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THE ALLOCATION OF AIRCRAFT BETWEEN MARKETS UNDER REGULATION AND DEREGULATION

By

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ABSTRACT

THE ALLOCATION OF AIRCRAFT BETWEEN MARKETS UNDER REGULATION AND DEREGULATION

By

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The work of Douglas and Miller prior to deregulation suggested that competition in flight frequency led the airlines to acquire larger stocks of aircraft, and particularly smaller aircraft, than were necessary in a deregulated environment. Stocks of aircraft acquired when regulation held fares above minimum levels of average cost were too large, since frequent flights require more aircraft. In addition, airline fleets contained too many smaller aircraft because the economies of aircraft size were not realized under regulation.

The relationship between airline route structures and the fleets of aircraft possessed by airlines both before and after regulation is investigated here. The chief

theoretical assertation of this dissertation is that airline behavior since deregulation is best understood in terms of the unique characteristics of aircraft as capital goods. It is asserted here that the major consequence of regulation of the airlines was they were not able to adopt efficient route structures, i.e. hubbing-and-spoking. (Hubbing-and-spoking is a method of increasing flight frequency which is treated as a problem of joint production.) Airline stocks of aircraft chosen to maximize profits under regulation were efficient in a deregulated environment since flight frequency remains a competitive variable.

Several distinct strands of evidence are brought to bear on this question. First, analysis of route level data shows that the pattern of aircraft allocation subsequent to deregulation did not vary in a manner consistent with prederegulation prediction. Regression analysis is also performed using gross fleet composition data and route structure variables. These regressions indicate that, although the relationship between the numbers of aircraft in airline fleets and route structure variables changed with deregulation, the relative shares of each type of aircraft in relation to route structure was unchanged. The evidence is thus consistent with the hypothesis advanced in this dissertation.

DEDICATED TO THE MEMORY OF

HOWARD GRAHAM BROWN (1907-1987)

HUSBAND, FATHER, GRANDFATHER, BUILDER

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Any modern work of scholarship is in reality a collaboration. Most of the contributors are acknowledged in the bibliography. However, two groups deserve special recognition.

The first of these is the members of my guidance committee who, individually and collectively, have provided the assistance and constructive criticism necessary to transform a vague notion into an acceptable work of scholarship. As is usual, they cannot be held responsible for the shortcomings of this work.

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INTRODUCTION

The process of deregulation of domestic air transport in the United States has attracted considerable attention. There are several reasons for this. First, the domestic air transport industry in the United States, as in most countries, was "born regulated"; government policy has determined the structure and conduct of the industry from its very beginnings. Thus, the adjustments which the industry experiences as it moves towards a more competitive structure will indicate what the resource misallocation costs of regulatory intervention were. A second reason is that the deregulatory process is among the most advanced of the attempts at deregulation in this country in the past decade. In addition, the airline industry has been proposed as an industry closely fulfilling the requirements of contestability (Baumol and Bailey 1984).

Although a great deal of attention has been paid to the process of deregulation, most of the literature has analyzed the effects of deregulation on the product markets. Thus, pricing policy, route structure, and quality of service effects of deregulation have been analyzed intensively. Likewise, the effects on the labor force of the various carriers have been examined. However, little or no attention has been given to the changes which deregulation has or is likely to bring about in the airlines' usage of aircraft types. This dissertation begins by analyzing the manner in which airlines can be expected to adjust their deployment of aircraft in deregulated markets. Previous treatments of the effects of airline regulation have not yielded accurate predictions about the nature of airline responses to deregulation.

It is demonstrated below that this failure is the result of three flaws in previous treatments of airline industry behavior. The first flaw is that aircraft have been treated as homogeneous units of capacity. However, aircraft provide capacity which varies in quality from the point of view of both consumers and airlines. Second, it has been assumed that airlines would not vary their route structures after deregulation. In fact, previous treatments viewed routes in isolation rather than treating an airlines' route structure as a form of joint product. In addition, they have uniformly assumed that airlines will only charge a single fare to their customers, or at least only charge differential fares to the extent that such fares can be justified by differences in service class. As demonstrated below, airlines have utilized a unique form of price discrimination as a part of their response to deregulation.

This dissertation consists of five chapters. The first defines the problem. The second chapter is a literature review discussing in detail the relevant theoretical and empirical results which have been produced about the effects of airline deregulation on the deployment of capital equipment (i.e. aircraft). The third chapter outlines the model which is used to analyze these effects. The fourth chapter is devoted to empirical tests of this model. The fifth chapter summarizes the findings of this dissertation, analyzes the welfare effects of airline deregulation, and suggests some possible extensions of the theoretical and empirical work discussed herein.

CHAPTER I

THE STRUCTURE OF THE PROBLEM

The airline industry exists to provide transportation services to consumers and businesses. These services can take the form of passenger or freight transportation, separately or jointly provided. Firms provide these services by combining labor, materials, and capital. Airline capital is largely embodied in the form of vehicles, the aircraft. These vehicles differ significantly from the form capital is usually conceived of in economic theory. Airline capital is "lumpy", that is, it is available only in discrete units. In addition, the vehicles are of different capacities in terms of both the number of passengers they are capable of carrying and their range. This has important effects on the cost structures of individual flights.

The lumpiness of capital has important implications for the conduct of airlines. It implies airlines should offer scheduled service. This permits potential passengers to plan their trips effectively (De Vany 1975). However, since flights are not continuously available, some passengers must accept departure times that are not their preferred times. This fact of life for air passengers is acceptable only because scheduled service can be supplied at a much lower cost than individualized but unscheduled service.

When regulation was established in the 1930s, the existing (trunk) airlines were granted authority to operate on the routes which they operated at the start of regulation (grandfathered). All other attempts to begin operations in city-pair markets were subject to approval by the Civil Aeronautics Board (CAB). Likewise, the fares which airlines were permitted to charge were brought under CAB regulation.[1]

The demand for aircraft, like that for all factors of production is a derived demand. Consequently, the price and incentive distortions imposed by regulation of the product markets are expected to distort the airline's investment decisions also.

When the process of deregulation began, the airlines possessed stocks of aircraft suited to maximize profits under the regulatory constraint. Since the lead time for new aircraft orders is from three to five years, the

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1 There are many excellent discussions of the regulatory process as it existed prior to deregulation, such as Levine 1987. For this reason I do not discuss the process in any detail here.

airlines were forced in the short run to change their patterns of equipment utilization rather than discard obsolescent aircraft and replace them with technically appropriate types. The process of adaption to the newly deregulated environment is the object of this study. In the following subsections, we consider more formally the elements of the markets for air transport which define the nature of the problem.

The Structure of Demand

In general, there are two major dimensions in the demand for airline services. The first dimension is, of course, price. The second major dimension is quality. This variable, or more properly, this set of variables, is of considerable importance in determining the overall level of demand for air transport. The complexity of quality as a variable has discouraged a complete treatment of it as an element in demand. Thus, such important aspects of air travel quality as passenger comfort (including, e.g. seat width, aisle arrangements, and in-flight service) have received scant attention (cf. Bennett 1984).

In fact, the only element of quality to receive extensive treatment--flight frequency--is really another element of the opportunity cost of travel. Under the usual assumptions of utility maximization and full information, consumers choose those goods which are lowest priced. The money price is not the only important variable in determining the opportunity cost of travel.[2] Indeed, if it were, there would be little or no demand for air transport, since it almost always suffers a price disadvantage relative to other modes of transportation. The other and more important element in determining the opportunity costs of air transport is the time savings that air travel confers relative to other modes of transportation. This time element in the opportunity costs of air travel is affected by the necessity of scheduling mentioned above. In brief, since airline capacity is lumpy, carriers must offer scheduled service in order to allow their customers to plan their itineraries.

To quote DeVany,

> "There are two significant consequences of the discreteness of airline capacity. First, it makes scheduling the most efficient means of offering capacity by allowing the passenger to preplan his activities. Second, the discreteness of capacity means that there will always be intervals between flights, and, therefore, an interval between a passenger's desired departure time (a stochastic variable) and the time he actually departs on a flight." (1975,328)

The fact of scheduling a departure at a particular

2 The literature on airline demand frequently refers to the combination of fare and time costs as the "full" costs of flying. Here, except when specifically citing previous literature, I will use the term opportunity cost.

time means that some potential passengers will not be able to depart at their preferred time. Thus, convenience of service is important to the demand for air transport, particularly where the time savings it offers is not great relative to alternative modes.

Another important aspect of this demand structure is that preferred departure times are *not* uniformly distributed over the course of any period. Instead, demand is subject to regular "peaking." This gives rise to one of the important characteristics of the airline industry. The industry produces an almost endlessly varied offering of differentiated products.[3] Each city pair between which air transport is offered defines a product class. Each departure time between any given city pair defines a distinct product. While the airline products in any city pair product class (i.e. differing departure times) are good substitutes they are not the same product.[4] This imperfect substitutability coupled with the temporal variation in demand gives rise to some interesting strategic problems for airlines in their scheduling of flights.

The Structure of Supply: The Capital Constraints

3 It nonetheless remains an industry on the criterion of Boyer (1984) i.e. all suppliers of air transportation services must be members of the producer cartel for cartelization to be effective.

4 Winston argues for a similarly disaggregate approach to transportation in the treatment of both costs and demand (1985, particularly 64-65).

The second blade of the Marshallian scissors, the supply of air transport services, is largely dictated by the capital available to provide them. The first major limitation imposed by the capital is that it is available only in discrete units. Some of the implications of this have already been touched upon, for example, that optimizing behavior implies scheduling of services. Yet another implication is that the costs of providing airline services consist of three distinct types. These are overhead costs; direct passenger, or traffic, costs; and what are commonly called capacity, or flight, costs (Douglas and Miller 1974, particularly 18-26).

Capacity costs arise because a large proportion of the costs of employing a particular aircraft on any given route are not affected by the actual number of passengers carried on the flight. This distinction is made by the airlines as the difference between *Available Seat Miles*, or capacity, and *Revenue Seat Miles*, or actual transportation services provided. Capacity costs are fixed with respect to any given flight (i.e., once the aircraft and route are chosen). Thus airline markets are served with declining average costs when the number of passengers rises, at least up to the capacity of the largest available aircraft. Since the airline product was defined above as transportation between city pairs at a particular time, the individual flight has the cost characteristics of a natural monopoly. Many airline markets (city pairs) may be natural monopolies if traffic density is so thin that competing flights can only be offered at increased average cost per *Revenue Passenger Mile*. This is, however, determined by the interaction of supply and demand.

Another important effect of capital on the provision of airline services arises because of the specific forms in which the capital is embodied. There are economies of aircraft size. All other things equal, the average cost of an *Available Seat Mile* falls as the size of aircraft on a given route rises. In addition, the average cost per mile of an *Available Seat Mile* declines as the distance covered on a route increases.

The nature of airline capital also contributes to another supply-side aspect of airline service. Airlines produce a product which is necessarily differentiated. However, the capital used to provide it is not specialized to the provision of any particular product or product class, as these concepts are described above. Aircraft can be freely transferred between markets. This, coupled with the necessity of providing gate and ground services in any market served, means that the provision of airline services is marked by substantial economies of scope.[5] Thus, substantial competitive advantages accrue to firms which offer air transport services in a network. This tendency is reinforced by the peculiarity of demand that travelers not able to make direct connections between their origin and destination prefer to make all stages of their journey with a single firm.[6] (Johnson, 1985)

Airline markets possess many features which make them differ from the sorts of markets which are usually subject to theoretical analysis in economics. Regulation added yet another layer of complexity. Both price charges and service entry on routes were regulated. The analysis of the effects of the combination of the industry's unique characteristics and of its regulation which has developed in the literature is the subject of the next chapter.

5 These economies of scope arise most clearly because of the existence of indivisibilities in the provision of gate and ground service. This in itself should not necessarily result in competitive disadvantage to firms offering only single city-pair service since time-sharing arrangements should be possible. In practice, however, most airlines seem to treat these services as indivisible.

6 Note: This peculiarity, so-called, in demand is probably a result of rational decision making on the part of the consumers of airline trips--minimizing connections also minimizes the wedge for "Murphy's law."

CHAPTER 2

AIRCRAFT UTILIZATION IN THE ECONOMIC LITERATURE

As mentioned in the introduction, the airline industry has been the subject of a considerable amount of economic analysis. Interest in the airline industry preceded the process of deregulation. Indeed, the analysis of economists was instrumental in providing the rationale for deregulation. In contrast, there has been far less economic analysis of the employment of aircraft by airlines. This chapter surveys and critiques the available literature.

There are two distinct strands to be considered in the literature. First, aircraft are chosen by airlines to provide certain performance characteristics in light of the airlines existing route system. In addition, the existing fleets of aircraft must be redeployed properly as the conditions in markets and the structure of an airlines routes change.

When regulated, both price and route structure are fixed. Thus, the airline planner has only two interrelated decision variables--flight frequency, and vehicle type to be employed. Since the route structure is known, the choice of airline fleets is based on choosing a fleet which offers optimum performance on the existing routes.

Peyrelevade (1969) was the first to consider the problem. He produced a method for computing the optimal structure of an airline fleet given the set of routes to be served. Unfortunately, his method is limited by two factors. First, the quantity of flights demanded is parametric. The effects of price and flight frequency on demand are not even considered. In addition, there is no treatment of rivalrous behavior on the part of airlines.

The failures of the work discussed above are addressed in the work of Douglas and Miller (1974). They hypothesize that firms respond to regulatory constraints on price by offering greater flight frequency. Flight frequency is a competitive tool since greater flight frequency reduces the opportunity cost of flying.

Given their model, Douglas and Miller explicitly discuss the rules for optimal allocation of aircraft among markets. Their model implies the following behavior with respect to allocation of aircraft. When all other things are equal:

1) Larger aircraft should serve more dense routes (density is in this case measured in emplanements per unit of time).

2) Larger aircraft should serve longer haul markets (Those where the time savings air travel confers are greatest).

3) Larger aircraft should serve markets where passenger value of time is low.

Douglas and Miller verify that these guidelines for efficient allocation of aircraft are violated by airlines in the regulated environment. They found, in particular, that load factors were the lowest, and average costs therefore the highest, on the most dense of the transcontinental routes. This was a result of the mechanism for fare computation developed by the CAB, the Standard Industry Fare Level (SIFL). The SIFL formula did not fully reflect the lower costs incurred by airlines when serving transcontinental routes. This encouraged excessive flight frequency, both absolutely and relative to shorter haul routes.

Pollack (1977) offers a critique of the existing methods of fleet planning, describing those elements which he asserts have been insufficiently considered in developing fleet planning models. There is no specific technique or conclusion cited; instead, there is a general discussion of the elements needed to construct an adequate fleet plan.

Baumol et al. (1982, 7) suggest that the contestability of airline city-pair markets leads to efficient allocations of aircraft on routes. Since aircraft are "...virtually 'capital on wings'...," firms which do not use the most efficient type of aircraft for a route will suffer entry by entrepreneurs seeking economic profits. Ironically, since their book largely deals with the topic, this argument ignores the economies of joint production which airlines can enjoy by restructuring their routes as hub-and-spoke systems.

Graham et al. discuss the evolution of the airline industry since deregulation. They offer a test of the Douglas and Miller excess-capacity hypothesis. They assert that the hypothesis "... implies that if there were economies of scale at the market level, load factors should have risen most in denser markets, ceteris paribus, as the result of deregulation"(1983 126-7). Their reported empirical results indicate that the effects of density on load factors did not change in the expected direction with deregulation.

The papers discussed above were mostly completed before the process of deregulation was well begun and assume that airlines view their route structures as fixed and beyond their control. After deregulation, planners must take into account a much wider range of variables. Thus, in place of a single price (or small set of prices) on a given route and a fixed route network, planners must choose routes served, schedules offered, and the pricing formula used. Aircraft choice remains an important problem for the airlines.

The extent to which airlines wish to alter their stock of vehicles depends in large part on environmental factors beyond the airlines direct control. For instance, the rapid increases in fuel costs in the late 1970s made fuel economy a primary consideration in fleet planning. These fuel-cost considerations interact with other costs of operation of a particular type of aircraft in determining the actual composition of an airlines fleet.

> "In 1978 aviation fuel cost $1.50 a gallon in America and interest rates were at 6%. Then it was easy to persuade airlines to buy efficient new aircraft (hence the peak in deliveries in 1981). After all, on McDonnell Douglas's calculations fuel accounted for 46% of the cost of flying 2,000 nautical miles; operating costs such as wages and landing fees another 30%; and ownership-paying off the price of the aircraft-only 24%. By last year, things had changed. Fuel was down to 88 cents a gallon and interest rates were up to 12%. The result was that fuel accounted for only 31% of a route's cost and ownership a daunting 36%. ...United Airlines, the world's biggest carrier, is still operating its first Boeing 727, bought more than 20 years ago. When interest rates are high and fuel prices low, economic obsolesence recedes to the horizon." (Economist S18)

Of course, airlines may also purchase used equipment.

Used airliners are usually cheaper. "A used aircraft's price tracked 15 to 20 percent below the price of a new model of the same aircraft" (Flying, March 1984, 64-66). Thus the capital costs for used aircraft can be significantly lower. This possibility can carry much weight in airline decision making, thus, "A 757 covers the route from La Guardia to Houston in about the same time and carries about the same number of passengers as a 727-200....But the public doesn't care whether the machine costs $35 million or $7 million" (Flying, op. cit.).

In either case, the same factors are important in making decisions regarding fleet composition. First of all, "...airlines tailor their fleets to their routes" (Economist, 1985). In doing so, they trade off among factors like trip costs and seat-mile costs, specific fuel consumption and fuel burn, over a set distance, payload and range, and "price per seat". In an application of these principles, Thayer notes,

> "...for Braniff's domestic route system and for some of our Latin American routes, the advanced 727-200 fills the needs well. This aircraft meets the requirements of markets with low density and heavy business travel; it meets schedule requirements of multiple frequencies and limited capacity per trip; and it meets equipment requirements of low operating cost and appropriate capacity." (James, 279-280)

As the preceding discussion indicates, airline choice of aircraft is centered on profit maximization. Profit maximization is also the central concern when determining what sort of route structure to serve.

The exact nature of the adjustments of route structure to deregulation is the concern of Morrison and Winston (1985). They provide a simple model of the behavior of intercity route structures after deregulation. They suggest that profit-maximizing firms alter their route structures according to a simple principle. If the cost savings of serving a route jointly with some other route are great enough to offset the revenue lost because demand falls on the jointly served route due to decreased convenience of service, the new joint route should be adopted. Thus, economies of scope are the crucial determinant of the routes adopted. In particular, when there exist economies of vehicle size, economies of scope are likely to exist. Such economies may lead to joint provision of service (hubbing and spoking). However, if the economies realized are insufficient to offset the decreased convenience of service, route structures are likely to remain linear. Their discussion does not consider any strategic elements that exist in firm decisions on route structures and their ultimate configuration.

Bailey and Baumol (1984) also note the presence of economies of scope in the provision of airline services. They assert that contestability in airline markets results in the restructuring of airline route systems as hub and spoke systems.

