i$ = estimated profitability of airline i, measured by cash flow

π_{Mj} = profitability of the manufacturer producing aircraft type j

Introduction: Behavioral Foundations of the Model

TRADITIONAL neoclassical microeconomic theory has been subjected in recent years to a steady and occasionally heavy stream of criticism in the economics literature. Among the more serious challenges to the neoclassical model are those relating to its treatment of the processes of technological change. While the elements of a more advanced theory were set forth four decades ago by Joseph Schumpeter[1] (who argued that, at the level of the individual firm, the crucial element was full recognition of the trial-and-error character of the innovation process), only scattered empirical work has been done to incorporate these considerations into formal models despite their apparent importance and prominent stature in the history of the discipline.[2,3] The approach in this paper is to illustrate a modified Schumpeterian model of technological change which can be applied to the aircraft manufacturing industry to explain its firms' behavior in adopting particular types of aircraft technology for the U.S. domestic trunk carriers and to generalize its applications.

At any given time, the behavior of an individual firm is postulated to be governed by its current decision rules, which link its actions to various environmental stimuli. While these rules may be both quite complex and sensible, they are not typically the result of a deliberate optimization (such as profit maximization) over some precisely defined set of alternatives. The objective functions of an individual firm (such as an aircraft manufacturer) may yield considerable variation of behavior in a changing environment.[4] The objective functions for airlines are probably multiple-attribute functions which may be subject to various forms of regulatory constraints. The fundamental difference between an analysis of airlines and the traditional neoclassical model is due not so much to a constant and known objective function such as profit maximization, but to the fact that the domestic trunk carriers are regulated by an independent regulatory commission. Therefore, the objective functions of an individual aircraft manufacturer may be approached from the viewpoint of the principles established by Cyert and March.[5] As an example, applying the concept of "satisficing" from the behavioral theory of the firm to the aircraft manufacturers would suggest a set of interrelated objective functions that predict a range of optimal points of production, whereas the strictly neoclassical postulate of profit maximization would yield only a single optimal output. (It should be noted that the Cyert-March type of model should not be confused with the disaggregate behaviorial demand models or choice models which have recently received substantial attention in the economics literature.)

Over a longer period of time, two types of dynamic mechanisms are assumed to be operative in the aircraft manufacturing industry. First, at the firm level, research and development policy changes may occur through the processes of deliberate problem solving, perhaps involving some imitation of the observed decisions and successes of other firms. Or, second, technological change may "just happen" as particular capabilities in the firm improve through "learning-by-doing," deteriorate through disuse, or are adapted to shifting input (labor or capital) characteristics.

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Our model will treat the economic growth of the aircraft manufacturing firm as an adaptive, and not as a maximizing, process. In contrast, the neoclassical theory assumes universal access to the same technology, that firms choose optimally and look to factor supply shifts for the explanation of productivity differences. To quote Ref. 3: "It is not a matter of different positions on the same isoquants; it is a matter of evolutionary change in the mix of firms of very different types."

The desirable feature in our model is its anticipated ability to explain the behavior of the aircraft manufacturers in adopting, developing, and promoting both the products and the timing of new aviation technology. What factors can be postulated to determine the rate of technological change in this industry? On a priori grounds, one would expect it to depend to a large extent on the amount of resources devoted by the airlines, the manufacturing firms, independent inventors, the military, and the federal government to the improvement of the industry's technology. The amount of resources devoted by the government depends on how closely this industry is related to national defense, on the extent of the economies external to the airline industry generated by the relevant research and development, and on more purely political factors. The amount of resources devoted by independent inventors and industry depends heavily on the profitability of their use and on internal industry political transactions. Comprehensive econometric studies[6,7] indicate that the total dollars a firm spends on research, technology, and development (R&D or R,T&D) is influenced by the expected profitability of the R&D projects under consideration, and that the probability of its accepting a particular R&D project depends on the project's expected returns. Case studies of particular inventions and studies of patent statistics seem to corroborate this view.[6,7]

In the aircraft industry, research into purely technological items (i.e., components of an aircraft such as the supercritical wing) needs to be separated from the "products" of technology (or the results of R&D that are produced and applied to existing aircraft). In the former case, many of the technology items are "placed on the shelf" and for one reason or another never find their way into application. However, some of these items are either transferred into aircraft production or represent "spinoffs" for other products of aircraft technology. In the latter case, visible output is produced by the manufacturers and represents the key dependent variable to be modeled and estimated here. For our modeling purpose, only those purely technological items which are converted (or can be immediately converted) into new or modified aircraft types were considered, especially on a year-to-year basis (the unit of temporal variation in our postulated behavioral model). Thus, the specification of the model should capture the underlying determinants behind the joint decision of the manufacturers to produce aircraft and of the airlines to purchase them during varying conditions of aircraft retirements, fleet expansion, and capital markets.[6-12]