They note that the drastic increases in fuel prices experienced between 1978 and 1981 rendered many multi-engine jets technologically obsolete. This created excess capacity, which they expect to result in substantial price warfare. Such price warfare is not in accord with the theory of contestablility but is seen as a transitional phase in the evolution of the airline industry to its ultimate deregulated structure.

Crandell suggests that stage length, trends in emplanements, and interdependence of routes are important factors in the process of deciding the routes to be served (James 1982, 231-232). In addition, he suggests that size, cost, fuel economy and environmental restrictions all play a role both in the short and longer term capital decisions of airlines. Also stressed is the importance of maximizing stage length in scheduling, since short hauls are more expensive per mile and imply that a larger proportion of the aircraft's day is spent on the ground.

Thayer also stresses the importance of long stage lengths. In addition, he stresses the importance of high density for profitable operation on a route (James, 265). Aircraft selection is, in his words,"...the fulcrum of this scheduling concept." Selection is made with the end of achieving low cost per seat-mile through high utilization of equipment and productivity, frequent service, and the capture of flow-through traffic. Particular stress is laid on the necessity of providing passengers with convenient connections on the carrier's own flights.

The logical outcome of the concern with establishing on-line connections is the hub-and-spoke pattern of routing that emerged with deregulation. As Bailey et al. note, "The hubbing carrier serves more passengers on its flights so it can use larger aircraft at higher load factors. Its greater traffic may also enable it to offer more frequent flights" (1985, 74). They present evidence showing that flights have increased (p. 84). Flight frequencies are shown to have risen substantially for large hubs connecting to other large hubs, also for both other size classes of hubs and for non-hubs connecting to large hubs. On the other hand small hubs and non-hubs have lost interconnections both among themselves and with medium hubs. This suggests a decline in the ability, in general, to complete direct connections which were previously achievable. The increased overall flight frequency reported appears contrary to the beliefs held before deregulation that carriers offer too large an amount of flight frequency while regulated. In fact, it is not, since those predictions assume an unchanged route structure. Freedom of exit and entry makes that assumption invalid.

Thomchick (1978) attempts to determine the characteristics which make existing airline routes profitable or unprofitable. These route characteristics and a model of firm behavior are employed to determine which of a sample of routes are likely to be served after deregulation. On the basis of these techniques, she offers a series of hypotheses about the evolution of airline route structures after deregulation.

First, small communities close to hub airports lose the services they previously received, as do routes which are less than 200 miles long. A second prediction is that quality of airline service will vary in certain predictable ways. For instance, she infers that airlines will offer more one-stop flights in place of multi stop flights. However, she also asserts that more non-stop flights will be offered, which does not appear to be the case. She also asserts that smaller aircraft will be employed to increase the frequency of flight service. Finally, in discussing how the industry as a whole will change, she predicts that airlines will include large numbers of small- and medium-sized aircraft in their fleets and commuter airlines will become more important providers of service. Thus, the behavior which she predicts is almost exactly opposite the predictions of Douglas and Miller.

Bailey, Graham, and Kaplan, in their evaluation of the effects of deregulation, note that part of the reason for the low fares experienced by airlines after deregulation "...was the excess supply of equipment, and most notably wide-bodied equipment during the recession" (1985, 62).

They contend that

> "...regulation encouraged service competition, [thus] carriers faced incentives to purchase a larger stock of equipment than they needed. The freedom to exit and enter markets allowed carriers to more efficiently employ their narrow-bodied equipment, further exacerbating the excess supply of wide bodies....Three- and four-engine wide-bodied equipment was especially in excess supply. The Board's regulatory policy set fares in dense long-haul markets well above costs. Yet this equipment can only be efficiently deployed in these markets." (p.62)

To summarize the preceding discussion, it was generally recognized before deregulation that airlines had adopted inefficient patterns of aircraft utilization. However, the predictions of airline behavior after deregulation gave insufficient recognition to the efficiencies which airlines could achieve through changing their route structures. The key factor is that vehicles are capable of providing low average costs on routes given the densities attained on those routes.

The general status of belief about the relationship between regulation and aircraft size is that plane sizes would rise following deregulation, that is, that regulation encouraged aircraft that were too small. But these theories were all based on the assumptions of a fixed-route structure. Once the possibility of varying routes is admitted, the predictions of the effect of deregulation should have been much different. In the next chapter theoretical models will be presented which seek to explain the changes in airline utilization of their aircraft subsequent to deregulation in terms of these principles.

CHAPTER 3

THEORETICAL TREATMENT - AIRLINE DEMAND FOR CAPITAL

Previous treatments of airline deregulation have been flawed because they assumed that, upon deregulation, firms would only vary the number of flights offered on a fixed set of routes. Such treatments imply that, with deregulation, firms would abandon their dependence upon flight frequency as a competitive weapon, substituting price competition. They also predict that smaller communities might lose service because competition on profitable routes would eliminate the cross-subsidies that existed under regulation. In addition they assume that, under deregulation, airlines would charge a single fare, or would differentiate fares only according to class of service.

These adjustments to deregulation imply that, under regulation, airlines respond to regulatory constraints by making inappropriate decisions about their aircraft stocks.

In particular, airlines forced by regulation to compete with flight frequency tend to use smaller aircraft than those competing on price and maximizing without constraint. They also have stocks of aircraft that are too large for markets where price and entry are not regulated. In addition, airlines under regulation faced a fare structure intended to cross-subsidize by permitting fares well above costs on long-haul routes. Since rents were available on long-haul service, these were exactly the routes most likely to experience frequency competition. Thus, the changed environment created by deregulation was expected to induce airlines to replace their smaller craft with larger aircraft capable of flying longer stages.

This chapter establishes a theoretical framework to analyze the developments in the airline industry subsequent to deregulation. This framework permits a comprehensive approach to the problems of airline capital allocation, including a useful approach to empirical specification.

This chapter contains three major sections. The first presents a simple method of characterizing the demand faced by airline firms in a competitive market. The analysis is based on a model developed by Salop (1984). However, only the first section is directly based on Salop's model; the balance of the chapter is entirely new. The results derived from this model allow inferences about the nature of airline capital demand. The second section extends the model to treat the supply response of airlines where they are permitted to hub and spoke. The third section develops the empirical specifications which will be employed in the next chapter. A fourth section summarizes the results derived in the chapter.

Differentiated Products Treatment of Airline Flights and Aircraft Demand

A Model of Flight Scheduling

We begin with a consideration of the demand for air service on a particular route. We suppose that a consumer makes a choice between an outside good (for present purposes this may be considered an alternative transportation mode) and a differentiated good.[1] In addition, the consumer chooses the exact variety of the good to purchase. Because there are fixed costs of providing any variety of a good, "custom made" types of the good cannot be produced. The customer will purchase the commodity only if the cash price plus the opportunity cost of not getting precisely the desired variety of the commodity is less than his or her reservation price. In the case of airline service this opportunity cost can be quantified much more exactly than with other varieties of a

1 The original inspiration for this model is Stephen Salop's "Monopolistic Competition with Outside Goods"(1978). However, Salop specifically denies the realism of the product characterization that he employs.

differentiated product. The displacement from the preferred good is a departure time different than the preferred time, the cost of which is the wage of the individual displaced times the time differential.

In developing this model, we make the simplifying assumption that all consumers have identical preferences for the competing goods. Additionally, the consumers are assumed to be uniformly distributed on the circumference of a circle where each point on the circle represents a possible variety of the differentiated good. Different positions on the circumference of the circle are considered to represent the times of departure available throughout the course of a day. (This situation is represented in Figure 1.) All consumers have identical costs of being displaced from their preferred product.

Using these assumptions, we can develop two distinct demand equations for varieties of the differentiated good in this market.[2] Each variety of the good will have an identical demand equation because customers are distributed uniformly throughout the market. In the analysis which follows, each flight (i.e., variety of the good) is considered to be supplied by an individual profit-maximizing firm. Each variety's demand curve is thus a firm-demand curve. This assumption has the virtue of considerably simplifying the analysis which follows,

2 Salop characterizes these as the "monopoly" and "competitive" demands.

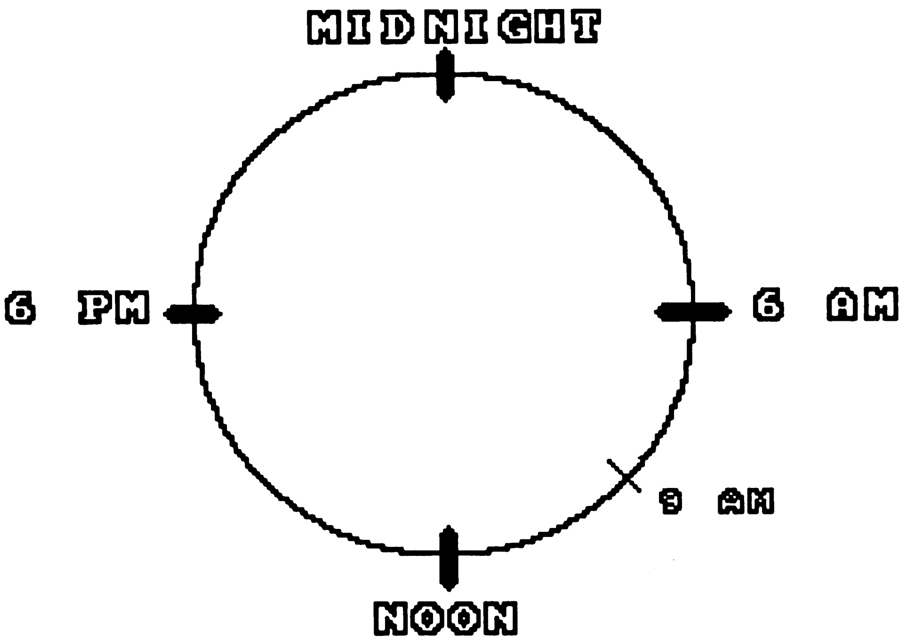

FIGURE 1
AIRLINE FLIGHTS AS
DIFFERENTIATED PRODUCTS
IN A CIRCULAR MODEL

although it is clearly not very realistic.

The first demand equation arises when not all customers in the market are served. In this case, there would be some times of day when customers would resort to alternative modes of transportation. Another way of describing this situation is that, when the price of a flight in an incompletely served market changes, only the quantity demanded for that flight changes. Other flights in the market are not affected. This demand function takes the form:

$$(1) \qquad q_p = \frac{2L}{T}(R-p)$$

where q_p is quantity demanded if not all customers in the market are served, L is total number of consumers in the market, and T is the opportunity cost per unit of displacement from a preferred product (in this case, it is the value of time wasted by the consumer because a flight at the preferred time is not available). In addition, R is the consumer's reservation price. Its value is determined by the opportunity cost, again in terms of the consumer's time used for travel, of the best alternative mode of transportation. Finally, p is the price paid for the transportation service. When all customers are served,the demand function becomes:

$$(2) \qquad q_r = \frac{L}{T}(p^{*} - \frac{T}{n} - p)$$

where, L,T,and p are defined as before, q_T is the quantity demanded when all preferred times of departure are served by a flight, p^* is the price charged on competing flights, that is, flights whose departure times are closest to the time of the flight in question, and n is the number of flights per day in the market.[3] In this model, a fully served market is one in which no potential customer chooses to buy the alternative good. The notion of a fully served market arises because the condition of identical costs of displacement from the preferred variety of the differentiated good is imposed on consumers. The identical cost assumption has considerable merit in simplifying the theory which follows but no appreciable merit as a characterization of any real market.

These two types of demand must be combined in a single demand curve faced by a flight serving this market and characterized by a "kink" where the two segments join. This occurs in spite of the Nash conjectures employed by the flights in the market, itself a remarkable result.

Given these demand characterizations and the assumptions about the nature of flight costs presented below, it is possible to determine a Symmetric Zero Profit Equilibrium (SZPE) for this market. In other words, in equilibrium there are no economic profits earned, thus no entry, and each firm will produce the same output, that is,

3 For a development of these demand characterizations from first principles, consult Salop op. cit.

carry the same number of passengers on a flight.

Each flight, which acts as a profit maximizing firm, is assumed to have total costs of the form:

$$C = mq + F \tag{3}$$

where C is total costs of the flight and m is marginal cost per unit of realized demand, that is, per passenger carried, assumed to be constant at all levels of demand. In this case, these are the costs associated with transporting one more passenger, for example, ticketing, baggage handling, and in-flight meals. F is the fixed cost of providing service, characterized in the airline literature as flight costs. It depends on the route flown, or, distance, and the type of aircraft employed on the route.

The conditions for a SZPE are:

$$p + q \left(\frac{dp}{dq}\right) \leq m \tag{4}$$

and:

$$p = m + \frac{F}{q} \tag{5}$$

In other words, marginal revenue must not exceed marginal cost and price must be equal to average cost so that no economic profits are earned. This is so because individual flights are thought of in this analysis as monopolistic competitors whose zero profit equilibrium will <u>not</u> be achieved at the minimum of average total cost. Since the equilibrium must be symmetric, and assuming it has no gaps (i.e., unserved customers) it will be true that:

$$(6) \qquad q = \frac{L}{n}$$

The derivative of each segment of the demand function, where the number of flights is fixed at the equilibrium number of flights on the route, can be calculated as:

$$(7a) \qquad \frac{dp}{dq_p} = \frac{-2L}{T}$$

and:

$$(7b) \qquad \frac{dp}{dq_f} = \frac{-T}{L}$$

for the incompletely- and completely-served segments of a flight's demand curve, respectively.

Combining these derivatives with the equilibrium conditions and equation (6), it is possible to solve for the equilibrium price and number of products offered (here flights per day) for both completely and incompletely served markets. These are:

$$(8a) \qquad p^p = m + \frac{T}{2n^p}$$

and

$$(8b) \qquad p_f = m + \frac{T}{n_f}$$

for the equilibrium prices and:

(9a) $$n^p = \sqrt{\frac{TL}{2F}}$$

and

(9b) $$n^f = \sqrt{\frac{TL}{F}}$$

for the number of flights offered in equilibrium.[4]

In addition to equilibria where the markets are either completely or incompletely served, there exists the possibility of an equilibrium at the "kink" where the two demand segments join. Since no tangency is possible at the "kink," a range of parameter values will be consistent with an equilibrium at the kink. The upper bound of these values is the partially served equilibrium where the demand and average cost curves are just tangent, or:

(10) $$R - 2m = \sqrt{\frac{2TF}{L}}$$

The lower bound is the upper limit for tangency in fully served equilibrium, or:

(11) $$R - m = \frac{3}{2}\sqrt{\frac{TF}{L}}$$

The three possible equilibrium outcomes of the model are illustrated in Figure 2. Considering the choice by an

4 In this expression, n_p is in fact only the upper limit of the number of products which may be offered in the market. This reservation will be true of all the incompletely served markets considered below.

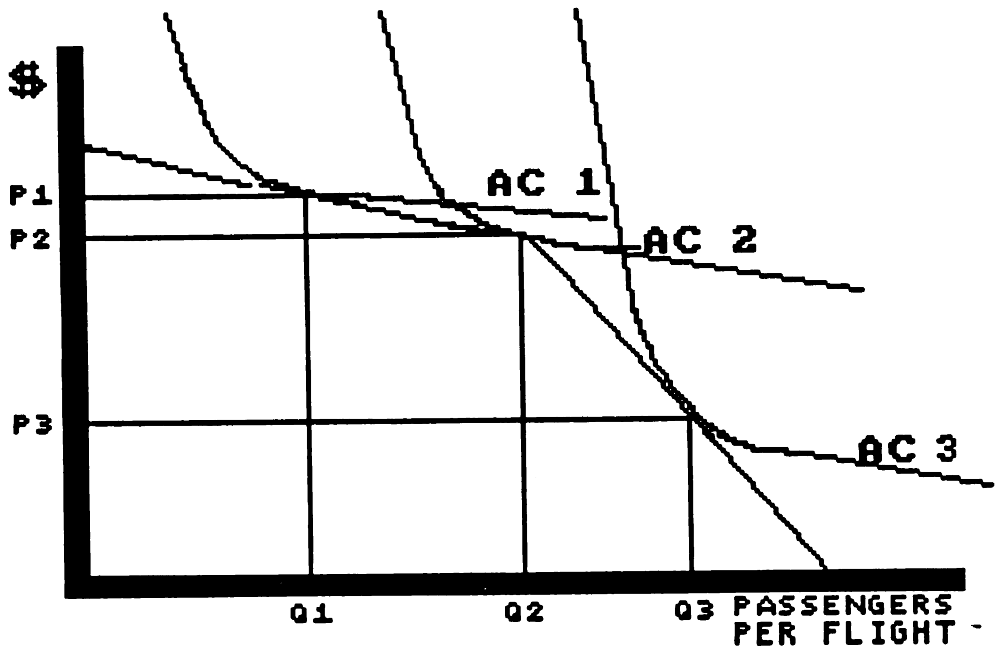

FIGURE 2

POSSIBLE EQUILIBRIA
FOR AN INDIVIDUAL FLIGHT

airline of aircraft to fly a particular route, the number of aircraft used is obviously a direct function of the number of flights (n^p, n^f) which a market will support.

Airline Responses to Regulation

In this section, the model is altered to consider the case of an exogenous price. This alteration reflects the situation faced by airlines during the regulatory period when the CAB controlled both the price of the airlines services and the routes on which the airlines were able to offer service. Thus the model also holds route structure constant, and only the number of flights which can be offered will be varied. Price is set at the level p_r, which the firms accept as a given in their maximization process. As a result the zero profit equilibrium condition is altered to:

(12) $$p_r\, q_r = m\, q_r + F$$

Here q_r is the equilibrium quantity demanded realized at the fixed price p_r. Rearranging this expression yields:

(13) $$q_r = F/\,(p_r - m)$$

Remembering that if the entire market is served, $q = L/n$ and $q = q_r$, then the number of flights offered is :

(14) $$n = L\,/\,q_r$$

So that the equilibrium number of flights under regulation is :

(15) $$n_r = (p_r - m)\ L / F$$

where n_r is the number of flights offered under regulated price p_r. The equilibrium for an individual flight is illustrated in Figure 3. In Figure 3, average cost is not minimized, since to do so would result in economic profits. Instead, entry occurs until economic profits have disappeared.