Model Specification

One of the major issues faced by the aircraft manufacturers is how to determine the proclivity of individual airlines to purchase new equipment. The manufacturers must understand and estimate how rapidly the airlines are able to displace older aircraft and replace them with newer ones. This replacement process depends on two factors: 1) the rate of imitation, i.e., the rate at which the airline industry as a whole begins to use newer aircraft; and 2) the intrafirm rate of diffusion, i.e., the rate at which a particular airline, once it has begun to use a newer aircraft, proceeds to substitute it for older ones. Note that the intrafirm rate of diffusion does not measure the speed with which the airlines begin to use newer equipment, but only its activity after the type of equipment has been originally procured. Together the rates of imitation and intrafirm diffusion determine how rapidly economic productivity increases in response to the existence of the newer more productive aircraft. While our work has been primarily influenced by Mansfield's contributions,[6] more recent studies have helped us to narrow our focus.[7-12]

Our general model can be specified in three interrelated stages: first, a T equation which relates a technology variable (this is $T_{ij}(t)$, the cumulative number of new aircraft of a particular type delivered to an airline through time period t to a set of explanatory variables that reflect purely economic characteristics of that airline, the aircraft manufacturers' performance, and external factors; second, an equation which describes the time patterns in the stocks or inventories of existing aircraft types in the fleets of the airlines; and third, an equation which explains variations in the profitability or cash flow positions of the airlines who are the users of the new aircraft. The estimates of the second and third equations are postulated to become arguments (explanatory variables) in the first equation. The specific functional forms of the model equations are the following: for any airline i,

$$T_{ij}(t) = f(\hat{\pi}_i, \pi_{Mj}, R_{Mj}, \quad \text{FRPMS}, I, P_{ij}) \qquad (1)$$

where the independent variables are given for different time periods $t, t-1, t-2, \ldots$.

$$P_{ij}(t) = [1 + e^{-(\alpha_{ij} + \hat{M}_{ij} t)}]^{-1} \qquad (2)$$

where M_{ij} is a technology diffusion coefficient (the slope of the resulting linear relationship) and where α_{ij} is the intercept. Equation (2) is simply a logistic function relation $P_{ij}(t)$ to time. For example, taking natural logarithms of both sides of Eq. (2) yields

$$\ln\left[\frac{P_{ij}(t)}{1 - P_{ij}(t)}\right] = \alpha_{ij} + M_{ij} t$$

Empirically, it is an easy matter to regress the left-hand side of this equation against t to generate an estimated M_{ij}. This equation was not used only to derive an estimate of the P variable -- the proportion of aircraft of a given type that could appear in a given airline's fleet at any point in time.

Finally,

$$\hat{\pi}_i(t) = g[\text{YLD}_i(t), \text{AVCOST}_i(t), C_i(t), \text{LFA}_i(t), \text{RPMS}_i(t), \text{RPMNS}_i(t)] \qquad (3)$$

In our system of three equations, the variables P and π are estimated sequentially and their values inserted as arguments in the technology equation, $T_{ij}(t)$ [Eq. (1)].

The process by which new aircraft are ordered by airlines and produced and delivered by the aircraft manufacturers has been fascinating to observe and analyze. The methods (some observers might say game-theoretic devices) used by the participants in the process are intricate and frequently subtle. A single error in ordering equipment can cost a manufacturer or an airline millions of dollars. Thus, the success or failure of a new aircraft order depends on a careful calculation and assessment by all participants of each airline's requirements, profitability, and anticipated traffic, as well as a variety of external macroeconomic factors. The first portion of the model reflects these latter factors as they influence the distribution of aircraft deliveries by the manufacturers to the airlines (the T equation). The model's second portion is designed to explain the timing and diffusion of aircraft types within each airline's fleet (the P_{ij} equation). Finally, the model's third equation is intended to explain each airline's ability to pay for the aircraft, especially in relation to its cash flow position.

The theory behind the aircraft technology (T) equation in the context of the expected signs of the regression coefficient, a priori, is the following:

π_M = expected sign *positive,* with lags. Since the dependent variable represents delivered aircraft and since airline payments for new aircraft represent on average 67% of the delivered cost in the period in which the delivery occurs (5% down payment on order date, escalating to 33% by delivery date, the remaining 67% on delivery), it is expected that increases in the manufacturer's profit position will induce an increase in the ordering of that manufacturer's aircraft by a given airline.

R_M = expected sign *positive,* with lags. In order for revenues of the manufacturers to have increased in the past, aircraft sales would have to be providing a foundation and therefore a proclivity toward an increased market share for the range of aircraft in which type *j* aircraft competes. Thus, increased revenues implies a marketing advantage for the manufacturer of type *j* aircraft, thereby suggesting even larger sales.

FRPMS = expected sign *positive,* with forward lags. On the order date of aircraft type *j*, a value of the expected rate of growth in the industry is generated for the next three years to coincide with the average delivery date: the higher the expected growth rate, the greater the deliveries.

I = expected sign *negative.* The higher the interest rate, the more cumbersome is the financing package (and the greater the incentive for alternative uses of funds); therefore fewer deliveries will take place.

Initial regression runs were conducted on the *T* model, even though some data on the *T* variable were not yet available. Early results suggested that the profitability and growth variables possess good explanatory power for B-707, DC-8, B-727, DC-9, and B-737 aircraft deliveries. These aircraft types were the only ones on which experiments were conducted because the time series data for the wide-bodied aircraft are not sufficiently long.

Essentially, the aircraft replacement model [Eq. (2)] is an attempt to describe the process by which airlines decide to purchase new aircraft and the timing of aircraft deliveries from its manufacturer. This equation represents a "stock" or inventory item that is inserted into the *T* equation as an argument. The basic thrust of the equation is an estimate of the relationship between the proportion of aircraft of type *j* in the *i*th airline's fleet at different points in time. The remainder of "unfilled slots" for potential deliveries of aircraft type *j* to airline *i* in the future represents the potential demand for that aircraft type from airline *i*.

Aircraft were grouped into three basic types by range, number of engines, and the kind of routes they could serve: Boeing 727-100 and 727-200 series, Boeing 707 and Douglas DC-8 aircraft, and Douglas DC-9 and Boeing 737-100/200 series aircraft. (The Boeing 720 was omitted from all groups on the basis of its unique characteristics with regard to performance, number of engines, and range—and its general deletion from existing fleets.) Historical data on fleet size of aircraft type *j* at year-end were collected for each U.S. airline from the date of first delivery to the end of 1975 inclusive.

For the proportion variable, the value predicted for each year from the equation

$$P_{ij} = [1 + e^{-(\alpha_{ij} + \hat{M}_{ij} t)}]^{-1}$$

was introduced as an explanatory variable in the *T* model. A two-year lag was applied to the proportion P_{ij} such that an aircraft delivery in year *t* was generally associated with the predicted proportion of the aircraft in the airline's fleet in year $(t-2)$. The two-year average lag time between order dates and delivery dates was further supported by the empirical evidence from B-727 deliveries which suggest an average lag in 1963-1976 of 2.3 years for all the domestic trunk carriers. In one particular case a four-year lag was more appropriate.

The profitability of the manufacturer producing aircraft type *j* was considered as a model variable. Pretax operating profit was taken from the Boeing Airplane Company and McDonnell Douglas Corporation annual income statements. These companies have extensive manufacturing activities in military and aerospace markets outside of the production of any particular aircraft. Various lags were tried, although usually a two-year lag provided the best statistical results.

Airline profitability was defined as annual operating profit *before* deduction of depreciation allowances. In strictly accounting terms, this figure could be considered to be more a measure of cash flow than profitability but it is regarded in the empirical sense as the major variable on which airlines base their aircraft ordering decisions.

The profitability of an airline (not only two years, but also three and four years prior to delivery) was hypothesized to be appropriate in explaining acquisitions of new aircraft. The problem then arose of how to distribute the lagged values of profitability to make the variable most powerful in the *T* model.[13] Distributed lags were used in Elliott's analysis of corporate financial performance. In one of his equations, he used a three-year Almon-weighted average of money supply and high-employment government expenditures, with a second-degree polynomial constraint. Almon-weights, however, can be computed only for equations where all explanatory variables are to be lagged. Elliott sidestepped this problem by computing his weights on macroeconomic data before inserting them into his equations. Unfortunately, no studies have been done on the lagged relationship between profitability and acquisition of major assets in other industries which might be applicable to our aircraft production potential model. As a "next best" approach two types of fixed weighting were tested:

Equal weights: $$\frac{1}{3}\left[\hat{\pi}_{t-2} + \hat{\pi}_{t-3} + \hat{\pi}_{t-4}\right]$$

Declining weights: $0.5\hat{\pi}_{t-2} + 0.3\hat{\pi}_{t-3} + \hat{\pi}_{t-4}$

However, the results of testing the model with these weighting schemes showed that the method of weighting was not very critical to the significance of the profitability variable in the equation. Thus, we were able to use exogenously selected lags in each airline equation with increased confidence.