Consulting equation 9b, we see that in fully served markets the number of flights offered without regulation of price is:

(16) $$n^f = \sqrt{\frac{TL}{F}}$$

So that relative to unregulated competition, the number of flights offered under regulation is :

(17) $$n^r = (p^r - m)\sqrt{\frac{L}{TF}}\ n^f$$

From the conditions of equilibrium it is possible to calculate the value of T as a function of equilibrium price and the parameters of the model :

(18) $$T = (p_f - m)^2\left(\frac{L}{F}\right)$$

The relationship between the number of flights offered when the price is exogenous and the number offered when price is market-determined is :

(19) $$n_r = \frac{(p_f - m)}{(p_r - m)}\ n_f$$

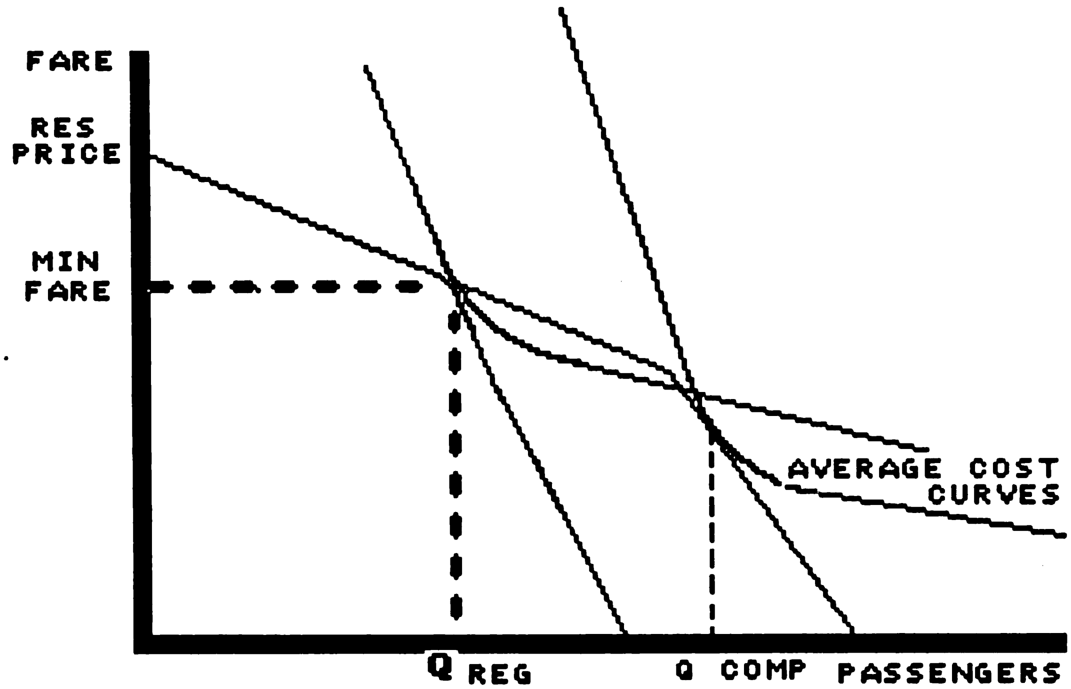

FIGURE 3
COMPARISON OF REGULATED
AND COMPETITIVE EQUILIBRIA

Thus, the number of flights offered under regulated prices is proportional to the relative price cost margins under regulation and competition. Since there is no competition to insure that prices will be driven to minimum average total cost, prices and number of flights must be higher under regulation. This implies that the number of aircraft held by firms under regulation must be excessive. This result depends crucially on the fact that regulated airlines are not able to alter the routes which they serve.

So far, this result is not novel; it depends on the model used by most economists before deregulation. But this result has been contradicted by airline experience since deregulation. This dissertation provides an alternative framework, one which explains the experience of deregulation in a more satisfactory fashion.

Airline response to varying aircraft capacity

Airlines do not choose only the number of flights to offer in either the regulated or deregulated state. They must also determine which of the several different varieties of aircraft to employ on any given route. They face this problem because different aircraft types will offer superior cost performance for different routes.

There are two distinct variables which determine the behavior of aircraft costs on a route. One is economies of aircraft size. Economies of aircraft size result in decreasing average costs on a per passenger basis as progressively larger aircraft are employed on a particular route. This is the case since the marginal costs of providing service on a route are not strongly dependent on choice of aircraft and the flight costs of a route increase less than proportionately as aircraft size increases. This phenomenon leads to the economies of density reported by Caves et al.(1984), since increases in the density of a route will permit an airline to employ larger aircraft on any given route without decreases in flight frequency.

The second variable which determines the behavior of flight costs is the distance covered on a route. Flight costs increase less than proportionately with the distance covered by the route for all aircraft types. In addition, the rate of increase in flight costs with distance is slower for large aircraft varieties than for smaller aircraft types. As a result, average costs per mile decline with distance and decline more than proportionately as aircraft capacity increases. The relationship of average costs to both distance and aircraft capacity is illustrated in Figure 4.

In the model presented below, aircraft assignment to an already selected route is considered. Thus the distance of the route is fixed and the variables controlled by a

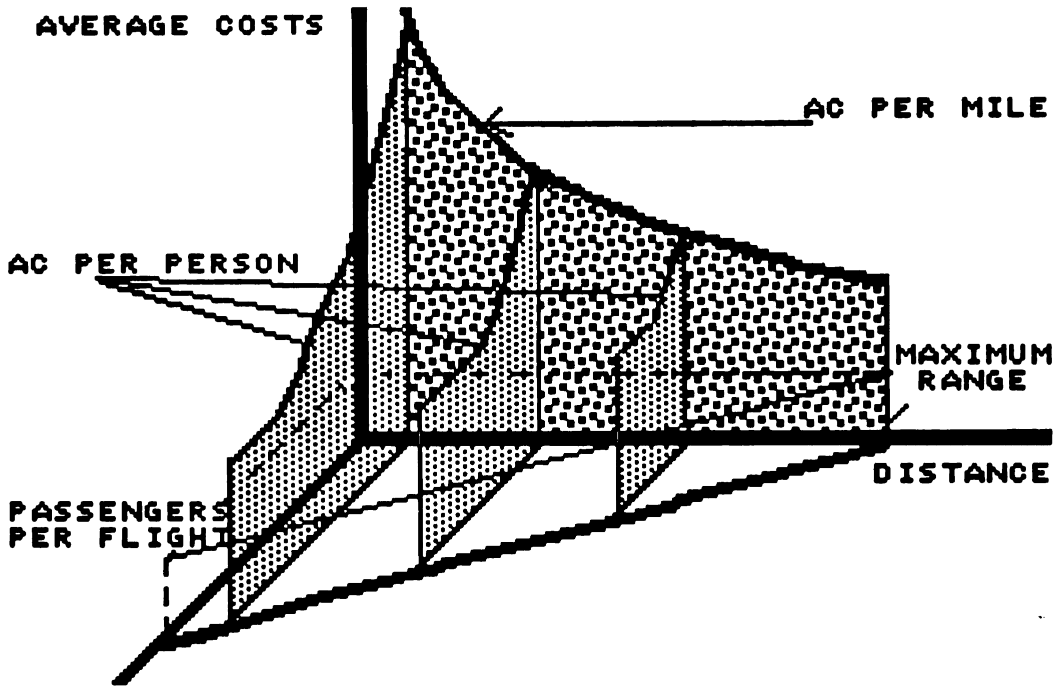

FIGURE 4
THE RELATIONSHIP OF AVERAGE COST PER MILE AND PER PERSON FOR A SINGLE VARIETY OF AIRCRAFT

firm are the number of flights to offer and the type of aircraft to assign.

As a simplifying assumption, suppose that the per passenger marginal costs on a route are identical for all varieties of capital. This assumption may not be too unrealistic. The marginal cost of handling another passenger is related to such items as ticketing, baggage handling, and in-flight meals, which are not necessarily specific to any given route or aircraft. Thus the firm may choose to bear fixed (flight) costs:

(20) $$F_1 < F_2 < F_3$$

The relationship between these costs is such that for some q_1, the average cost per flight using technology 1 is equal to the average cost per flight of technology 2. For demands less the q_1, technology 1 is lowest cost, and for demands greater than q_1 but less than q_2, technology 2 is least cost. At demand levels greater than q_2, technology 3 dominates the alternative technologies with respect to cost. The relationship between the three technologies' average cost curves is illustrated in Figure 5.

As a result of this modification in technology, equilibrium condition (5) is modified. It now becomes:

(21) $$\min \left(p = m + F_i/q \right) \quad i = 1 \text{ to } 3$$

Any higher price will result in entry by firms employing the more appropriate technology, assuming that competitive entry is permitted. This relationship yields an

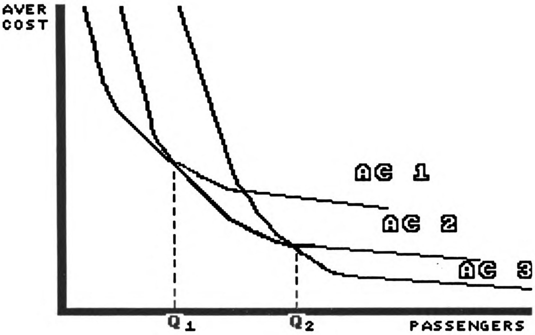

FIGURE 5
AVERAGE COST PER PASSENGER
WITH THREE AIRCRAFT VARIETIES

equilibrium when the slope of the demand curve (either -L/T or -2L/T) is equal to the slope of the average cost curve. The relationship of the family of average cost curves generated by the different varieties of aircraft and the demand curves for an individual flight on a route is illustrated in Figure 6. As is illustrated in Figure 6, each different size of aircraft, since it supports a different level of flights on a route, yields a slightly different demand curve. All demands share a common origin, since the reservation price is determined by the opportunity cost of alternative modes. Aircraft varieties with higher flight costs will support a smaller number of flights. Thus, such aircraft varieties are only chosen when their lower average costs more than offset the increased opportunity cost to the consumer of reduced flight frequency.

Referring to the previous section where price is set by some outside agency, Figure 6 makes it clear that, when price is not market-determined, smaller than optimal aircraft will be employed.

At the same time, this modification of the model leads to the prediction that a single type of aircraft will be employed on a route. Exactly which variety of aircraft will be employed on a particular route depends on which variety of aircraft fulfills condition 21.

This prediction is at variance with observation (see, for instance, the Official Airline Guide,

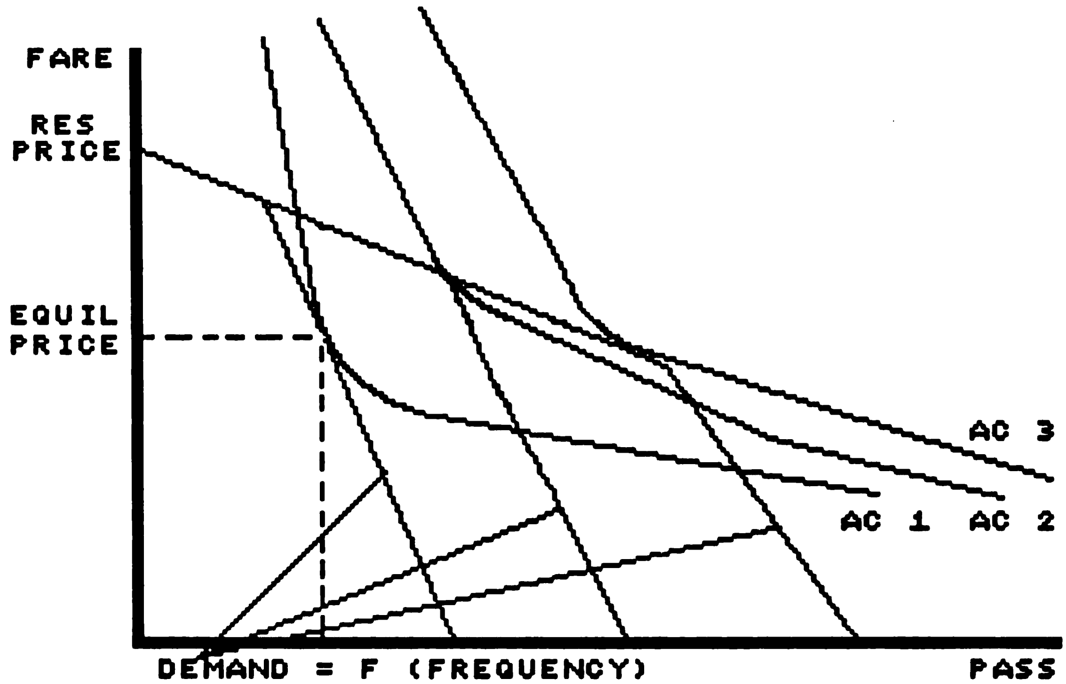

FIGURE 6
EQUILIBRIA WITH THREE
AIRCRAFT VARIETIES

which lists aircraft assignments on each route). Two plausible explanations can be supplied for this. First, the deviation between the model's prediction and observation is largely the result of an unrealistic simplifying assumption used in creating the model. The parameter values T,R and D = L/c are not, as assumed, constant, but vary along the circumference of the circle or over the course of a day.[5] In Figure 1, the period between midnight and 6 A.M. was assumed to have as many potential customers as the equally long period between 6 A.M. and noon. Of course this is not the case. The variation of these parameters destroys the symmetry properties of the equilibrium. Different times of day have different demands for flights and so different types of aircraft could be appropriate.

This pervasive asymmetry creates some interesting strategic problems for airlines considering the structure of their flight schedules. However, these strategic problems will not be further considered here.

In addition, even if the market were symmetric, the equilibrium number of cost-minimizing flights of a single aircraft variety in a market is unlikely to be an integer. If only a single scale of operation is possible (i.e. if only one variety of aircraft is employed) in a market and

---

5 T is the opportunity cost of passengers' time, R is the reservation price for a flight, and D is the density of customers per unit of the circle,c, the circumference of the circle.

the equilibrium number of flights is noninteger, economic profits can be earned in the long run. The use of other varieties of aircraft, permitting entry on another scale, could erode these economic profits.

Effects and Mechanisms of Price Discrimination

We complete the analysis by considering a variant of the model where there are two distinct and equal-sized classes of consumers distributed around the circle. Both of these consumer groups are assumed to be uniformly distributed around the circumference of the circular product space. In other words, there are equal numbers of consumers for each hour of the day. These consumer groups differ only in the costs they bear when displaced from their preferred product (time of departure). Each set of consumers has demand:

$$q_p = \frac{2L}{T_i}(R-p) \tag{22}$$

when not all of the customers of type i in the market are served and :

$$q_f = \frac{L}{T_i}(p - \frac{T_i}{n} - p \ ) \tag{23}$$

when all customers of type i in the market are served. These demand functions are minor modifications of equations 1 and 2 above.

If the firm can charge only one price in the market, the demand curve a firm faces will consist of three segments. In the first segment, demand will consist of the sum of the demands for each class of consumers when not all consumers in the market are served or:

$$(24) \qquad q_p = 2L\ (\ R - p\ )\left(\frac{T_1 + T_2}{T_1T_2}\right)$$

Let $T_1 < T_2$; then the second segment of the demand curve faced by the firm will equal the sum of consumer type 1's fully served demand and consumer type 2's incompletely served demand over the appropriate range of prices and outputs, or :

$$(25) \qquad q_i = \frac{2L}{T_2}(\ R - p\ ) + \left(\frac{L}{T_1}\right)\left(\ p^* - \frac{T_1}{n} - p\right)$$

Finally, for price sufficiently low, firm demand will equal the sum of competitive demands for both consumer types :

$$(26) \qquad q_f = \frac{L}{T_2T_1}\left((T_2 + T_1)(\ p^* - p) + \frac{T_1T_2}{n}\ \right)$$

This segmented demand curve could be subjected to analysis similar to our earlier treatment for a market with only two demand segments. However, the real interest in this variant lies in analyzing supply responses when the different classes of consumers can be charged different prices. In this we can follow our previous procedure quite closely. In other words, we will seek a Symmetric Zero Profit Equilibrium, where each supplier charges two prices.

As is apparent from the characterization of product demands above, three distinct cases may be distinguished. The first is the analog of the earlier case, where not all customers in each class are served. A second case is where customers of the class with the lowest displacement costs are fully served and customers with higher displacement costs are not. Finally, there is the case where all customers of both classes are served.

The starting point of this analysis is a modification of condition (3), that marginal revenue be less than or equal to marginal cost. In this case, the condition must hold for both classes of consumers:

$$(27a) \qquad p_1 + q_1 \left(\frac{dp_1}{dq_1}\right) \leq m$$

and

$$(27b) \qquad p_2 + q_2 \left(\frac{dp_2}{dq_2}\right) \leq m$$

All customers are assumed to give rise to the same incremental costs of service, m. The zero profit condition must also be rewritten to reflect the fact that the revenue contribution of one class of consumers affects the contribution the other class must make. The zero profit condition thus becomes:

$$(28) \qquad (p_1 q_1) + (p_2 q_2) = m(q_1 + q_2) + F$$

Condition (5), $q_1 = L/n$, is still fulfilled and the value of the derivative of price with respect to quantity is either:

$$\text{(29a)} \qquad \frac{dp_1}{dq_1} = -\frac{2L}{T_1} \quad \text{or} \quad \frac{dp_1}{dq_1} = -\frac{L}{T_1}$$

and (29b) $$\frac{dp_2}{dq_2} = -\frac{2L}{T_2} \quad \text{or} \quad \frac{dp_2}{dq_2} = -\frac{L}{T_2}$$

depending on whether or not all customers of a given service class are served in the market.

Combining all these equations and solving for p_1, p_2 and n in the completely, mixed, and incompletely served markets respectively yields: [6]

$$p_1 = m + \frac{T_1}{n} \quad \text{and} \quad p_2 = m + \frac{T_2}{n}$$

$$\text{(30a)} \qquad n = \sqrt{\frac{(L(T_1 + T_2))}{2F}}$$

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6 The algebra involved in deriving these equilibrium values is tedious and will not be reproduced here. Details can be supplied upon request.

$$p_1 = m + \frac{T_1}{n} \quad \text{and} \quad p_2 = m + \frac{T_2}{2n}$$

$$\text{(30b)} \qquad n = \sqrt{\frac{(L(2T_1 + T_2))}{2F}}$$

$$p_1 = m + \frac{T_1}{2n} \quad \text{and} \quad p_2 = m + \frac{T_2}{2n}$$

$$\text{(30c)} \qquad n = \sqrt{\frac{L(T_1 + T_2)}{F}}$$

This analysis raises two points of interest for the topic of this dissertation. The first is how the number of flights offered in a market changes when the airline is able to practice a form of price discrimination such as the one outlined above. The second is the method by which an airline might be able to achieve segregation of its customers according to their different demand elasticities.

The ratio of equation 31c to equation 9b is:

$$\text{(31)} \qquad \frac{n_1}{n_f} = \sqrt{\frac{(T_1 + T_2)}{2T}}$$

Rearranging this equation yields:

$$\text{(32)} \qquad n_1 = \sqrt{\frac{(T_1 + T_2)}{2T}}\; n_f$$

where n_1 is the number of flights offered when price discrimination is practiced in a fully served market, n_f is the number of flights offered where price discrimination is not practiced, T_1 and T_2 are the unit displacement costs of the price discriminating markets, and T is the cost per unit of displacement from ones preferred product in the non discriminating market.

Condition 32 means the number of flights offered will be greater with price discrimination than without. This is only true if the average of the displacement costs of the consumer classes in price-discriminating markets is greater than the displacement cost of markets without price discrimination. In other words, the average value of time must be higher in a market for the number of flights to be increased by the practice of price discrimination.

The price-discriminating airline will charge a lower price to individuals who place a lower value upon their time. This raises the problem: What mechanism permits the airline to segregate customers according to their differing elasticities with respect to displacement from desired time of departure? One possibility is purchase and length-of-stay restrictions on tickets.

The price discrimination practiced by airlines since deregulation is unique. It hinges upon the elasticity of demand with respect to flight frequency. It has long been observed in the airline industry that flight frequency serves as a competitive variable, since the traveler's opportunity cost of air travel is minimized by flights departing frequently from any given origin (i.e., a departure will occur close to the desired time of departure). This resulted in a competitive strategy under regulation involving increasing flight frequency until the price fixed by regulators just covered average costs. Average costs, of course, increased since load factors declined with increasing flight frequency.

The mechanism through which the airlines are able to achieve segregation is the tactic of fares subject to significant restrictions upon the flexibility with which the tickets can be employed. The requirement of advance purchase effectively reduces the implicit flight frequency from an origin available to the consumer to one flight per week, month, or other relevant time period. The same reasoning applies to restrictions on length of stay. In return for this lowered flight frequency, the customer will only be willing to pay a lower fare. The lower fare in turn increases the quantity demanded for transport at the relevant flight frequency. In effect, the airline is combining consumers off of several distinct demand curves, one for each flight frequency implicit in the restrictions imposed in the fares.

This concept is illustrated in Figure 7. In Figure 7, the vertical axis represents fare; the horizontal axis extending out of the page, the quantity demanded of a particular flight; and the horizontal axis in the plane of the page, the reciprocal of flight frequency. The

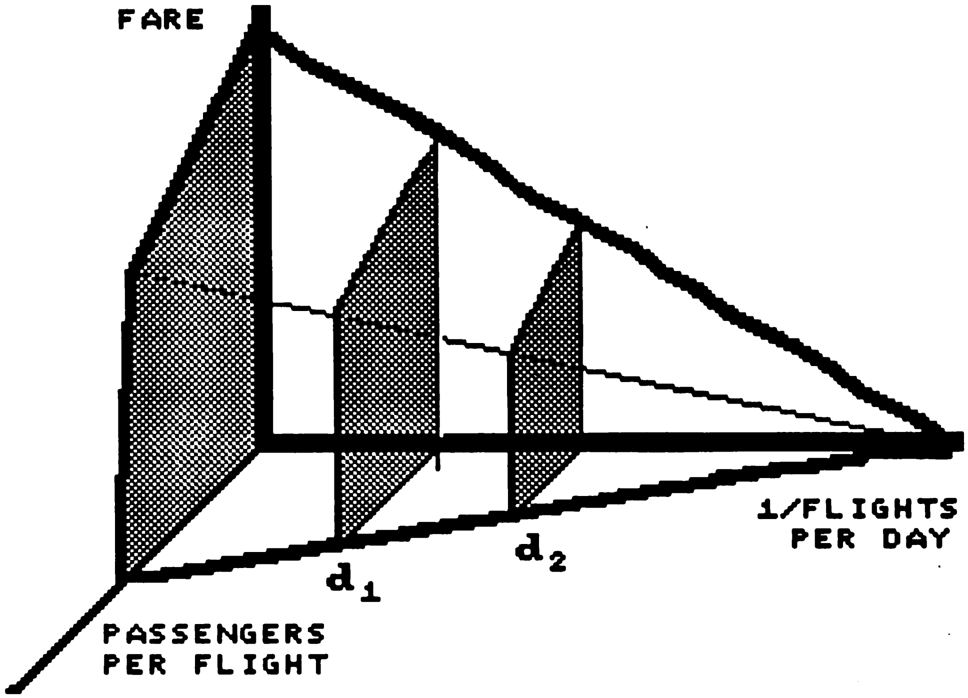

FIGURE 7
THE RELATIONSHIP BETWEEN
FLIGHT FREQUENCY, FARES, AND
QUANTITY OF FLIGHTS DEMANDED

reciprocal is used to dimension this second horizontal axis since the amount of time spent waiting for a flight, and with it the opportunity cost of flying, decreases as flight frequency increases.

As illustrated in Figure 7, each flight frequency has a demand curve associated with it. Airlines are able to maximize profits by choosing output levels where the marginal revenue of each class of passenger is equal to the marginal costs of flying the passengers in that class.

Joint Products and Hubbing and Spoking as Explanations of Airline Behavior

The theoretical framework outlined in this section has implications distinctly different than the theories advanced before deregulation whose content has been outlined above. Previous theoretical treatments of deregulation implicitly assumed that airlines would change their deployment of aircraft within an essentially fixed set of routes.

The early literature anticipated that there would be a significant decrease in flight frequency in deregulated markets as carriers switched to competition based on price, since less frequent flights would permit the airlines to utilize more economically sized aircraft. What was not anticipated was the extent to which airlines would be able to achieve the higher densities necessary for successful operation through the restructuring of their networks into so-called hub-and-spoke route systems.

In fact, the major effect of deregulation has been a restructuring of airline route networks as hub-and-spoke systems. Hub-and-spoke networks make possible higher levels of frequency than could be achieved in the linear networks that prevailed before deregulation. These increased flight frequencies can be achieved in two ways--either by increasing the stock of aircraft or by utilizing existing stocks of aircraft more efficiently. Both appear to have occurred subsequent to deregulation.

Hub-and-spoke restructuring of airline routes implies that airlines should maintain relatively larger stocks of aircraft subsequent to deregulation than suggested by earlier theories such as that of Douglas and Miller (1974). This contradicts the results of previous sections which imply that stocks of aircraft under price and entry regulation should have been too large. An additional implication is that airlines should make few changes in the relative holdings of aircraft types in their fleets. Flight frequency still plays an important competitive role and smaller aircraft are necessary to provide high levels of flight frequency.

It is the contention of this dissertation that airline behavior since deregulation has been directed towards achieving economies of density.[7] Two distinct strands have constituted the industry response to the challenge of attaining economies of density. The first consists of the hub-and-spoke restructuring of airline routes. The second is the unique form of price discrimination discussed in the previous section. The interaction of these two strategies has resulted in the achievement of notable economies on the part of airlines since deregulation.

The basic principle of the hub-and-spoke routing is simple. Passengers from a single origin, proceeding to diverse destinations, are brought to a central point. There they change planes to proceed to their final destinations, along with other passengers who have been similarly concentrated at the hub. The advantages of this type of routing for achieving economies of density are obvious. Passengers for many destinations use a single aircraft, permitting a larger aircraft to service the airport, At the same time the airline can maintain, or even expand, the number of flights offered. Likewise, flights outbound from the hub combine passengers from many origins, which also permits larger, and more economical, aircraft to be used.[8]

The efficiency of hub-and-spoke routings from the point of view of an individual air carrier is enhanced by

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7 See Caves, Christensen, and Tretheway (1986) for evidence that economies of density exist for airlines and are of substantial importance.

8 This argument depends on the economies of aircraft size, i.e. on the assumption that larger aircraft with equal load factors will have lower average costs. This is generally accepted in the literature (Bailey and Panzar 1981).

the known reluctance of passengers to accept interline routings. Thus, airlines need not fear that the passengers which they deliver to the hub will be lured to other carriers to reach their destination. In fact, there exists some evidence that airlines are using the reluctance of passengers to accept interline routings as a marketing tool (Oster and Pickrell 1986). Consequently, hubbing and spoking guarantees the high load factors and high passenger densities necessary to achieve economies of density.

So far, no mention has been made of possible economies of scope in the provision of airline services through a network. It is possible that the pursuit of economies of density has been the sole motive for the restructuring of airline route networks subsequent to deregulation. However, substantial economies of scope would, if available, strengthen the tendencies implicit in the pursuit of economies of density. In particular, the reported economies of scale in baggage handling could be a source of economies of scope for individual airlines operating hub-and-spoke networks, since the volume of baggage to be handled at the hub will be substantially greater than in non hub-and-spoke systems (Bailey et al. 1986).

In the following subsection, a simple method of treating demand in hub and spoke routings will be presented.

Joint Products and Hubbing and Spoking

In treating the profit maximization problem of an airline which hubs and spokes, the key element is the fixed (flight) cost each flight incurs. The so-called flight costs of an aircraft flying a spoke are fixed and can be spread over the passengers for many origins or destinations. As presented above, the demand for airline transportation on a particular route can be considered as distributed along the circumference of a circle. Different points on a circle are considered to represent different times of departure throughout the day. Flights offered at particular times of day are then seen as monopolistic competitors with other flights on the same route.

Routes sharing a point of origin were previously treated as unrelated. In terms of the theory, the demands for flights on routes sharing an origin are treated as distinct products. Each route, in our clock face analogy presented in Figure 1, lies on a non-intersecting circle.

The novelty of the treatment of hubbing in this section is the manner in which different routes are seen as relating to each other. The central element of the hub-and-spoke concept is that customers proceeding from a single origin to diverse destinations are served by a single aircraft. Thus, each flight is located at a point where a number of distinct product spaces intersect. Each route has its own distinctive demand characteristics.

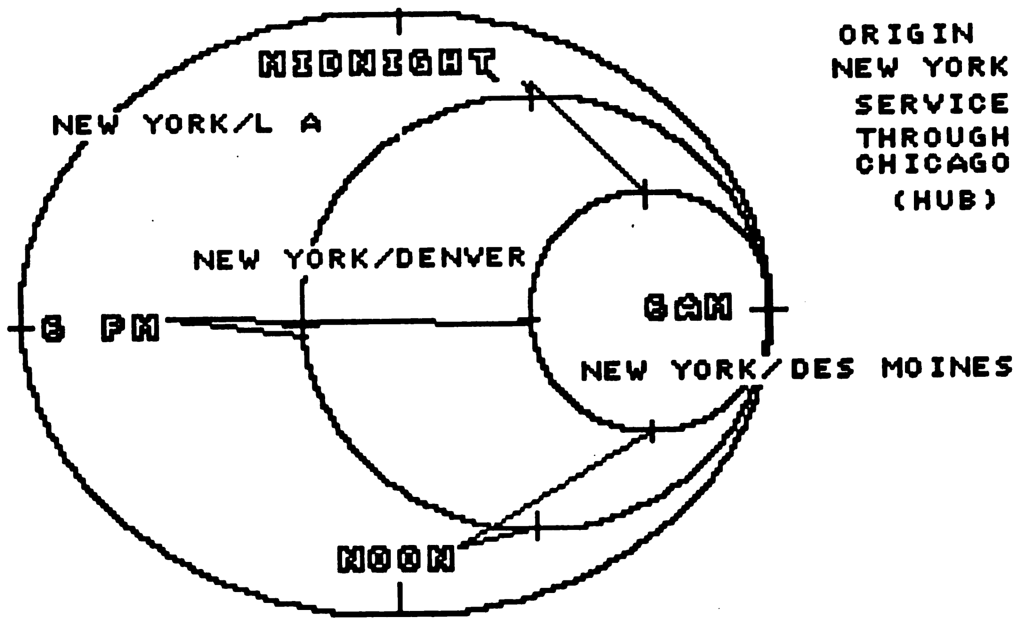

FIGURE 8
SERVING SEVERAL MARKETS
ON A SINGLE FLIGHT

These include the population of potential customers on the route, the value of time of that population, and the reservation price for the route.

Each flight is then imagined as occupying a point on the circumference of many distinct circles simultaneously. This situation is illustrated in Figure 8, where each circle is labeled as a distinct route. (An infinite number of distinct circles can, of course, share a single common point.) In each of these distinct markets, the demand for the product q_i is represented by a demand curve with two segments, as previously described. When demand is insufficient to insure that all passengers on all routes will be served, the flight faces demand such that:

$$(33) \qquad Q = \sum_{i=1}^{n} q_i = \sum_{i=1}^{n} \frac{2L_i}{T_i} (R_i - p)$$

If, on the other hand, all passengers on all routes are served then:

$$(34) \qquad Q = \sum_{i=1}^{n} q_i = \sum_{i=1}^{n} \frac{L_i}{T_i} (p_* - \frac{T_i}{n} - p)$$

In this analysis, neither the incomplete service case nor the intermediate case (i.e., where some markets are fully served and others not) will be considered, since it appears that hubbing and spoking will insure that all markets are fully served.

The firm then must maximize the profit function:

$$(35)\quad \Pi = \sum_{i=1}^{n}(p_i - m)q_i - F_h$$

Here, F_h is the per-flight cost of flying from the origin to the hub.

Since we are still seeking Symmetric Zero Profit Equilibria, the zero profit condition still holds, or:

$$(36)\quad \sum_{i=1}^{n} p_i q_i = m\sum_{i=1}^{n} q_i + F_h$$

If the demand on each route is independent of the demand on any other route, then differentiation with respect to q_i yields n identical first-order conditions of the form:

$$(37)\quad \frac{\delta\Pi}{\delta q_i} = p^* + \frac{T_i}{n} - \frac{2T_i q_i}{L_i} - m$$

Solving these n equations and the zero-profit restriction for q_i, p_i, and n_h, the number of flights offered from an origin yields:

$$(38a)\quad q_i = L_i / n_h$$

$$(38b)\quad p_i = T_i/n_h + m$$

$$(38c)\quad n_h = \sqrt{\frac{\sum_{i=1}^{1} T_i L_i}{F_h}}$$

The expressions for price and quantity are identical to the expressions derived when the problem of price discrimination was considered previously. Thus hubbing and spoking is one of the class of problems where different classes of customer share the fixed costs of a product with a joint production technology. Hubbing and spoking in effect means that a flight from an origin provides a set of joint products, that is, one for each unique passenger destination on the flight. This result can be extended to multiple classes of consumers on a particular route as was done in a previous section.

The relative number of flights in a market when route structures are fixed in proportion to the number of flights in a hub-and-spoke route system cannot be determined analytically from these results. However, in general, products offered under conditions of joint production are produced in greater quantity than if joint production were not possible. This is the case, since an airline flight is an example of a public input in the sense of Baumol *et al.*; that is, once a spoke flight is provided, it is capable of providing a variety of different products (1982, 75-77). Thus the lower costs of production permit a firm to offer a larger supply at any particular price. The fixed costs of production can be allocated to the consumers most willing to bear the burden of the fixed cost, that is, those with the least elastic demand for the product. Other classes of consumers will benefit from lower prices for the jointly produced good.

In addition, two crucial assumptions underlie the preceding analysis. First, the number of routes served per point of origin do not vary when airline markets are deregulated. Second, the number of points of origin served by an airline is unchanged after deregulation. Both of these assumptions are invalid for the American experience of deregulation. Thus, as airline flights became joint products because of hubbing and spoking and the number of points served as origins increased, the airlines' demand for aircraft should have increased with deregulation.

From Theory to Empirical Specification

Empirical Specification of the Relationship of Flights per Day to Route Characteristics

The first section of this chapter investigated theories of airline response to various constraints where route structure was accepted as given. This is the situation which airlines faced while regulated. The subsequent section presented an alternative theory whereby airlines alter their route structures into hub-and-spoke systems. In this section, we develop an empirical specification of the relationship between route characteristics and number of flights offered per day on the route which is intended to permit a test of the nature of the relationship.

Each of the previous subsections developed a different relationship between route characteristics and flights per day. (The different results are summarized in table 1.) All employed the same variables to explain the relationship, differing only in functional form. Prederegulation predictions offer the expectation that the number of flights on a route per day will decline with deregulation. In contrast, the theory of hubbing and spoking offered here suggests that the number of flights offered per day should remain constant or increase upon the removal of regulation.

Table 1

Alternative Specifications of the Relationship Between Market Parameters and Number of Flights Offered

1. Completely Served Markets with Free Entry and Unregulated Pricing

$$n_{ij} = \sqrt{\frac{T_{ij}L_{ij}}{F_{ijn}}} \qquad (10b)$$

2. Completely Served Markets with Price Regulation

$$n_r = \frac{(p_f - m)}{(p_r - m)} n_f \qquad (19)$$

3. Serving Two Classes of Consumers in One Market

$$n_i = \sqrt{\frac{(T_1 + T_2)}{2T}} n_f \qquad (32)$$

4. Hub and Spoke Networks (i.e. multiple routes served on one flight)

$$n_h = \sqrt{\frac{\sum_{i=1}^{I} T_i L_i}{F_h}} \qquad (38c)$$

n is number of flights per day on a route except for equation 4, where it is number of flights per day to and from origin. Subscripts indicate differing assumptions used to derive the formulae.

T is the opportunity cost of an air traveler's time, measured in dollars.

L is the population of potential air travelers.

F is the cost of providing a flight on a given route.

As exemplified in table 1, all specifications require number of flights per day to be determined by the population of potential travelers (L), the opportunity costs of the travelers' time (T), and the fixed costs of providing the services (F). Theoretically reasonable proxies must be developed for each of these variables.

The populations of the route terminals are employed as a proxy for L. This is a general practice in making estimates of airline demand (Brueckner 1985). As a proxy for T, the per capita income of the respective route terminals is employed. In addition, the percentage of families with high incomes (more than $15,000 [1974] or $35,000 [1984]) was employed as an opportunity cost variable. Finally, the distance of the route is used as a proxy for the flight costs of serving the route, F.

Two further additions to the model are necessary before it can be estimated econometrically. The first, mandated by theoretical considerations, is the addition of a variable identifying routes that have as a terminal popular vacation destinations. This variable is added to allow for the differences in opportunity cost of pleasure travelers as opposed to business travelers. Use of a dummy variable is a common practice in empirical estimation of airline demand (Ippolito 1981). Alternatively, variables measuring the per capita expenditures at a route terminal on hotels or on both hotels and amusement facilities are used to show the extent of vacation travel on the route.

The other addition to the model to be estimated is a dummy variable for flights which serve as connecting flights. According to the theories presented above, where airlines are able to establish hub-and-spoke route structures, their response will be to increase the number of flights offered from an origin per day. Accordingly, a dummy variable was constructed, taking the value of one (1) when the flight is one providing connections through a third city and zero otherwise.

A final consideration is the functional form in which the relationship should be estimated. The multiplicative nature of the relationships illustrated in table 1, indicates that the independent variables should enter the estimating equations in logarithmic form.

The model to be estimated then is :

(39) $n = c + \alpha_1 \ln POP + \alpha_2 \ln INC + \alpha_3 \ln DIS + \alpha_4 HUBDUM + \alpha_5 VACDUM + \epsilon$

n is number of flights per day on a route, POP is population of the route terminals, INC is per capita income of the route terminals, DIS is the distance of the route, HUBDUM is the dummy variable for connecting as opposed to direct flights described above, and VACDUM is the dummy variable for preferred vacation spots. Population and per capita income enter this equation both separately and combined in different estimates.

Empirical Specification of the Relationship of Equipment Choice to Route Characteristics

The model of the demand for flights in the previous sections is effectively a model of the demand for aircraft, since every flight must have an aircraft assigned to it. However, this model must be extended to provide estimable forms for the relationship between choice of aircraft type and route characteristics.