The acquisition of new aircraft must be based to some extent on previous traffic forecasts conducted by the airlines. Individual airline forecasts could differ from the overall industry forecasts due to a greater optimism by airline forecasters and the individual airline's route plans, although expansion in the latter is affected by CAB policies. Therefore, the traffic growth variable should ideally be the estimate of traffic growth actually made by the airline two or three years prior to delivery of the new aircraft. (It has been assumed in this study that airlines had projected their traffic growth by a simple extrapolation of their growth in the previous five years. While this approach may seem rather simplistic in light of present-day techniques, for the period under consideration it is a good approximation. It also places relatively high weight on more recent events, a factor which might be considered appropriate to management decisions at the time of ordering aircraft.)

If any new aircraft were delivered in period *t*, projections of traffic growth have been estimated at period $(t-3)$ on the basis of the previous five-year trend. This average annual growth rate has then been applied to the actual number of revenue passenger miles at $(t-3)$ to arrive at the forecast number of RPMS for year *t*. This variable was given the abbreviation FRPMS. The same forecast number of RPMS was also applied to deliveries in period $(t+1)$ to produce another variable FRPMS 1 which was tried as an alternative explanatory variable.

The average annual level of yields on corporate bonds (Moody's Aaa rating) was used as a proxy I for the general economic climate at the time the decision to acquire the aircraft was made. As with the other explanatory variables, a two-year lag was considered to be best from both behavioral and expectational points of view. Other proxy variables for macroeconomic activity were tested such as money supply and real GNP. In addition, other indicators of the aircraft manufacturers were considered such as total revenues and current assets. Since our early results, however, confirmed the highly interactive nature of some of these variables, these were eliminated as arguments in the equations during subsequent computer runs. An existing model which uses some of these variables (e.g., money supply) is given in Ref. 14.

Model Structure and Evaluation Techniques

The majority of the evaluation was performed on models which were linear in both parameters and variables of the type:

$$Y_i = \beta_0 + B_1 X_{i1} + \beta_2 X_{i2}, \ldots, + \beta_n X_{in} + \epsilon_i$$

Since the specified model is recursive in nature, each equation was individually calibrated using the ordinary least-squares technique. In order to find the minimum number of explanatory variables which maximizes the accuracy in prediction as well as providing the best behavioral analysis of the relationship, the Mallows C_p criterion[15] was chosen. Of the normal ordinary least-squares assumptions, multicollinearity was the only one of any concern; an adjustment was made to handle this problem through the use of principal components.

Empirical Results

Boeing 727-100/200 Equations

Models were calibrated for the Boeing 727s in all U.S. domestic trunk airlines except one. Since Delta Airlines acquired its B-727 aircraft in 1972 as a result of their merger with Northeast, they did not receive delivery of the aircraft based on the same stimuli as the other trunk lines. For the remaining trunk carriers, the initial B-727 deliveries occurred in 1963 for United, followed by American, Eastern, National, Northwest, and TWA in 1964.

Both the proportion and profitability variables appear in all the equations in Table 1 with high t ratios. Priority was given to developing a model where the effect of changes in explanatory variables both individually and jointly on the response variable could be estimated with a high degree of confidence.

The entries of Table 1 should be read across the rows for each airline. For example, in the case of American Airlines (AA), the significant variables are $P4$ and $\pi 2$ or a four-year lagged proportion variable and a two-year lagged profitability variable, respectively. This model suggests that a unit change in the proportion of B-727 aircraft in American's fleet four years ago produced a 1.21 increase in the number of B-727 aircraft needed in its fleet now, ceteris paribus. Also, a unit increase in American's profitability $\pi 2$ two years ago will be associated with a 0.044 unit increase in the number of B-727s in its fleet now, ceteris paribus. The complete equation for American Airlines suggests that 98% of the variation in the introduction and diffusion of B-727s throughout American's fleet can be explained by changes in the lagged proportion and profitability variables over the relevant time period.

Each of the airline's equations can be interpreted in a similar fashion by reading across the rows of Table 1. Note that some airlines' equations contain more statistically

Table 1 Summary of B-727 regression coefficients

Airline	Variables	P_{ij}, proportion (lagged 2 or 4 periods)	π_M, profitability of manufacturer (lagged 2 periods)	π_i, profitability by airline (lagged 2 periods)	FRPMS, traffic projection by airline i	I, interest rates (lagged 2 or 3 periods)	Computed F	$\bar{R}^2$	n
AA	Coefficient	1.210[4a]	–	0.044	–	–	219.5	0.98	12
	t ratio	7.23		6.62					
	Intervals[b]	±0.373		0.015					
BN[c]	Coefficient	0.046[2]	–	0.020	–	0.026[2]	35.2	0.94	10
	t ratio	6.50		28.6		4.63			
	Intervals	±0.022		±0.02		±0.018			
CO[c]	Coefficient	0.016[2]	–	0.016	0.002	–	39.4	0.95	9
	t ratio	1.36		3.40	2.69				
	Intervals	±0.040		±0.016	±0.003				
EA[c]	Coefficient	0.057[2]	–	0.048	0.002	–	21.0	0.89	12
	t ratio	2.13		3.22	3.62				
	Intervals	±0.077		±0.043	±0.002				
NA	Coefficient	0.38[2]	0.005[2]	0.016	–	–	33.0	0.90	12
	t ratio	5.27	1.68	1.43					
	Intervals	±0.021	±0.009	±0.032					
NW	Coefficient	0.050[2]	0.004[2]	0.020	–	0.040[3]	60.8	0.96	12
	t ratio	2.43	1.11	4.36		1.75			
	Intervals	±0.062	±0.011	±0.014		±0.069			
TW	Coefficient	0.205[4]	–	0.011	–	–	72.9	0.93	12
	t ratio	10.14		1.57					
	Intervals	±0.045		±0.016					
UA[c]	Coefficient	0.068[2]	–	0.088	0.001	−0.095[2]	16.4	0.89	13
	t ratio	4.32		6.42	1.79	−2.76			
	Intervals	±0.044		±0.039	±0.002	±0.097			
WA	Coefficient	0.040[2]	–	0.014	0.003	–	61.0	0.97	7
	t ratio	2.04		1.63	5.17				
	Intervals	±0.089		±0.039	±0.003				

[a]2,3,4 = number of years lag prior to aircraft delivery (appearing as exponent references). [b]Bonnferoni joint confidence interval, $\pm t(1-\alpha/2p, n-p)S(b)$, where $\alpha = 10\%$. [c]Indicates that principal component analysis was used.

significant variables than others, but in every case estimates of the proportion and profitability variables (with appropriate lags) appear in the main T equation.

The model results have been tabulated for the U.S. domestic trunk lines as a whole (Table 2) and for individual airlines (Table 3). The results in Table 2 are merely the sums of the individual airline's forecasts generated from the equations in Table 3. For each trunk carrier (excluding Delta) separate equations were estimated, with each time series beginning during the year of each carrier's first deliveries of B-727s. Table 3 presents simply the differences between the fitted (predicted) and the actual (observed) data for the best equation calibrated on the historical time series of each carrier.

Two effects tend to suggest that model predictions might not track actual data on a year-by-year basis. First, the timing of deliveries depends very much on the manufacturer's rate of production, excess capacity, and international orders. The assumption of an approximately two-year lead time between airline decision and delivery is a rough average over the period and will clearly depend on whether an order was made, say, in 1964 or in 1973.

Second, the trend of actual fleet sizes will follow a stepwise path, whereas the model variables will suggest a more continuous time path. For example, a drop in profitability and slowdown in traffic growth in one year can be accommodated by using the existing fleet less intensively, rather than selling or leasing some of the fleet to other carriers and reacquiring them again when traffic picks up, which could be a costly way of matching capacity to traffic.

Table 2 Model results, observed vs predicted, for Boeing 727, total U.S. trunks lines

Year	Col. 1 observed	Col. 2 predicted	Predicted/ observed
1963	4	6	1.50
1964	94	108	1.15
1965	156	131	0.84
1966	248	226	0.91
1967	362	315	0.87
1968	455	425	0.93
1969	545	527	0.97
1970	568	542	0.95
1971	585	623	1.06
1972	609	640	1.05
1973	638	645	1.01
1974	651	635	0.98
1975	674	687	1.02

American (AA)

Early year predictions are out of line for the reasons given above, while more recent results are good. The model predicts a rise in fleet size to 105 aircraft in 1971 due to good profitability two years previously, and perhaps a faster rate of BAC-111 retirements estimated from the proportion model.

Braniff (BN)

Results are reasonably good with a noticeable divergence between observed and predicted aircraft in 1973. Actual additions in that year totalled 13 aircraft compared with 3 predicted by the model. One possible explanation is the fleet standardization policy which this airline adopted around that time and which would override any natural growth in economic, traffic, or profitability parameters.

Continental (CO)

Relative latecomers to the Boeing 727 operation, Continental's fleet size has increased steadily since 1970. The model predictions follow closely the observed pattern.

Eastern (EA)

The model predicts a slower rate of introduction of these aircraft up to 1969. Over this period, the airline was also acquiring Douglas DC-9s which may be considered interchangeable with the B-727s on some of Eastern's routes. Thus, it is possible that the DC-9 model would overstate the rate of introduction of those aircraft. As in the case of American, the model predicted a relatively large increase in new aircraft in 1971 which did not occur.