The choice of aircraft on a particular route is determined by which type is able to provide lowest cost service. However, since realizable demand is different at different times of day, differing aircraft may exhibit least-cost characteristics over the course of the day. The number of flights per day must equal the number of aircraft of all types used to provide flights on the route during the day, or :

$$(40) \qquad n_i = \sum_l K_l$$

The right hand side of this expression is substituted directly into the left hand side of the estimating form developed in the previous section, which yields:

$$(41) \qquad \sum_l K_l = c + \alpha_1 \ln POP + \alpha_2 \ln INC + \alpha_3 \ln DIS$$
$$+ \alpha_4 \, HUBDUM + \alpha_5 \, VACDUM + \epsilon$$

To derive the estimating relationship between any particular aircraft type and route characteristics, the expression must be rearranged, yielding:

$$(42) \qquad K_1 = c + \alpha_1 \ln POP + \alpha_2 \ln INC + \alpha_3 \ln DIS + \alpha_4\, HUBDUM + \alpha_5\, VACDUM - \sum_{l=2}^{m} \beta_l K_l + \epsilon$$

where K_1 is the quantity of aircraft variety one and $\sum_{l=2}^{m} \beta_l K_l$ is the total of all other varieties of aircraft employed on the route. There is a system of m such equations. The relationship of each aircraft variety to the characteristics of a route can be determined by applying the principle of cost minimization. In other words, given the cost performance of each aircraft type as relevant variables change, the model developed above can make detailed predictions about the manner in which aircraft deployments will alter with deregulation.

Empirical Specification of the Relationship of Fleet Composition to Route Characteristics

The analysis of the preceding subsection has illustrated how the number of airline flights (and thus the number of aircraft employed) on a given route depends on market characteristics such as density (i.e., the number of passengers in the market), value of time of passengers in the market and the cost of offering a flight (chiefly determined by aircraft choice). In this section, the analysis will be extended to the choice of number of aircraft when an airline serves many different routes from many different points of origin.

The number of flights offered on any particular route is determined by the theory outlined above. When an airline offers flights on many different routes from a single point of origin, the number of flights the airline is able to offer from that point of origin is :

(43) $$N_j = \sum_i n_{ij}$$

where N_j is total flights from point j, and n_{ij} is the number of flights per day on route i from point j. It is assumed that each aircraft is able to provide only one flight per day on a route from any point of origin, although an aircraft may serve several different routes, each with a different point of origin, in one day. Thus the minimum number of aircraft required by the airline is:

(44) $$\sum_l K_l \geq \max \sum_i n_{ij}$$

where K_l is the number of aircraft of type l in the airlines fleet, and the total of all aircraft in the fleet must be greater than or equal to the number of flights offered per day from the the point of origin with the largest number of originations per day.

If this constraint is not binding, the total number of flights offered by the airline will be:

(45) $$N_T = \sum_j \sum_i n_{ij}$$

where N_T is total number of flights offered over a network of j points of origin and i routes served per origin.

In addition, since an aircraft must be assigned to every flight, total flights will also be :

(46) $N_T \geq \sum_l c_l K_l$

where c_l is the average number of flights per day for aircraft of type l. This relationship must be expressed as an inequality, because aircraft characteristics may be such that some types of aircraft are not usable on some routes. Thus, aircraft may be used at less than full capacity in an airline's fleet. Assuming profit-maximizing behavior on the part of airlines, however, the relationship expressed in equation 16 should tend towards equality. Thus an airline's total capital should approximate:

(47) $\sum_l c_l K_l = \sum_i \sum_j n_{ij}$

Substituting for n_{ij} from equation 10b and rearranging yields:

(48) $K_n = \frac{1}{c_n} \left(\sum_i \sum_j \sqrt{\frac{T_{ij} L_{ij}}{F_{ijn}}} - \sum_{l=1}^{n-1} c_l K_l \right)$

In this equation, K_n is the number of aircraft of type n held by an airline, c_n the average number of flights per day by an aircraft of type n. T_{ij} is the opportunity cost per unit of deviation for a passenger on the ith route from origin j taking a flight departing at a time other than the passenger's preferred time. L_{ij} is the population of potential passengers on route i from origin j. These passengers are making the choice between some alternative mode of transport and flying. F_{ijn} is the cost of a flight on the ith route from the jth origin when aircraft of type n is used.[9] There is a simultaneous system of n such equations which can be solved for unique values of each K_n.

In the econometric analysis which follows, a different set of proxies is employed for the independent variables in the regression. The classification of airline origins and destinations as large, medium, and small hubs is assumed to be related to the demand characteristics of hubs. The inner summation in the equation above (representing the product of the potential passengers and the opportunity cost of those passengers' time) is proxied for each airline by the average number of passengers per day served in each hub classification. The number of each type of hub served then enters as a significant variable for characterizing the total scope of the airline's operations. This is similar to the procedure followed by Gillen et al.(1985). In other words, the total number of hubs served is the index of summation of the outer summation, j. Each class of hub enters the estimating equation separately. Average stage length here serves as a proxy for F_{ijn}, the fixed costs of providing a flight. The estimating form then becomes:

$$(49)\quad K_n = C + \beta_1 L + \beta_2 M + \beta_3 S + \beta_4 RPE + \beta_5 ASL + \sum_{i=1}^{n-1} c_i K_i + \epsilon$$

where K_n is the number of aircraft of type n in an

9 F_{ijn}, under the assumptions of this model, always achieves the smallest attainable value on the route for the type of aircraft actually employed.

airlines fleet, L is the number of large hubs an airline serves, M is the number of medium hubs served, S is the number of small hubs served, RPE is revenue passenger emplanements, or, the number of passengers served annually, and ASL is the airlines average stage length.

There is a system of these equations, one for each type of aircraft. In addition, the relative percentages of different types of aircraft are employed as a dependent variable.

Summary of Results

Let us summarize what our theory leads us to expect. The analysis began with a stylized model of the demand for airline flights. This model permits prediction of the number of flights per day that a market could support. The number of flights was related to the population of potential customers, the opportunity costs of not having a flight depart at the desired time, and the costs of providing a flight which do not vary with the number of passengers per flight. These results are presented as the first entry in table 1. The capital (i.e., aircraft) requirements of an airline, in terms of the number of flights per day that an airline offers from all of the origins it serves, were then determined.

A series of extensions to the model were developed. First to be investigated was the response of airlines to the regime of price and entry regulation. As illustrated in the second entry of table I, the number of flights per day should be increased by the imposition of price regulation.

Next, the problem of fleet composition was considered. When load factor (i.e., percentage of aircraft capacity actually used) is held constant, average costs decline as larger aircraft are used. Thus, the largest aircraft capable of minimizing average costs will be employed on a route.

Where airline competition is limited to competition over flight frequency, smaller aircraft will actually be employed. This occurs because higher frequency, given a fixed population of potential customers, means fewer passengers per flight. Average costs of a flight can then only be minimized by high-load factors on smaller aircraft.

Results to this point merely duplicated predictions which were made prior to deregulation. They imply that airlines entered deregulation with aircraft fleets which contained too many aircraft for efficient operations. Additionally, they possessed relatively too many smaller aircraft.

The results of subsequent sections yielded the opposite conclusion. The ability of airlines to use demand for flight frequency as a method of segregating passengers in order to practice price discrimination was investigated. Then, hubbing and spoking was analyzed as a problem of joint production. The results indicate that airline responses to deregulation were more sophisticated than economists had predicted. In particular, route restructuring into hub-and-spoke systems coupled with price discrimination meant increased flight frequencies. Thus, smaller aircraft types remained in use to provide high-flight frequencies on lower- density spokes. Larger aircraft were used on both high density spokes and interhub flights. Route restructuring permitted airlines to realize economies with their existing fleets.

Prederegulation predictions about airline fleet composition imply a different set of empirical outcomes than the theory developed here. In particular, they predicted that flight frequencies should fall on most individual routes and that the average size of aircraft employed should increase. Finally, the theoretical models developed previously were used to develop the empirical specifications needed to test the performance of airlines when deregulation occurred. In the next chapter, the results of the empirical investigations are reported.

CHAPTER IV

EMPIRICAL TESTS

In this chapter the hypotheses developed in the previous chapter are subjected to empirical test. Two distinct sets of tests will be conducted. In the first set reported, tests of the relationship of market characteristics to aircraft assignments and routings are conducted. In the second, the relationship of airline route structures and the gross composition of their fleets is tested.

As discussed in the previous chapter , an airline's demand for aircraft can be explained in terms of the demand characteristics of the markets served and the economic and regulatory environment. The variables presented in the theory are not represented exactly by any data sources readily available. In order to perform econometric estimates, proxies must be found for four distinct varieties of variables.

The first is aircraft types. Two distinct sources of data were consulted to develop models of aircraft utilization. The aircraft data for the route level estimates presented in chapter 3 comes from the July 1974 and July 1984 editions of The Official Airline Guide, North American Edition.

The demographic and other market demand-related data are derived from supplements to The Statistical Abstract of the United States and other U.S. government publications. These were supplemented as necessary by commercially available data sources. [1]

For the second set of regressions the primary source of data was The Handbook of Airline Statistics, published biennially between 1963 and 1973, with a supplement published for the years 1974 and 1975. This data source was supplemented for years after 1976 by The Inventory and Age of Aircraft Trunks and Locals, prepared by the Office of Economic Analysis of the CAB and the Air Transport Association's Annual Report for 1983 and 1984. In these data sources, different models of aircraft were classified according to their body style (i.e., either narrow bodied or wide bodied.) In addition, aircraft are classified by type and number of engines. These data were collected for the period 1963-1984 and consisted of the inventory of each of the CAB-defined types of aircraft in carriers fleets as of December 31 of a given year.

1 The nature and sources of the data are described in greater detail in Appendix A.

The descriptive statistics used to characterize the route structure of the carriers were constructed from Airport Activity Statistics of Certificated Route Carriers reported annually for the years 1963-1984. In using this data, the conventions of the FAA in classifying airports as large,medium, small hubs, and non-hubs, depending on the percentage of U.S. airline passenger emplanements, was adopted. Airline route structures were characterized by the numbers of each hub classification that they served and the total number of revenue passenger emplanements each airline experienced.[2]

The chapter consists of three sections. First, the results of tests of the model relating route characteristics to number of flights offered per day are reported. Second, the results for aircraft assignment on individual routes are reported. Finally, the empirical results related to gross fleet composition are reported.

The Relationship of Number of Flights to Route Characteristics

In this section of the chapter, data drawn from The Official Airline Guide are used to test the theoretical results derived in the previous chapter. The validity of

2 Large hubs have more than 1% of US passenger emplanements. Medium hubs have between 0.99% and 0.50% of US passenger emplanements. Small hubs have between 0.49% and 0.25% of emplanements. Non-hubs emplane fewer than 0.25% of U.S. airline passengers.

the general model is tested by a simple regression of the number of flights per day on a specific route against the population, real income, and distance of the route for both of the years 1974 and 1984. In the second set of tests, the utilization of specific varieties of aircraft on a route is regressed against the same demographic and technical variables using two stage least squares techniques.

In chapter 3 the result was derived that indicated the number of flights offered in a particular airline market (i.e., on a specific route) would depend on three factors. These are, first, the density of potential purchasers of the transportation service. The second is the cost to passengers of not receiving the precise variety of the product (i.e., time of departure) which they prefer. These costs depend both on the availability of alternative modes of transportation and the distance of the route. The final independent variable is the cost of providing service on the route, known in the context of the airline industry as the flight costs.

In the text of chapter 3, a number of variants of a basic formula are developed dependent upon market structure, regulatory environment and carrier strategies. (See table 1 above for a summary of the theoretical results derived in chapter 3.) The purpose of this chapter is to determine which of the different theoretical treatments in chapter 3 correctly describes the airline response to deregulation. The maintained hypothesis of this dissertation is that aircraft choice was not distorted by regulation but that airline utilization patterns were.

The basic estimating equation is equation (40) of chapter 3, reproduced below .

$$(40) \quad n = c + \alpha_1 \ln POP + \alpha_2 \ln INC + \alpha_3 \ln DIS + \alpha_4 HUBDUM + \alpha_5 VACDUM + \epsilon$$

The results of these regressions for both 1974 and 1984 are reported in table 2.

All estimates using the basic functional form outlined above are highly significant with F-statistics greater than ten. This implies, with a sample size of 657, that there is less than one chance in one thousand that the relationship is one arising from chance. The R^2 associated with these estimates are quite modest--approximately 0.1. The coefficients for the population proxies are uniformly significantly different from zero at the 5% level, as are the constant terms.

Average income per capita is significant in only one equation. Route distance has a significant negative coefficient of approximately -0.5. All of the coefficients of route distance are not significantly different from the value of -0.5. This is of particular interest, since all of the theoretical models specified above imply a coefficient of precisely this value when the equation is

TABLE 2

THE RELATIONSHIP OF NUMBER OF FLIGHTS PER DAY TO ROUTE CHARACTERISTICS

DEPENDENT VARIABLE	NUMBER OF FLIGHTS '74	NUMBER OF FLIGHTS '74	NUMBER OF FLIGHTS '84	NUMBER OF FLIGHTS '84
CONSTANT	-27.711	-35.649*	-38.062*	-41.002*
	15.407	15.377	13.644	13.573
ORIGIN POPULATION	0.858*		0.261	
	0.141		0.143	
DESTINATION POPULATION	0.701*		0.890*	
	0.135		0.243	
COMBINED POPULATION		1.305*		1.094*
		0.219		0.216
AVERAGE OF ORIGIN AND DESTINATION PER CAPITA INCOME	1.472	2.559	2.859	3.218*
	1.974	1.979	1.596	1.587
ROUTE DISTANCE	-0.532*	-0.431*	-0.519*	-0.503*
	0.173	0.172	0.159	0.159
HUB DUMMY	-1.575*	-1.144*	0.305	0.358
	0.435	0.424	0.389	0.389
VACATION SPOT DUMMY	-0.237	-0.272	-0.762*	-0.740*
	0.358	0.361	0.327	0.327
R-SQUARED	0.100	0.082	0.099	0.095
ADJ R-SQ	0.092	0.075	0.091	0.088
F-STATISTIC	12.083*	11.570*	11.964*	13.645*

ALL EQUATIONS ESTIMATED WITH 657 OBSERVATIONS AND ARE SIGNIFICANT AT THE 99% LEVEL. STARRED COEFFICIENTS ARE SIGNIFICANTLY DIFFERENT FROM ZERO AT THE 5% LEVEL. STANDARD ERRORS OF THE COEFFICIENTS ARE REPORTED BELOW THE COEFFICIENT.

estimated in log-linear form.

An interesting pattern develops in the case of the two dummy variables. The dummy for connecting flights is significantly different from zero only for the regressions on 1974 data. The vacation dummy, introduced to allow for the lower value of time of vacationers as opposed to business travelers, is only significantly different from zero for regressions run on 1984 data.

Each of these results presents no problem of interpretation for our theoretical framework. In the case of the hub dummy, the 1974 (i.e., pre-deregulation) coefficient values are negative. This represents the fact that before deregulation, airlines were not able to systematically provide connecting flights through "hubs" as they can today. During the regulatory period, airlines were not able to improve connections, since regulatory approval was required for scheduling additional connections on new routes.

In the case of the vacation dummy, the significant negative coefficients are precisely of the sign predicted. A lower value of time on a particular route, all other things being equal, indicates that fewer flights should be scheduled. The fact that this variable is statistically significant only in 1984 indicates that airlines were able to employ the greater pricing freedom enjoyed under deregulation.

In the era before deregulation, airlines were constrained by the presence of competition in the form of charter flights to popular vacation destinations. Thus, since they were unable to compete on price, they competed for vacation travelers in the same manner as all other travelers--with flight frequency. Deregulation permitted airlines to use price to compete for the vacation traveler, which in turn allowed them to decrease flight frequencies on routes connecting with popular vacation spots.

Specific Aircraft Types and Route Characteristics

Econometric Procedure

In the preceding section it was established that the model developed in chapter 3 was a good predictor of the number of flights scheduled on a particular route. In this section the model as extended is applied to allocation of specific types of aircraft to particular markets. The basic model to be utilized was presented in equation 40 above. Two distinct sets of equations are estimated. In the first set, the dependent variable is the average number of seats flown on a route per day. This is computed by taking the maximum number of seats for each type of aircraft actually flown on the route and multiplying it by the number of flights using that variety of aircraft. This number is then divided by total flights per day on the route. These results are reported in table 3. They will

TABLE 3
THE RELATIONSHIP OF AVERAGE SEATS PER FLIGHT
AND ROUTE CHARACTERISTICS
(VARIABLES IN NATURAL FORM)

DEPENDENT VARIABLE	AVERAGE SEATS '74	AVERAGE SEATS '84
CONSTANT	-68.713*	-113.578
	33.140	23.017
ORIGIN POPULATION	5.358×10^{-6}*	1.119×10^{-6}
	1.272×10^{-6}	1.322×10^{-6}
DESTINATION POPULATION	5.444×10^{-6}*	2.558×10^{-6}*
	1.052×10^{-6}	9.570×10^{-7}
ROUTE DISTANCE	4.731	10.779*
	2.887	2.397
HUB DUMMY	13.680*	40.097*
	7.102	5.817
ORIGIN PER CAPITA INCOME	0.0103*	0.00294*
	0.0050	0.00126
DESTINATION PER CAPITA INCOME	0.00313	0.00264*
	0.00475	0.00132
R-SQUARED	0.133	0.211
ADJ R-SQ	0.125	0.204
F-STATISTIC	16.668*	28.948

ALL EQUATIONS ESTIMATED WITH 657 OBSERVATIONS AND SIGNIFICANT AT THE 99% LEVEL. STARRED COEFFICIENTS ARE SIGNIFICANTLY DIFFERENT FROM ZERO AT THE 5% LEVEL. UNDERLINED COEFFICIENTS ARE SIGNIFICANTLY DIFFERENT FROM ZERO. STANDARD ERRORS OF THE COEFFICENTS ARE REPORTED BELOW THE COEFFICIENT.

be discussed in the following section with the results reported for individual aircraft types.

In the second set of equations, the dependent variable is the number of each variety of aircraft flown on the route. The form of the estimating equation actually appropriate to relating specific types of aircraft to particular routes is equation (43), reproduced below.

$$(43) \quad K_i = c + \alpha_1 \ln POP_i + \alpha_2 \ln INC_i + \alpha_3 \ln DIS_i + \alpha_4 HUBDUM_i + \alpha_5 VACDUM_i - \sum_{l=2}^{m} \alpha_l K_{li} + \epsilon$$

In order to estimate this set of equations, both the natural logarithms of the proxies for T_i, L_i, $F_i n$ and untransformed values of the data were employed. The same proxies are employed as were used in estimating the general model. In determining the varieties of capital to be utilized as K_n, the same classifications used were the classifications employed by the CAB and the FAA.[3] These were chosen for two reasons. First, this permits comparisons with the panel data results reported later. Second, more detailed breakdown of types of aircraft would require treatment of the idiosyncrasies of individual airlines' fleets. (e.g., for many years only United and Western among the majors flew Boeing 737s). In other words, both the type of route served and the type of aircraft are related to a third (unobserved) variable, the

3 Aircraft were classified by the CAB and FAA, according to their body style (i.e., either narrow or wide bodied) and the number and type of their engines. It is an important assumption of these econometric results that the categories employed by the FAA and CAB for aircraft make economically meaningful distinctions.

airline holding the route franchise, when aircraft types are treated at too high a level of detail.