National (NA)

The fleet size for National increased to 38 aircraft in 1967 and has remained unchanged since then. Since 1967, traffic expansion on National's routes has been taken up by an increasing load factor, aircraft utilization, and the acquisition of Douglas DC-8s and later DC-10-10s. The model has to some extent taken these effects into account, mostly through the proportion variable.

Northwest (NW)

The model predictions have closely followed actual fleet size, especially in recent years. Six new deliveries were, however, predicted for 1971, when none actually occurred.

TWA (TW)

The model forecasts additions to the TWA fleet in every year, whereas in three of the years no new aircraft were acquired. The rate of new deliveries was higher than predicted in earlier years and lower in the years since 1971.

Table 3 Model results: observed vs predicted aircraft in fleet for Boeing 727, individual airlines

	American		Braniff		Continental		Eastern		National		Northwest		TWA		United		Western	
Year	Obs	Pred	Obs	Pred	Obs	Pred	Obs	Pred	Obs	Pred	Obs	Pred	Obs	Pred	Obs	Pred	Obs	Pred
1963	–	–	–	–	–	–	–	–	–	–	–	–	–	–	4	6	–	–
1964	18	28	–	–	–	–	25	18	7	10	3	6	16	18	25	28	–	–
1965	19	30	–	–	–	–	42	17	10	10	14	7	21	19	50	48	–	–
1966	41	34	12	14	–	–	53	37	13	14	24	28	22	25	83	74	–	–
1967	47	44	24	15	5	7	67	56	38	30	32	35	29	28	120	100	–	–
1968	80	76	27	28	13	9	75	69	38	34	36	43	44	56	142	110	–	–
1969	98	94	33	34	13	15	86	84	38	39	54	50	67	59	150	147	6	5
1970	98	100	39	42	13	14	101	96	38	41	56	52	67	61	150	129	6	7
1971	98	105	44	48	19	18	101	106	38	36	56	58	72	66	150	179	7	7
1972	100	101	50	56	22	24	109	114	38	38	56	56	72	68	150	141	12	12
1973	100	99	63	59	29	29	118	123	38	36	56	57	72	72	150	158	12	12
1974	101	101	67	63	33	33	114	116	38	37	55	52	74	78	151	138	18	17
1975	107	105	69	68	36	34	113	112	38	44	63	62	77	83	150	158	21	21

United (UA)

As the largest operator of this type of aircraft, United's fleet has a large weight in the aggregate fleet size. United was the first to take delivery of this aircraft in 1963, and reached their present fleet size in 1969. The model results for United were not good, with actual United deliveries very much higher than predicted in the years 1966-1968 and lower than predicted in 1971-1972. The main reason for this imbalance is found in a paper giving the story of the United airlines $750 million order of new aircraft made in April 1965[16]:

> "To offset the delay in getting the small jet (Boeing 737), the Boeing Company was quite willing to deliver more B-727s in 1966 and 1967 so that United could offer the same quantity of jet service as if it had purchased DC-9s (with no delay). But this would have meant operating a more expensive airplane for a year and possibly ending up with more 727s than were needed."

Western (WA)

The model results track very closely the actual deliveries from the time of introduction in 1969.

Boeing 707/Douglas DC-8 Equations

Models were calibrated for six U.S. trunk airlines having the Boeing 707 (all variants, but excluding the 720) and the Douglas DC-8 (all variants). Of the other four airlines, Continental retired their last Boeing 707 in 1973 and operated no DC-8s such that the aircraft group had no forecasting relevance. Since Western Airlines operated only B-707s for the past five years and their fleet was only five aircraft, the ordinary least-squares technique was not considered appropriate. Braniff operated both aircraft types, posing some problems in aggregation, in particular for the manufacturer's profitability. The results for Eastern, although reasonable statistically, did not include profitability as a significant explanatory variable. Aircraft deliveries could, however, be explained in terms of the proportion variable with a four-year lag, manufacturer's profitability with a two-year lag, and corporate bond yields with a three-period lag. The Northwest model also suggested variables other than those chosen as being more powerfully associated with aircraft deliveries. The proportion variable was particularly weak for two-, three-, and four-year lags, and may have been influenced by a rapid reduction in fleet size from 30 aircraft in 1972 to only 8 in 1975.

For United, a regression equation incorporating the proportion and traffic growth variables explained 78% of the variation in aircraft deliveries. As with Eastern, profitability was not significant.

The model results for the narrow-bodied, long-haul aircraft were generally inferior to those for the Boeing 727. The American and TWA models gave predictions which followed closely actual aircraft fleet size. The TWA model predicted a reduction in fleet size in 1971 of 16 aircraft which did not occur (the airline acquired two more), while the American model forecast a decline in these aircraft starting in 1972-1973 when in fact it took place a year later.