Theoretical Expectations

Before analyzing the regression results, the *a priori* predictions of the theoretical model should be reviewed. Increased density of potential customers should cause an increase in the number of flights offered in the market, *ceteris paribus*. Thus we expect this parameter to have a positive coefficient. However, this result is strictly true only when the supplier of airline flights is limited to a single type of aircraft. Typically the scheduler has several types of aircraft which will have lowest average cost at different levels of usage. The aircraft with lowest average cost at low volumes of traffic is usually the smallest. As volume of traffic rises, larger aircraft become the lowest cost variety of aircraft in roughly increasing order of capacity. Assuming cost minimization, smaller aircraft would be expected to have smaller coefficients with respect to population, while larger aircraft will have larger coefficients.

Since prior treatments of regulation maintain that it causes too many flights to be scheduled, previous treatments of deregulation implied that smaller aircraft types would experience decreases in relation to route density relative to larger aircraft. The alternative theoretical model of this dissertation implies that this not need be the case.

The theoretical model indicates that increases in the opportunity cost of a flight not leaving at the preferred time will lead to an increase in the number of flights offered. A cost minimization assumption leads to the expectation that as the number of flights is increased the size of aircraft employed will decrease. Thus the proxy employed in these regressions, per capita income, is expected to have a positive sign for smaller aircraft and a negative sign for larger aircraft.

An increase in flight costs, all other things equal, should result in a decreased number of flights offered. It is expected that the costs of a flight increase with distance, thus the number of flights should decrease as distance increases. Another reason for this expectation is that as distance increases, the opportunity cost of alternative means of transportation also increases. In fact, alternative transportation modes experience relatively greater increases in opportunity cost than air travel. Thus the opportunity cost of air travel, in terms of waiting for a flight, can rise significantly without a loss of customers to alternative modes. A final consideration, cost minimization, also comes into play; the largest aircraft have the lowest average cost per passenger on longer flights. Thus the expectation is that smaller aircraft have negative parameters in route distance while larger aircraft possess positive coefficients.

The treatment of the response of airlines to price regulation of the sort to which they were subjected prior to 1976 indicated that airlines did not minimize costs. This was true because airlines responded to regulation of their prices by reducing the opportunity cost of the air traveler through increased flight frequency. Thus smaller aircraft should be expected to be more heavily utilized in the earlier sample period (1974). In the later, post-deregulation period, larger aircraft should be more heavily utilized.

However, as previously asserted, earlier arguments about the effects of deregulation ignore airlines' ability to achieve better aircraft utilization by changing the structure of their route networks. As the theoretical treatment of hub-and-spoke networks in the previous chapter suggests, hubbing and spoking is a means for airlines to spread the flight costs over several classes of customer. It is thus an example of the problem of pricing a joint product. Hub-and-spoke route structures should result in a larger number of flights offered than linear route structures, common before deregulation.

The general principles outlined above can be used to make specific predictions about the relationships of the number of a given aircraft employed on a route and the characteristics of that route. In addition, it is possible to make predictions about the how the parameter values will change subsequent to deregulation. As an example of the process of deriving such predictions from the theory of hubbing and spoking, the behavior of three-engined regular bodied jets is analyzed below. Detailed predictions of the sign and post-deregulation behavior of all parameters for each dependent variable are provided in table 4.

Three-engine regular bodied aircraft are among the most versatile of the aircraft types available to the airlines during the sample period. Their most important limitation is their limited capacity of only about 120-150 seats, depending on the configuration adopted. As is expected for all aircraft types, increased market size will cause an increase in the number of aircraft employed on a route. The effect of deregulation in the hub-and-spoke model presented here is to increase the effective demand for a flight, since any flight serves many different routes. Thus the value of this parameter should increase with deregulation.

Distance, as an independent variable, is expected to have a negative sign for two reasons. First, it is the expectation of the theory in general that increased distance will cause a decrease in the number of flights. In addition, theory leads to the expectation that increased route distance will result in a movement towards larger aircraft. In the environment after deregulation, the

TABLE 4
COMPARISONS OF THEORETICAL PREDICTIONS AND EMPIRICAL RESULTS: ROUTE LEVEL DATA

PART I
Dependent variable is number of flights by all types of aircraft per day

INDEPENDENT VARIABLE	EXPECTED SIGN 74	OBSERVED SIGN 74	EXPECTED CHANGE 84	OBSERVED CHANGE
POPULATION	+	+	?	NO CHANGE
FLIGHT COSTS (DISTANCE)	-	-	DECREASED ABSOLUTE VALUE	NO CHANGE
HUB DUMMY	-	-	INCREASED MAGNITUDE	YES
INCOME	+	+	DECREASED MAGNITUDE	?
VACATION	-	-	DECREASED ABSOLUTE VALUE	YES

+ means the parameter is expected to be or measured as positive, - means the parameter is expected to be or measured as positive, ? means sign is ambiguous.

Dependent variable is average number of seats per flight

INDEPENDENT VARIABLE	EXPECTED SIGN 74	OBSERVED SIGN 74	EXPECTED CHANGE 84	OBSERVED CHANGE
POPULATION	+	+	?	DECREASED MAGNITUDE
FLIGHT COSTS (DISTANCE)	+	+	INCREASED MAGNITUDE	YES
HUB DUMMY	+	+	INCREASED MAGNITUDE	YES
INCOME	-	+	DECREASED MAGNITUDE	YES
VACATION	+	N.A.	N.A.	N.A.

PART II
Dependent variable is number of flights
by a type of aircraft per day
PROPELLER

INDEPENDENT VARIABLE	EXPECTED SIGN 74	OBSERVED SIGN 74	EXPECTED CHANGE 84	OBSERVED CHANGE
POPULATION	+	+	DECREASED MAGNITUDE	?
FLIGHT COSTS (DISTANCE)	-	-	INCREASED ABSOLUTE VALUE	YES
HUB DUMMY	+	-	DECREASED MAGNITUDE	YES
INCOME	+	+	DECREASED MAGNITUDE	NONE
VACATION	-	-	INCREASED ABSOLUTE VALUE	?

+ means the parameter is expected to be or measured as positive, - means the parameter is expected to be or measured as positive, ? means sign is ambiguous.

Two-engine NARROW-BODY

INDEPENDENT VARIABLE	EXPECTED SIGN 74	OBSERVED SIGN 74	EXPECTED CHANGE 84	OBSERVED CHANGE
POPULATION	+	+	?	NONE
FLIGHT COSTS (DISTANCE)	-	-	INCREASED ABSOLUTE VALUE	NO
HUB DUMMY	+	-	INCREASED MAGNITUDE	YES
INCOME	+	?	DECREASED MAGNITUDE	?
VACATION	-	?	INCREASED ABSOLUTE VALUE	YES

Three-engine NARROW-BODY

INDEPENDENT VARIABLE	EXPECTED SIGN 74	OBSERVED SIGN 74	EXPECTED CHANGE 84	OBSERVED CHANGE
POPULATION	+	+	INCREASED MAGNITUDE	INCREASED MAGNITUDE
FLIGHT COSTS (DISTANCE)	-	?	DECREASED ABSOLUTE VALUE	YES
HUB DUMMY	+	+	INCREASED MAGNITUDE	?
INCOME	+	+	DECREASED MAGNITUDE	INCREASED MAGNITUDE
VACATION	-	?	DECREASED ABSOLUTE VALUE	NO

+ means the parameter is expected to be or measured as positive, - means the parameter is expected to be or measured as positive, ? means sign is ambiguous.

four-engine NARROW-BODY

INDEPENDENT VARIABLE	EXPECTED SIGN 74	OBSERVED SIGN 74	EXPECTED CHANGE 84	OBSERVED CHANGE
POPULATION	+	+	AIRCRAFT TYPE BECAME OBSOLETE	
FLIGHT COSTS (DISTANCE)	+	+		
HUB DUMMY	-	?		
INCOME	-	?		
VACATION	+	?		

THREE-ENGINE WIDE-BODY

INDEPENDENT VARIABLE	EXPECTED SIGN 74	OBSERVED SIGN 74	EXPECTED CHANGE 84	OBSERVED CHANGE
POPULATION	+	+	DECREASED MAGNITUDE	DECREASED MAGNITUDE
FLIGHT COSTS (DISTANCE)	+	+	DECREASED MAGNITUDE	DECREASED MAGNITUDE
HUB DUMMY	-	?	DECREASED ABSOLUTE VALUE	?
INCOME	-	?	DECREASED ABSOLUTE VALUE	?
VACATION	+	?	INCREASED MAGNITUDE	?

+ means the parameter is expected to be or measured as positive, - means the parameter is expected to be or measured as positive, ? means sign is ambiguous.

four-engine WIDE-BODY

INDEPENDENT VARIABLE	EXPECTED SIGN 74	OBSERVED SIGN 74	EXPECTED CHANGE 84	OBSERVED CHANGE
POPULATION	+	+	DECREASED MAGNITUDE	NONE
FLIGHT COSTS (DISTANCE)	+	+	DECREASED MAGNITUDE	YES
HUB DUMMY	-	-(?)	INCREASED ABSOLUTE VALUE	NO CHANGE
INCOME	-	?	DECREASED ABSOLUTE VALUE	MAYBE
VACATION	+	?	INCREASED MAGNITUDE	?

continued use of frequency as a competitive variable leads to the prediction that distance will be less negative. This prediction arises because the three-engine wide-body jet can be employed on both the dense spokes of a hub-and-spoke system and the thin inter-hub routes.

The dummy used to denote connecting flights is expected to have a positive value before deregulation. These aircraft are especially suited to short-haul routes which means that they will be useful to fly spokes.

Income as a variable is expected to be positively related to the number of small aircraft of all types, since an increased opportunity cost of time will lead to more flights being scheduled which, when a firm attempts to minimize costs, implies use of smaller aircraft. In the new environment, where airlines have the flexibility both to hub and to practice price discrimination based on the demand for flight frequency, income should not affect flight frequency as strongly, since high opportunity cost passengers will share flights with other lower opportunity cost passengers.

The variables intended to measure the effect of vacation travel on a route are expected to result in a negative parameter estimate. Since vacationers are presumed to have lower opportunity cost of time, they are assumed to be less sensitive to displacement from desired time of departure. Thus they can be accomodated on larger aircraft. Subsequent to deregulation, the mechanisms of hubbing and spoking and price discrimination, described above in relation to the effects of income on aircraft scheduling, have the opposite effects. In other words, after deregulation, vacationers can be accommodated on the same aircraft as high-value-of-time business travelers, and the effect of a route leading to a popular vacation spot is diminished.

Analysis of Empirical Results

Before addressing the values of the various coefficients reported below, a few general statements can be made about the equations. First, all equations possess a high degree of statistical significance. A second point is that the R^2 achieved are quite modest, ranging from about .035 to .166. With the exception of the equations estimated for the smallest types of aircraft (i.e., propeller-driven and two-engine narrow-bodied jet aircraft), higher correlations and levels of significance are achieved when explanatory variables are entered in their natural rather than logarithmic forms. This may indicate that the relationship of utilization to route characteristics for the smaller aircraft is non-linear.

All of the estimates made using the various combinations of variables yielded significant F-statistics. The various coefficient values of the equations tended to maintain the patterns of significance reported below.

The behavior of variables as shown in table 5 is discussed below. These variables are treated in the same order as the previous section to facilitate comparisons.

Population is discussed first. Coefficients for all aircraft types have the expected positive sign for the population variable. For the propeller driven aircraft, the coefficient is significant only for the 1974 data in log form. For the smallest classes of aircraft, coefficients are significantly smaller than those for three-engine regular bodied jets. (The most important type of aircraft in this category is the Boeing 727, long a workhorse of airline fleets.) This is in accord with the predictions made above. However, the coefficients on population decrease for the larger varieties of aircraft.

The other important aspect of the relationship of aircraft scheduling to population is whether and how much it has changed since the advent of deregulation. The manner in which these relationships changed with deregulation is not, in fact, simple. It was expected that larger aircraft would become more heavily utilized relative to the population of the routes they served. Here the nature of the changes subsequent to deregulation is ambiguous. For the very largest aircraft types (four-engine wide bodies, i.e., the Boeing 747), there is no evidence of any change. For the next smaller size class, there is limited evidence for an actual decrease in the coefficient of population. On the other hand, the relationship of population to the utilization of three-engine regular-bodied aircraft shows an unambiguous increase. In other words, increases in population on a route lead to heavier utilization of these aircraft. Two-engine jets show some evidence of also experiencing increased utilization in more populous markets after deregulation. Propeller-driven aircraft give slight evidence of a decline in this relationship. Overall, the evidence disconfirms the naive prederegulation predictions about aircraft utilization patterns subsequent to deregulation, but is consistent with the predictions of the theory, including hubbing.

The income coefficients are almost all statistically insignificant. Two factors probably serve to explain this. First, per capita income is a very weak proxy for the opportunity cost of an air traveler's time. About the only thing which can be said in favor of it is that the data is readily available. Second, some of the effects of the opportunity costs of time may be captured in the variable measuring route distance.

For the only aircraft type where the coefficients on income are generally significant (three-engine narrow-bodied aircraft), they are uniformly greater than zero. There is also strong evidence that these coefficients increased with deregulation, approximately doubling. For other aircraft types, the only other statistically

TABLE 5

FLIGHTS PER DAY - INDEPENDENT VARIABLES IN NATURAL FORM

ALL EQUATIONS ESTIMATED WITH 657 OBSERVATIONS AND ARE SIGNIFICANT AT THE 99% LEVEL. STARRED COEFFICIENTS ARE SIGNIFICANTLY DIFFERENT FROM ZERO AT THE 5% LEVEL. STANDARD ERRORS ARE REPORTED BENEATH COEFFICIENTS.

PART A: PROPELLOR-DRIVEN AIRCRAFT

DEPENDENT VARIABLE	NUMBER OF FLIGHTS '74	NUMBER OF FLIGHTS '74	NUMBER OF FLIGHTS '84	NUMBER OF FLIGHTS '84
CONSTANT	0.338	0.328	1.220*	1.250*
	0.310	0.310	0.480	0.480
ORIGIN		1.059D-08		-5.411D-09
POPULATION		1.253D-08		2.254D-08
DESTINATION		1.622D-08		1.564D-08
POPULATION		1.042D-08		2.162D-08
COMBINED	1.419D-08		5.222D-09	
POPULATION	8.387D-09		1.639D-08	
ORIGIN PER CAPITA		5.356D-05		4.915D-05
INCOME		4.938D-05		5.996D-05
DESTINATION PER CAPITA		5.086D-06		-8.465D-05
INCOME		4.690D-05		6.250D-05
AVERAGE OF ORIGIN AND DESTINATION	5.581D-05		-2.971D-05	
PER CAPITA INCOME	6.750D-05		8.797D-05	
ROUTE	-0.000278*	-0.000278*	-0.000520*	-0.000517*
DISTANCE	4.318D-05	4.320D-05	8.136D-05	8.130D-05
HUB	-0.396*	-0.396*	-0.432*	-0.426*
DUMMY	0.071	0.071	0.132	0.132
VACATION	-0.0135		-0.0271	
SPOT DUMMY	0.061		0.111	
R-SQUARED	0.0853	0.0859	0.0802	0.0836
ADJ R-SQ	0.0783	0.0775	0.0732	0.0752
F-STATISTIC	12.141	10.184	11.355	9.884

TABLE 5
PART B: TWO-ENGINE REGULAR-BODIED AIRCRAFT

DEPENDENT VARIABLE	NUMBER OF FLIGHTS '74	NUMBER OF FLIGHTS '74	NUMBER OF FLIGHTS '84	NUMBER OF FLIGHTS '84
CONSTANT	0.813 0.584	0.872 0.582	1.018 0.670	0.926 0.673
ORIGIN POPULATION		4.498D-08 2.351D-08		4.786D-08 3.162D-08
DESTINATION POPULATION		2.277D-08 1.955D-08		4.977D-08 3.033D-08
COMBINED POPULATION	3.452D-08* 1.581D-08		4.496D-08* 2.286D-08	
ORIGIN PER CAPITA INCOME		-0.0001045 8.803D-05		-1.930D-05 8.411D-05
DESTINATION PER CAPITA INCOME		0.0001140 9.268D-05		1.650D-05 8.768D-05
AVERAGE OF ORIGIN AND DESTINATION PER CAPITA INCOME	1.927D-05 0.0001273		-5.576D-06 0.0001227	
ROUTE DISTANCE	-0.000561* 8.142D-05	-0.000557* 8.108D-05	-0.000422* 0.000114	-0.000428* 0.000114
HUB DUMMY	-0.158 0.133	-0.150 0.133	0.304 0.185	0.294 0.185
VACATION SPOT DUMMY	0.0163 0.114		-0.343* 0.155	
R-SQUARED	0.0713	0.0803	0.0428	0.0358
ADJ R-SQ	0.0642	0.0718	0.0354	0.0269
F-STATISTIC	9.996	9.463	5.821	4.025

TABLE 5

PART C: THREE-ENGINE REGULAR-BODIED AIRCRAFT

DEPENDENT VARIABLE	NUMBER OF FLIGHTS '74	NUMBER OF FLIGHTS '74	NUMBER OF FLIGHTS '84	NUMBER OF FLIGHTS '84
CONSTANT	-1.195 0.726	-1.191 0.727	-4.212* 0.848	-4.305* 0.850
ORIGIN POPULATION		1.211D-07* 2.937D-08		1.395D-07* 3.994D-08
DESTINATION POPULATION		9.802D-08* 2.442D-08		1.703D-07* 3.831D-08
COMBINED POPULATION	1.055D-07* 1.966D-08		1.514D-07* 2.892D-08	
ORIGIN PER CAPITA INCOME		0.000107 0.000116		0.000392* 0.000106
DESTINATION PER CAPITA INCOME		0.000241* 0.000110		0.000376* 0.000111
AVERAGE OF ORIGIN AND DESTINATION PER CAPITA INCOME	0.000357* 0.000158		0.000765* 0.000155	
ROUTE DISTANCE	-0.000283* 0.000101	-0.000284* 0.000101	-0.000138 0.000144	-0.000145 0.000144
HUB DUMMY	-0.120 0.166	-0.123 0.166	0.449 0.233	0.438 0.234
VACATION SPOT DUMMY	-0.0836 0.142		-0.373 0.197	
R-SQUARED	0.0742	0.0748	0.147	0.143
ADJ R-SQ	0.0671	0.0662	0.141	0.135
F-STATISTIC	10.430	8.753	22.484	18.0827

TABLE 5
PART D: FOUR-ENGINE REGULAR-BODIED AIRCRAFT

DEPENDENT VARIABLE	NUMBER OF FLIGHTS '74	NUMBER OF FLIGHTS '74	NUMBER OF FLIGHTS '84	NUMBER OF FLIGHTS '84
CONSTANT	-0.155 0.457	-0.1786001 0.460		
ORIGIN POPULATION		6.727D-08* 1.850D-08		
DESTINATION POPULATION		7.038D-08* 1.538D-08		
COMBINED POPULATION	6.901D-08* 1.238D-08			
ORIGIN PER CAPITA INCOME		4.642D-05 7.291D-05		
DESTINATION PER CAPITA INCOME		-2.405D-05 6.926D-05		
AVERAGE OF ORIGIN AND DESTINATION PER CAPITA INCOME	1.921D-05 9.964D-05			
ROUTE DISTANCE	0.000199* 6.374D-05	0.000198* 6.379D-05		
HUB DUMMY	-0.153 0.104	-0.153 0.104		
VACATION SPOT DUMMY	-0.0725 0.0894			
R-SQUARED	0.0971	0.0970		
ADJ R-SQ	0.0902	0.0886		
F-STATISTIC	14.006	11.634		

Note: There were not sufficient observations available to run regression for four-engined regular-bodied aircraft in 1984, due to the technological obsolescence of the class.

TABLE 5
PART E: THREE-ENGINE WIDE-BODIED AIRCRAFT

DEPENDENT VARIABLE	NUMBER OF FLIGHTS '74	NUMBER OF FLIGHTS '74	NUMBER OF FLIGHTS '84	NUMBER OF FLIGHTS '84
CONSTANT	-0.292 0.536	-0.277 0.537	-0.475 0.273	-0.470 0.273
ORIGIN POPULATION		9.758D-08* 2.167D-08		5.775D-08* 1.284D-08
DESTINATION POPULATION		8.557D-08* 1.802D-08		6.414D-08* 1.232D-08
COMBINED POPULATION	9.049D-08* 1.451D-08		6.103D-08* 9.325D-09	
ORIGIN PER CAPITA INCOME		-1.068D-05 8.544D-05		3.389D-05 3.417D-05
DESTINATION PER CAPITA INCOME		-1.518D-05 8.116D-05		9.713D-06 3.562D-05
AVERAGE OF ORIGIN AND DESTINATION PER CAPITA INCOME	-2.105D-05 0.0001168		4.440D-05 5.006D-05	
ROUTE DISTANCE	0.000371* 7.471D-05	0.000372* 7.475D-05	0.000102* 4.630D-05	0.000102* 4.634D-05
HUB DUMMY	-0.0580 0.122	-0.0572 0.122	-0.0226 0.0753	-0.0219 0.0753
VACATION SPOT DUMMY	-0.0176 0.105		-0.00500 0.0634	
R-SQUARED	0.137	0.137	0.115	0.115
ADJ R-SQ	0.130	0.129	0.108	0.107
F-STATISTIC	20.583	17.178	16.872	14.089

TABLE 5

PART F: FOUR-ENGINE WIDE-BODIED AIRCRAFT

DEPENDENT VARIABLE	NUMBER OF FLIGHTS '74	NUMBER OF FLIGHTS '74	NUMBER OF FLIGHTS '84	NUMBER OF FLIGHTS '84
CONSTANT	0.141	0.141	0.0402	0.0458
	0.131	0.132	0.0939	0.0940
ORIGIN		2.187D-08*		1.905D-08*
POPULATION		5.321D-09		4.413D-09
DESTINATION		2.181D-08*		2.296D-08*
POPULATION		4.425D-09		4.233D-09
COMBINED	2.179D-08*		2.127D-08*	
POPULATION	3.562D-09		3.203D-09	
ORIGIN PER CAPITA		-2.711D-05		-3.884D-06
INCOME		2.098D-05		1.174D-05
DESTINATION PER CAPITA		-2.260D-05		-1.417D-05
INCOME		1.993D-05		1.224D-05
AVERAGE OF ORIGIN AND DESTINATION	-4.968D-05		-1.780D-05	
PER CAPITA INCOME	2.867D-05		1.719D-05	
ROUTE	8.799D-05*	8.795D-05*	2.679D-05	2.714D-05
DISTANCE	1.834D-05	1.835D-05	1.590D-05	1.592D-05
HUB	-0.0449	-0.0450	-0.0389	-0.0383
DUMMY	0.0301	0.0301	0.0259	0.0259
VACATION	0.000158		0.0160	
SPOT DUMMY	0.0257		0.0218	
R-SQUARED	0.117	0.117	0.0884	0.0884
ADJ R-SQ	0.117	0.109	0.0814	0.0800
F-STATISTIC	17.245	14.355	12.619	10.504

significant coefficient is negative (two-engine regular-bodied jet).

As usual, the vacation dummy variable is included to allow for the lower value of time that vacationers are likely to have relative to business travelers. Generally this dummy is not statistically significant at a 5% level. For two-engine jets it is significant in 1984. For four-engine regular-bodied jets it is significant in 1974, while it is significant at the 10% level for three-engine regular bodied jets in 1984. The sign on all of these is negative. This is in accord with the expectation that lower value of time results in fewer scheduled flights on a route.

The coefficients associated with route distance usually differ significantly from zero at the 5% level. For smaller aircraft varieties (i.e., prop and two-engine jets), the parameter values are uniformly negative, as was predicted a priori. Wide-bodied aircraft have positive values, as was also predicted. A more interesting case is three-engine regular bodied jets. Here the sign of the parameter differs between the pre and post deregulation periods. For 1974 data, the parameter was significantly negative, with a value in the log form of about -0.1. In 1984, the parameter value in the logarithmic form was about +0.2. For the variables in natural form, the indicated coefficient value is always negative but apparently rises significantly with deregulation.

The effects of deregulation on these parameters are dramatic. For propeller aircraft, the value of the parameter on route distance doubles in absolute value (i.e. becomes significantly more negative) for both log and natural forms. For two-engine jets, in log form, the value of the parameter increases (i.e., becomes less negative) by about 60%. As mentioned above the parameter value for 3 engine regular bodied aircraft changes dramatically with deregulation. In addition, the parameter values for wide bodied aircraft diminish notably in the later period, falling in absolute value by 40% to 60%. All of these changes are consistent with the reorganization of airline route structures on hub-and-spoke principles. For instance, before deregulation a 2.5% increase in route distance would cause the number of two-engine regular-bodied aircraft employed on a route to fall by one. After deregulation, a 5 % increase in route distance caused the same change. This reflects the greater flight frequencies used as a competitive variable after deregulation, with smaller aircraft employed on the spokes to provide the high frequency.

The final variable to be discussed is the hub dummy. This variable is given a value of one on routes which provide a connecting flight for a route from the original sample. The variable is assigned a value of zero for flights listed as direct in the Official Airline Guide. Only for propeller aircraft is this variable significantly different from zero. Here the value is consistently negative and in the range of 0.4. No other types of aircraft have significant values of this coefficient for all years. For 1974, in the log form, four-engine wide-bodies have a negative and significant coefficient for the hub dummy. In 1984, the log form of the equation for three-engine regular-bodied jets has a significant and positive coefficient, equal to approximately 0.6.

Further evidence regarding the effects of deregulation is shown in table 6. This table reports the results of Chow tests performed on the estimating equations reported here. The null hypothesis tested is that the estimated coefficients were jointly identical for both 1974 and 1984.

These tests produce several interesting results. First, combining 1974 and 1984 observations for the general model--that is, where the dependent variable is the number of flights per day on a particular route--yields a lower residual sum of squares than does estimating each year separately. This is exactly what would be expected when additional observations generated by the same process are added to a regression. The number of flights offered on a route is apparently unaffected by the elimination of regulation.

In addition, it is not possible to reject the null hypothesis of the equality of coefficients for 1974 and 1984 for both three and four-engined wide bodied aircraft. Since such aircraft have been and can only be employed on longer routes with more passengers per day, it is not

TABLE 6

ROUTE LEVEL DATA RESULTS 1974 & 1984

The statistics reported here are calculated as Chow statistics and are distributed as F, with degrees of freedom as reported. They were calculated by combining the data from the 1974 and 1984 samples and running the same regressions as for the separated samples. The null hypothesis is that the coefficients are jointly identical for both 1974 and 1984.

Natural form variables

Aircraft type	Chow - statistic All Fs have 10 & 1292 d.f.
Number of Flights	1.820
Average Seats Per Flight	5.897*
Two-engine Narrow-body	3.924*
Three-engine Narrow-body	2.648*
Four-engine Narrow-body	7.822*
Three-engine Wide-body	2.732*
Four-engine Wide-body	1.124
Propeller	2.475

Logaritmic form variables

Aircraft type	Chow - statistic All F's have 10 & 1292 d.f.
Number of flights	2.422
Average seats per flight	6.934*
Two-engine Narrow-body	6.968*
Three-engine Narrow-body	3.912*
Four-engine Narrow-body	6.900*
Three-engine Wide-body	1.407
Four-engine Wide-body	0.219
Propeller	4.132*

Starred F-statistics indicate that the differences between the coefficients of the equations for the sample years are significantly different from zero at the 5% level.

unreasonable that their patterns of deployment did not change with deregulation.

In other words, even before deregulation wide bodied aircraft were chiefly employed connecting major hubs. Deregulation resulted in no change in this pattern of deployment.

Most of the other Chow statistics indicate a significant change in the relationship of aircraft types and route characteristics. The case where the Chow statistic is not significant at the 5% level--for propeller driven aircraft--the relationship is insignificant at the 5% level for variables estimated in natural form.

The Effects of Route Structure on Fleet Selection

Econometric Procedure

The analysis of chapter 3 demonstrated a relationship between certain demand characteristics of a route and the number of flights that would be offered on that route in a given time period. Tests of this basic relationship derived were presented previously. In this section the composition of an airline's fleet is analyzed as it is affected by the characteristics of the airline's routes.

The hypothesis of this analysis is that an airline's route characteristics determine the numbers and relative frequency of different varieties of aircraft in the fleet.

In addition, the average number of seats on the airline's flights is employed as a dependent for one set of regressions. This analysis uses the number of hubs of each size class defined by the CAB and the number of revenue passenger emplanements of each airline as characterizations of the route structure. The estimating equation presented in chapter 3 as equation (50) is reproduced below.

$$(50) \quad K_n = C + \beta_1 L + \beta_2 M + \beta_3 S + \beta_4 \ RPE + \beta_5 ASL + \sum_{i=1}^{n-1} c_i K_i + \epsilon$$

Since these are panel data each year was identified by a unique dummy variable. Each of these was assigned a value of one for that year and zero for all other years. These dummies control for such unobserved common effects on industry behavior as business cycle effects and industry growth trends (Fomby, Hill, and Johnson 1984).

The results of the regressions using average number of seats is shown in table 7. Selected regression results for specific aircraft types are shown in table 8. This table is divided into two sections. In the first, the dependent variable is the number of aircraft of each type present in an airline's fleet. In the table these are referred to as absolute variables, since the absolute number of a type of aircraft in an airline's fleet is the dependent variable. Five types of aircraft were present in significant quantities in airlines' fleets during the sample period. These are two-, three-, and four-engine regular-bodied jet aircraft, and three- and four-engine wide-bodied jet

TABLE 7
THE RELATIONSHIP OF AVERAGE SEATS PER FLIGHT AND ROUTE CHARACTERISTICS- FLEET DATA
(VARIABLES IN NATURAL FORM)

DEPENDENT VARIABLE	AVERAGE NO. SEATS 63-84	AVERAGE NO. SEATS 63-75	AVERAGE NO. SEATS 76-84
CONSTANT	67.047*	68.076*	75.230*
	7.651	7.515	12.408
NO. LARGE HUBS	1.331*	1.383*	1.272*
	0.428	0.492	0.643
NO. MEDIUM HUBS	-2.913*	-2.057*	-3.864*
	0.377	0.475	0.531
NO. SMALL HUBS	-0.211	-0.418	-0.119
	0.233	0.250	0.409
STAGE LENGTH	0.0950*	0.0696*	0.133*
	0.0084	0.0106	0.0119
REVENUE PASSENGER EMPLANEMENTS	0.00139*	0.00128*	0.00160*
	0.00028	0.00046	0.000354
R-SQUARED	0.836	0.765	0.862
ADJ R-SQ	0.819	0.737	0.841
F-STATISTIC	47.907*	27.506*	42.225*
NUMBER OF OBSERVATIONS	281	185	96
NUMBER OF REGRESSORS	27	19	13

ALL EQUATIONS SIGNIFICANT AT THE 99% LEVEL. STARRED COEFFICIENTS ARE SIGNIFICANTLY DIFFERENT FROM ZERO AT THE 5% LEVEL. UNDERLINED COEFFICIENTS ARE SIGNIFICANTLY DIFFERENT FROM ZERO. STANDARD ERRORS OF THE COEFFICENTS ARE REPORTED BELOW THE COEFFICIENT.

TABLE 8
EQUATIONS RELATING ROUTE STRUCTURE AND NUMBERS OF AIRCRAFT IN AN AIRLINES FLEET

PART A

TABLE 8-PART A ABSOLUTE VARIABLES
SECTION 1 - TWO-ENGINE REGULAR BODIED JETS

DEPENDENT VARIABLE	NUMBER OF PLANES 1963-1984	NUMBER OF PLANES 1963-1977	NUMBER OF PLANES 1978-1984
CONSTANT	-1.733	2.642	50.796*
	7.705	3.365	15.891
NUMBER OF LARGE HUBS SERVED	-0.836*	-1.143*	-1.603*
	0.431	0.424	0.825
NUMBER OF MEDIUM HUBS SERVED	-0.0662	-1.028	-0.256
	0.367	0.408	0.640
NUMBER OF SMALL HUBS SERVED	1.173*	0.939*	2.204*
	0.221	0.195	0.529
AVERAGE STAGE LENGTH	-0.0278*	-0.0135*	-0.0506*
	0.0058	0.0058	0.0110
REVENUE PASSENGERS EMPLANEMENTS	0.00112*	0.00255*	0.000391
	0.00028	0.00037	0.000440
R-SQUARED	0.572	0.642	0.624
ADJ R-SQUARED	0.528	0.603	0.569
F-STATISTIC	13.041*	16.509*	11.460*
NUMBER OF OBSERVATIONS	281	185	96
NUMBER OF REGRESSORS	27	19	13

STARRED COEFFICIENTS ARE SIGNIFICANTLY DIFFERENT FROM ZERO AT THE 5% LEVEL. STANDARD ERRORS OF THE COEFFICIENTS ARE REPORTED BELOW COEFFICIENT. STARRED F-STATISTIC INDICATES SIGNIFICANT AT 5% OR BETTER. COEFFICIENTS OF ANNUAL DUMMY VARIABLES NOT REPORTED.

TABLE 8-PART A ABSOLUTE VARIABLES
SECTION 2 - THREE-ENGINE REGULAR BODIED JETS

DEPENDENT VARIABLE	NUMBER OF PLANES 1963-1984	NUMBER OF PLANES 1963-1977	NUMBER OF PLANES 1978-1984
CONSTANT	-5.080	-0.764	-33.0760*
	6.617	5.118	15.395
NUMBER OF LARGE HUBS	1.302*	1.195*	2.396*
SERVED	0.370	0.341	0.799
NUMBER OF MEDIUM HUBS	-1.075*	-1.467*	0.250
SERVED	0.315	0.328	0.620
NUMBER OF SMALL HUBS	-0.799*	-0.485*	-1.585*
SERVED	0.190	0.157	0.512
AVERAGE STAGE	-0.00355	-0.00391	0.00690
LENGTH	0.00495	0.00463	0.01064
REVENUE PASSENGERS	0.00299*	0.00267*	0.00296*
EMPLANEMENTS	0.00024	0.00030	0.00043
R-SQUARED	0.754	0.706	0.696
ADJ R-SQUARED	0.728	0.674	0.655
F-STATISTIC	29.889*	22.169*	16.027*
NUMBER OF OBSERVATIONS	281	185	96
NUMBER OF REGRESSORS	27	19	13

STARRED COEFFICIENTS ARE SIGNIFICANTLY DIFFERENT FROM ZERO AT THE 5% LEVEL. STANDARD ERRORS OF THE COEFFICIENTS ARE REPORTED BELOW COEFFICIENT. STARRED F-STATISTIC INDICATES SIGNIFICANT AT 5% OR BETTER. COEFFICIENTS OF ANNUAL DUMMY VARIABLES NOT REPORTED.

TABLE 8-PART A ABSOLUTE VARIABLES
SECTION 3 - FOUR-ENGINE REGULAR BODIED JETS

DEPENDENT VARIABLE	NUMBER OF PLANES 1963-1984	NUMBER OF PLANES 1963-1977	NUMBER OF PLANES 1978-1984
CONSTANT	-29.579*	-25.828*	-33.913*
	7.478	8.0726	10.601
NUMBER OF LARGE HUBS SERVED	0.740	0.523	-0.142
	0.418	0.538	0.550
NUMBER OF MEDIUM HUBS SERVED	2.111*	1.133*	1.626*
	0.356	0.517	0.427
NUMBER OF SMALL HUBS SERVED	-0.393	-0.533*	0.0872
	0.215	0.247	0.353
AVERAGE STAGE LENGTH	-0.0639*	-0.0689*	-0.0455*
	0.0056	0.0073	0.0073
REVENUE PASSENGERS EMPLANEMENTS	0.000591*	0.00220*	9.801×10^{-5}
	0.000275	0.00047	0.000293
R-SQUARED	0.668	0.729	0.550
ADJ R-SQUARED	0.634	0.700	0.485
F-STATISTIC	19.655*	24.828*	8.457*
NUMBER OF OBSERVATIONS	281	185	96
NUMBER OF REGRESSORS	27	19	13

STARRED COEFFICIENTS ARE SIGNIFICANTLY DIFFERENT FROM ZERO AT THE 5% LEVEL. STANDARD ERRORS OF THE COEFFICIENTS ARE REPORTED BELOW COEFFICIENT. STARRED F-STATISTIC INDICATES SIGNIFICANT AT 5% OR BETTER. COEFFICIENTS OF ANNUAL DUMMY VARIABLES NOT REPORTED.

TABLE 8-PART A ABSOLUTE VARIABLES
SECTION 4 - THREE-ENGINE WIDE BODIED JETS

DEPENDENT VARIABLE	NUMBER OF PLANES 1970-1984	NUMBER OF PLANES 1970-1977	NUMBER OF PLANES 1978-1984
CONSTANT	1.602	-0.980	-16.822*
	2.722	4.272	5.765
NUMBER OF LARGE HUBS SERVED	-0.212	-0.0254	0.235
	0.152	0.259	-0.299
NUMBER OF MEDIUM HUBS SERVED	-0.419*	-0.0644	-0.0818
	0.139	0.298	0.232
NUMBER OF SMALL HUBS SERVED	-0.130	-0.423*	0.0413
	0.078	0.128	0.192
AVERAGE STAGE LENGTH	0.00481*	-0.00163	0.0200*
	0.00204	0.00298	0.0040
REVENUE PASSENGERS EMPLANEMENTS	0.00119*	0.00109*	0.00105*
	9.992×10^{-5}	0.00026	0.00016
R-SQUARED	0.722	0.626	0.713
ADJ R-SQUARED	0.694	0.575	0.672
F-STATISTIC	25.431*	12.331*	17.217*
NUMBER OF OBSERVATIONS	281	185	96
NUMBER OF REGRESSORS	27	19	13

STARRED COEFFICIENTS ARE SIGNIFICANTLY DIFFERENT FROM ZERO AT THE 5% LEVEL. STANDARD ERRORS OF THE COEFFICIENTS ARE REPORTED BELOW COEFFICIENT. STARRED F-STATISTIC INDICATES SIGNIFICANT AT 5% OR BETTER. COEFFICIENTS OF ANNUAL DUMMY VARIABLES NOT REPORTED.