Extension and Applications of the Model

The model to date has been calibrated on time series data for those generic aircraft types that satisfy two criteria: 1) that the aircraft is still a prominent part of the trunk carrier's fleets, and 2) that the time series data be of sufficiently long duration to meet the inherent statistical and econometric requirements. In the above analysis, the following aircraft types would have met these criteria: B-727, DC-8, DC-9, and B-737.

Since the B-727 series aircraft is the overwhelmingly dominant airliner in the domestic fleet at the present time, it is very useful that our model did capture its ordering and delivery process. This aircraft is also expected to increase in popularity in the future, especially in its larger capacity 200 series. On the other hand, the DC-8 and B-707 aircraft have been experiencing declining usage within the commercial fleets, having been relegated to supplemental carriers or sold to foreign purchasers. Although the twin-engine commercial aircraft types (DC-9 and B-737) are expected to hold their own over the next decade, the duration of the annual time series data is insufficient for use in econometric tests of significance. These comments, of course, will be altered by any new derivative aircraft being introduced commerically or by any substantial entry to the American markets by foreign airframe manufacturers (such as the A-300).

What about the wide-bodied aircraft? Here in the case of the DC-10, L-1011, and B-747 aircraft, existing time series also is not sufficiently long to meet criterion 2 above. Even so, we were tempted to determine if any relationships existed using the current data series and concluded that the results were promising, despite the inability to make any statistical inferences. This area clearly offers exciting opportunities for the application of this integrated model during the next two or three years. Then the model could be used to forecast the total trunk carriers' fleets and to improve upon and supplement existing (largely judgmental) forecasts such as those provided in Table 4.

A final cautionary note pertains to the statistical importance of the length of the time series for each airline, regardless of the type of aircraft being analyzed. Even in the case of the B-727s, the degrees of freedom for each airline bordered on the sparse side—thus the results should be interpreted with the usual caveats. However, as time passes, longer time series should provide better opportunities to assess the qualitative virtues of the postulated equations as well as confirmations of reliability, robustness, and efficiency in the forecasting process. At this stage, we are more interested in whether the model is appropriately suggestive rather than statistically exhaustive.

Applications for Forecasting

While many applications of the model can be performed in its use as a forecasting tool, this section discusses briefly three cases. We have selected B-727 aircraft (because of its intrinsic importance) as the generic type to be forecast for three different trunk carriers: American, United, and Western. The target year is 1985.

The forecast results are displayed in Table 5. In the upper third of the table are the results for American Airlines. Here the significant variables are the proportion variable, lagged four periods, and the profitability variable, lagged two periods. In our narrative discussion above, Eq. (2) was a model developed to forecast the proportion of B-727 aircraft in each airline's fleet, while Eq. (3) was a model designed to forecast individual airline's profitability (cash flow). In Table 5, the actual data are displayed for 1975. In addition, since our time series terminated with 1975 data, we present a "forecast" for 1976 and show the comparison between the 1976 forecast and the 1976 actual numbers for the T variable, the number of B-727 in each airline's fleet. Finally, in the right-hand column are the forecast numbers for 1985.

American

The model forecasts 110 B-727 aircraft in American's fleet, a deviation of 4% from its actual 115 at year end. For 1985, however, assuming that the proportion of B-727s in its fleet in 1981 is 0.60 (the four-year lag in $P4$), and assuming that the airline's profitability in 1983 is $184.7 million (the two-year lag embodied in $\pi 2$), the model forecasts a mean value of 158 B-727 aircraft required for American's fleet in that year. If there were a ±20% shift in American's profitability (20% being selected arbitrarily in our forecast scenario) in 1983, then its 1985 forecasts for B-727 aircraft would be 175 and 142 aircraft, respectively. Any other perturbations to the explanatory variable would be handled accordingly.

Table 4 Fleet additions to meet 1976-85 total ASM requirements: an existing forecast (from Ref. 17)

Type	12/31/75 Operating fleet	1975-85 Changes Retirements	Additions	12/31/85 Operating fleet
747	95	6	58	147
DC-10	121	–	161	282
L-1011	78	–	88	166
707-300B/C	179	141	–	38
707-100B	89	87	–	2
707-300	10	10	–	–
720B	23	23	–	–
DC-8-61/62	59	32	–	27
DC-8-20/50	85	85	–	–
727-200	379	–	239[a]	618[a]
727-100	380	257	–	123
DC-9-30/50	134	–	30	164
DC-9-10	27	27	–	–
737	84	–	–	84
L-188	15	15	–	–
Model X[b]	–	–	155	155
Total	1758	683	731	1806

[a] Includes possible new generation aircraft in the 140 passenger size category. [b] New generation aircraft assumed to be in the 185-200 passenger size category.

Table 5 Selected model forecasts of B-727 aircraft in three airlines

Airline	Variable	Actual 1975	Forecast 1976	Forecast 1985
American	$P4$	38.5	42.6	60.0
	$\pi 2$[a]	1219.2	1231.2	1846.8
	T (number of B-727s in fleet)	107	110	175, high 158, middle 142, low
United	$P2$	51.3	56.5	60.0
	FRPMS[b]	22570	30393	60786
	$\pi 2$[a]	1904.8	2286.7	3355.1
	I^2	7.8	9.0	9.0
	T (number of B-727s in fleet)	150	185	404, high 329, middle 254, low
Western	$P4$	11.3	14.6	30.0
	$\pi 2$[a]	576.7	609.3	914.0
	FRPMS[b]	9001	8094	16188
	T (number of B-727s in fleet)	21	19	61, high 48, middle 36, low

[a] $\$ \times 10^5$. [b] Million RPMS.

United

The 1976 forecast of B-727 aircraft is 185, off considerably from the airline's actual number of 150. However, United did have two orders in mid-1979 for a total of 46 B-727-200 aircraft, for delivery completion at the end of 1979.

Since the model results were presented earlier in 1979 to several airlines' representatives, including those of United, it appears likely that United hesitated in making its ordering decision in 1975 and 1976 due to the adverse economic conditions prevailing at the time. By the end of 1979, it is probable that the model forecasts and the actual number of B-727 aircraft in United's fleet will coincide. For 1985, United's fleet is forecast at 329 B-727 aircraft, utilizing forecasts of the four variables in United's T equation: proportion, growth, profitability, and interest rate levels. As is the case with each airline's model, the forecasts of the proportion variable and the profitability variable are calculated internally, whereas the forecasts of all microeconomic variables are made exogenously.

Western

In Western's fleet, our model predicts 19 B-727 aircraft for 1976 (compared with 21 actual). In addition, under the same ground rules pertaining to the assumptions and forecasts of the other airlines' models, the 1985 forecast for Western's B-727 aircraft is 48, with a high of 61 and a low of 36, depending on the sensitivity of its profitability in 1983.

One interesting feature of this model is that a wide range of forecasting scenarios can be portrayed for any future year, assuming that forecasts for the exogenous variables (all those except the proportion, profitability, and growth variables) can be made. Since the airline decision with respect to aircraft acquisition does depend on both internal and external economic and technological factors, this model does manage to capture in the aggregate the relative importance of these factors.

Implications and Conclusions

Understanding various aspects of the aircraft ordering decision process has been undertaken in the past almost entirely on the basis of simplistic forecasts which relied to a large extent on judgmental factors. Now that the aircraft manufacturer and airline industries have reached a stage of maturity in their respective developments, the need to use more advanced analytical tools as a guide to economic forecasting becomes all the more compelling. In this paper, we show an analytical model which offers some promise in forecasting the distribution of aircraft among the nation's airline fleets. While the forecast of a specific airline's fleet for a given year in the future obviously contains a certain amount of unknown factors, the model does provide a mechanism and foundation on which forecasts can be made, even though possible future disturbances cannot be captured precisely.

The model of manufacturer's aircraft production and airline purchase potential presented in this paper represents a unique endeavor to portray some important factors which influence both the airlines and the aircraft manufacturers in the joint decision of purchasing and selling new aircraft. The model results can also be interpreted as contributive factors to the supply (cost) side of airline markets in which air passenger demand is influenced by the types of aircraft technology available. Also, while the findings of the model have reflected current and historical patterns of the airlines and the manufacturers, it is expected that the model could provide useful information on the impacts of incrementally new aircraft technology on airline demand variables. It is also possible that modifications of our model to major industries which experience technological change in patterns similar to the airline/aircraft industrial configuration should fortify the inherent value of the overall model.

Together with previous results, the model suggests that there exist important economic and technological analogs to the classic psychological laws that relate reaction time to the intensity of the stimulus. Profitability opportunities act as stimuli, from which the intensity of the airlines' speed of response seems to be governed quite closely. With respect to the diffusion process of new aircraft technology, our model also suggests both how rapidly the airlines begin to use new aircraft technology (subject to manufacturer production constraints) and how rapidly the airlines substitute newer aircraft technology for older equipment. In addition, the model depicts the economic conditions under which the purchases of newer aircraft by the airlines have been historically worthwhile and profitable endeavors. To this end, while the uses of the model for forecasting purposes may not provide definitive solutions at this time, it is anticipated that future applications and refinements to this model will substantiate the most appropriate directions and likely impacts of future developments in new aircraft technology.

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