TABLE 8-PART A ABSOLUTE VARIABLES
SECTION 5 - four-engine WIDE BODIED JETS

DEPENDENT VARIABLE	NUMBER OF PLANES 1963-1984	NUMBER OF PLANES 1970-1977	NUMBER OF PLANES 1978-1984
CONSTANT	-8.022*	-10.971*	-23.254*
	2.288	3.323	4.727
NUMBER OF LARGE HUBS SERVED	0.334*	0.542*	0.795*
	0.128	0.201	0.255
NUMBER OF MEDIUM HUBS SERVED	-0.606*	-0.430	-0.804*
	0.109	0.232	0.198
NUMBER OF SMALL HUBS SERVED	0.190*	-0.0653	0.398*
	0.066	0.0993	0.164
AVERAGE STAGE LENGTH	0.0258*	0.0189*	0.0376*
	0.0017	0.0023	0.0034
REVENUE PASSENGERS	0.000105	0.000296	$-3.676\text{x}10^{-5}$
EMPLANEMENTS	$8.400\text{x}10^{-5}$	0.000199	0.000136
R-SQUARED	0.653	0.689	0.723
ADJ R-SQUARED	0.618	0.647	0.683
F-STATISTIC	18.396*	16.309*	18.903*
NUMBER OF OBSERVATIONS	281	185	96
NUMBER OF REGRESSORS	27	19	13

STARRED COEFFICIENTS ARE SIGNIFICANTLY DIFFERENT FROM ZERO AT THE 5% LEVEL. STANDARD ERRORS OF THE COEFFICIENTS ARE REPORTED BELOW COEFFICIENT. STARRED F-STATISTIC INDICATES SIGNIFICANT AT 5% OR BETTER. COEFFICIENTS OF ANNUAL DUMMY VARIABLES NOT REPORTED.

PART B

TABLE 8-PART B RELATIVE VARIABLES
SECTION 1 - TWO-ENGINE REGULAR BODIED JETS

DEPENDENT VARIABLE	PERCENTAGE OF PLANES 1963-1984	PERCENTAGE OF PLANES 1963-1977	PERCENTAGE OF PLANES 1978-1984
CONSTANT	0.520*	0.518*	0.683*
	0.015	0.014	0.028
NUMBER OF LARGE HUBS SERVED	-0.00349*	-0.00406*	-0.00485*
	0.00082	0.00090	0.00148
NUMBER OF MEDIUM HUBS SERVED	0.00294*	0.00273*	0.00137
	0.00070	0.00087	0.00115
NUMBER OF SMALL HUBS SERVED	0.00124*	0.000931*	0.00259*
	0.00042	0.000417	0.00095
AVERAGE STAGE LENGTH	$-7.485\text{x}10^{-5}$*	$-4.164\text{x}10^{-5}$*	-0.000129*
	$1.100\text{x}10^{-5}$	$1.230\text{x}10^{-5}$	$1.970\text{x}10^{-5}$
REVENUE PASSENGERS EMPLANEMENTS	$-1.384\text{x}10^{-6}$*	$-2.816\text{x}10^{-7}$	$-1.655\text{x}10^{-6}$*
	$-5.397\text{x}10^{-7}$	$-7.981\text{x}10^{-7}$	$1.970\text{x}10^{-7}$
R-SQUARED	0.490	0.484	0.619
ADJ R-SQUARED	0.437	0.428	0.563
F-STATISTIC	9.284*	8.554*	11.111*
NUMBER OF OBSERVATIONS	281	185	96
NUMBER OF REGRESSORS	27	19	13

STARRED COEFFICIENTS ARE SIGNIFICANTLY DIFFERENT FROM ZERO AT THE 5% LEVEL. STANDARD ERRORS OF THE COEFFICIENTS ARE REPORTED BELOW COEFFICIENT. STARRED F-STATISTIC INDICATES SIGNIFICANT AT 5% OR BETTER. COEFFICIENTS OF ANNUAL DUMMY VARIABLES NOT REPORTED.

TABLE 8-PART B RELATIVE VARIABLES
SECTION 2 - THREE-ENGINE REGULAR BODIED JETS

DEPENDENT VARIABLE	PERCENTAGE OF PLANES 1963-1984	PERCENTAGE OF PLANES 1963-1977	PERCENTAGE OF PLANES 1978-1984
CONSTANT	0.486*	0.495*	0.554*
	0.0182	0.019	0.034
NUMBER OF LARGE HUBS SERVED	0.00464*	0.00570*	0.00342
	0.00101	0.00130	0.00178
NUMBER OF MEDIUM HUBS SERVED	-0.00136	-0.00243*	0.000310
	0.00087	0.00125	0.00138
NUMBER OF SMALL HUBS SERVED	-0.00162*	-0.00155*	-0.00278*
	0.00052	0.00060	0.00114
AVERAGE STAGE LENGTH	-2.806×10^{-6}	-1.962×10^{-5}	1.674×10^{-5}
	1.364×10^{-5}	1.762×10^{-5}	2.366×10^{-5}
REVENUE PASSENGERS EMPLANEMENTS	9.917×10^{-7}	1.517×10^{-6}	1.136×10^{-6}
	6.690×10^{-6}	1.143×10^{-6}	9.475×10^{-7}
R-SQUARED	0.408	0.375	0.1807
ADJ R-SQUARED	0.347	0.307	0.0608
F-STATISTIC	6.653*	5.472*	1.507
NUMBER OF OBSERVATIONS	281	185	96
NUMBER OF REGRESSORS	27	19	13

STARRED COEFFICIENTS ARE SIGNIFICANTLY DIFFERENT FROM ZERO AT THE 5% LEVEL. STANDARD ERRORS OF THE COEFFICIENTS ARE REPORTED BELOW COEFFICIENT. STARRED F-STATISTIC INDICATES SIGNIFICANT AT 5% OR BETTER. COEFFICIENTS OF ANNUAL DUMMY VARIABLES NOT REPORTED.

TABLE 8-PART B RELATIVE VARIABLES
SECTION 3 - four-engine REGULAR BODIED JETS

DEPENDENT VARIABLE	PERCENTAGE OF PLANES 1963-1984	PERCENTAGE OF PLANES 1963-1977	PERCENTAGE OF PLANES 1976-1984
CONSTANT	0.474*	0.469*	0.466*
	0.009	0.009	0.013
NUMBER OF LARGE HUBS	0.00244*	0.00358*	0.000210
SERVED	0.00048	0.00062	0.000665
NUMBER OF MEDIUM HUBS	0.00075	-0.00036	0.00143*
SERVED	0.00041	0.00060	0.00052
NUMBER OF SMALL HUBS	-0.000693*	-0.00075*	-0.000207
SERVED	0.000245	0.00029	0.000427
AVERAGE STAGE	7.592×10^{-5}*	8.390×10^{-5}*	6.086×10^{-5}*
LENGTH	6.397×10^{-5}	8.472×10^{-6}	8.861×10^{-6}
REVENUE PASSENGERS	2.748×10^{-7}	6.932×10^{-7}	5.438×10^{-8}
EMPLANEMENTS	3.139×10^{-7}	5.497×10^{-7}	3.548×10^{-7}
R-SQUARED	0.643	0.681	0.549
ADJ R-SQUARED	0.606	0.646	0.483
F-STATISTIC	17.356*	19.485*	8.305*
NUMBER OF OBSERVATIONS	281	185	96
NUMBER OF REGRESSORS	27	19	13

STARRED COEFFICIENTS ARE SIGNIFICANTLY DIFFERENT FROM ZERO AT THE 5% LEVEL. STANDARD ERRORS OF THE COEFFICIENTS ARE REPORTED BELOW COEFFICIENT. STARRED F-STATISTIC INDICATES SIGNIFICANT AT 5% OR BETTER. COEFFICIENTS OF ANNUAL DUMMY VARIABLES NOT REPORTED.

TABLE 8-PART B RELATIVE VARIABLES
SECTION 4 - THREE-ENGINE WIDE BODIED JETS

DEPENDENT VARIABLE	PERCENTAGE OF PLANES 1970-1984	PERCENTAGE OF PLANES 1970-1976	PERCENTAGE OF PLANES 1977-1984
CONSTANT	0.520*	0.529*	0.529*
	0.009	0.011	0.013
NUMBER OF LARGE HUBS	-0.000360	-0.000731	$5.960x10^{-5}$
SERVED	0.000469	0.000671	0.00068
NUMBER OF MEDIUM HUBS	-0.00109*	-0.000891	-0.00117*
SERVED	0.00041	0.000782	0.00053
NUMBER OF SMALL HUBS	-0.000539*	-0.000712*	-0.000456
SERVED	0.000266	0.000335	0.000434
AVERAGE STAGE	$-3.062x10^{-7}$	$-1.027x10^{-5}$	$1.285x10^{-5}$
LENGTH	$5.820x10^{-6}$	$7.839x10^{-6}$	$9.017x10^{-6}$
REVENUE PASSENGERS	$1.135x10^{-6}$*	$1.356x10^{-6}$*	$1.035x10^{-6}$*
EMPLANEMENTS	$3.039x10^{-7}$	$6.722x10^{-7}$	$3.611x10^{-7}$
R-SQUARED	0.289	0.249	0.208
ADJ R-SQUARED	0.208	0.144	0.092
F-STATISTIC	3.550*	2.375	1.797
NUMBER OF OBSERVATIONS	281	185	96
NUMBER OF REGRESSORS	27	19	13

STARRED COEFFICIENTS ARE SIGNIFICANTLY DIFFERENT FROM ZERO AT THE 5% LEVEL. STANDARD ERRORS OF THE COEFFICIENTS ARE REPORTED BELOW COEFFICIENT. STARRED F-STATISTIC INDICATES SIGNIFICANT AT 5% OR BETTER. COEFFICIENTS OF ANNUAL DUMMY VARIABLES NOT REPORTED.

TABLE 8-PART B RELATIVE VARIABLES
SECTION 5 - FOUR-ENGINE WIDE BODIED JETS

DEPENDENT VARIABLE	PERCENTAGE OF PLANES 1970-1984	PERCENTAGE OF PLANES 1970-1976	PERCENTAGE OF PLANES 1977-1984
CONSTANT	0.485*	0.505*	0.472*
	0.009	0.012	0.011
NUMBER OF LARGE HUBS	0.00124*	0.000343	0.00195*
SERVED	0.00045	0.000698	0.00056
NUMBER OF MEDIUM HUBS	-0.00241*	-0.00307*	-0.00247*
SERVED	0.00040	0.00081	0.00044
NUMBER OF SMALL HUBS	4.431×10^{-5}	-0.000302	0.000287
SERVED	2.563×10^{-4}	0.000348	0.000361
AVERAGE STAGE	4.571×10^{-5}*	2.858×10^{-5}*	6.381×10^{-5}*
LENGTH	5.602×10^{-6}	8.151×10^{-6}	7.488×10^{-6}
REVENUE PASSENGERS	5.167×10^{-7}	1.781×10^{-6}*	1.523×10^{-7}
EMPLANEMENTS	2.922×10^{-7}	6.989×10^{-7}	2.996×10^{-7}
R-SQUARED	0.585	0.496	0.717
ADJ R-SQUARED	0.538	0.426	0.677
F-STATISTIC	12.404*	7.073*	17.560*
NUMBER OF OBSERVATIONS	281	185	96
NUMBER OF REGRESSORS	27	19	13

STARRED COEFFICIENTS ARE SIGNIFICANTLY DIFFERENT FROM ZERO AT THE 5% LEVEL. STANDARD ERRORS OF THE COEFFICIENTS ARE REPORTED BELOW COEFFICIENT. STARRED F-STATISTIC INDICATES SIGNIFICANT AT 5% OR BETTER. COEFFICIENTS OF ANNUAL DUMMY VARIABLES NOT REPORTED.

aircraft.

In the second section of this table, the dependent variable represented is the percentage of each of the aircraft types listed above in the various airline fleets. For this reason these tables are referred to as relative variables. These dependent variables were subjected to a logit transformation before the estimating equations were run. The coefficients of the annual dummies are not reported in table 8.

In addition to the results reported for the entire sample period, estimates were made of the relationship between route characteristics and the number and type of aircraft employed for two sub-periods within the sample period. These sample periods were chosen on the basis of historical events which might have affected the relationships studied. The advent of airline deregulation in 1978 represents an obvious change in the operating environment of the airlines. The regression results reported in table 8 include full-period results for 1963-1984 or 1970-1984, depending on the variety of aircraft, and 1963-1977 or 1970-1977 and 1978-1984 are the sub-periods.

Of major interest in dealing with the sub-periods is the stability of the parameter values of the dependent variables. In order to determine this we perform the following test on the regressions. The null hypothesis is that there is no structural change over the full sample period. In the test, the regression is run with and without an interacted variable, which takes the value of zero for the prederegulation period and the value of the independent variables for the period subsequent to deregulation. The test of the null hypothesis is an F test of the equality of the coefficients of the interacted variables and zero. The results of these test are reported in table 9.

Theoretical Expectations

The maintained hypothesis of this dissertation is that the effects of airline regulation were felt most strongly in the inefficient allocation of aircraft among markets and not in the initial choice of aircraft. Thus deregulation should witness an alteration in the relationship between route structure and the number of aircraft in airline fleets. However, if efficient mixes of aircraft for serving diverse markets were chosen by airlines prior to deregulation, these relationships should not have been altered subsequent to deregulation. The results reported above support this hypothesis.

In the theoretical analysis of chapter 3, the number of aircraft an airline needs to serve its route network is a direct function of the number of flights per day scheduled on the network. The number of flights scheduled will in turn depend on the demand characteristics (i.e., passenger density or value of time) of each route served.

In the regressions conducted here, the average number of passengers per day emplaned at each of the three hub classes (small, medium, and large) are employed as proxies for the magnitude of the demand characteristics. The number of each class served also enters the regressions.

The numbers of each of the five varieties of aircraft respond differently to changes in the numbers of passengers emplaned. In the case of the smallest varieties of aircraft, cost minimization considerations should result in fewer aircraft in the fleet, ceteris paribus, as the number of large hubs served increases. For small hubs the opposite should hold. Also, as the number of passengers served by an airline increases, fewer small aircraft should be used. The coefficients for these independent variables should be negative for two- and three-engine narrow-body jets. In other words, the same cost minimization considerations should lead to greater representation of these aircraft in fleets.

Three- and four-engine wide-body jets, according to the same logic, will be the cost minimizing types for airlines which serve predominantly large hubs. Thus, for these aircraft, the expected sign of these independent variables is positive. Again, the reciprocal logic holds for small hubs for both average numbers of passengers and number served. The coefficients for these variables are expected to be negative.

TABLE 9

PANEL DATA RESULTS 1970-1984

The statistics reported here, distributed as F with the indicated degrees of freedom, were calculated from the data panel used in these regressions for the time period 1970-1984. The functional form estimated in the unrestricted regressions was:

Dependent variable = Intercept $+\beta_i$ Dependent variable + δ_i Dependent variable * Dummy (=0 for observations before 1978, =1 for observations there after) + μ_i dummy variables (=1 in year of the observation, =0 otherwise)

The null hypothesis is $\delta_i = 0$ for all i.

RELATIVE VARIABLES

AIRCRAFT TYPE	F-statistic (all Fs have 6&159 d.f)
two-engine narrow-body	2.6017465626*
three-engine narrow-body	1.2991934175
four-engine narrow-body	5.6073423858*
three-engine wide-body	1.5800478791
four-engine wide-body	3.2185994789*

TABLE 9 (CONT)
ABSOLUTE VARIABLES

AIRCRAFT TYPE	F-statistic (all Fs have 6&162 d.f)
two-engine narrow-body	5.5421539469*
three-engine narrow-body	6.0238452157*
four-engine narrow-body	4.3664467113*
three-engine wide-body	5.6120964069*
four-engine wide-body	3.8286429632*

STARRED F-STATISTICS INDICATE THE COMPUTED F EXCEEDS THE FIVE PERCENT LEVEL OF SIGNIFICANCE.

The intermediate cases (i.e., four-engine narrow-body jets and number of passengers and number of medium hubs served) have not yet been discussed. As might be expected, the signs for these variables cannot readily be predicted.

The predictions made above apply equally to the absolute variables and to the relative variables estimated as dependent variables in the regressions. One further prediction can be ventured, based on the hypothesis discussed in the first paragraph of this section. The maintained hypothesis is that aircraft choices, but not utilization, are efficient. In the post-deregulation environment, the relationship between route structure and the relative shares of different aircraft in an airline's fleet should not have changed significantly. On the other hand, given the joint product nature of airline flights where hubbing and spoking is employed, the number of flights and thus airline fleet requirements should have increased. Therefore, statistical tests of changes in the relationship of route characteristics to fleet composition should show a change for absolute variables and no such change for relative variables.

The theoretical predictions and the signs resulting from the empirical estimates are reported in table 10.

TABLE 10

COMPARISONS OF THEORY AND EMPIRICAL RESULTS

PART I

Dependent variable is the average number of seats per flight for an airline in a year.

INDEPENDENT VARIABLE	PREDICTED SIGN (FULL PERIOD)	OBSERVED SIGN (FULL PERIOD)	EXPECTED CHANGE ('76-'84)	OBSERVED CHANGE ('76-'84)
LARGE HUB	+	+	INCREASED MAGNITUDE	NONE
MEDIUM HUB	-	-	?	INCREASED
SMALL HUB	-	?	DECREASED ABSOLUTE VALUE	YES
PASSENGERS (REVENUE PASSENGER EMPLANEMENTS)	+	+	INCREASED MAGNITUDE	NOT SIGNIFICANT
AVERAGE STAGE LENGTH	+	+	DECREASED MAGNITUDE	INCREASED
ANNUAL DUMMIES	<0 before 1970 >0 after 1970		NEGATIVE VALUES	

PART II

Dependent variable is the number of aircraft of the given type in an airline fleet in a year.

two-engine narrow-body
(DC-9, B-737, MD-80)

INDEPENDENT VARIABLE	PREDICTED SIGN (FULL PERIOD)	OBSERVED SIGN (FULL PERIOD)	EXPECTED CHANGE ('76-'84)	OBSERVED CHANGE ('76-'84)
LARGE HUB	-	-	INCREASED ABSOLUTE VALUE	YES
MEDIUM HUB	?	?	?	?
SMALL HUB	+	+	INCREASED MAGNITUDE	YES
PASSENGERS (REVENUE PASSENGER EMPLANEMENTS)	-	+	INCREASED ABSOLUTE VALUE	NO
AVERAGE STAGE LENGTH	-	-	INCREASED ABSOLUTE VALUE	YES
ANNUAL DUMMIES	?		ACHIEVE POSITIVE SIGNIFICANCE	

three-engine narrow-body
(BOEING 727)

INDEPENDENT VARIABLE	PREDICTED SIGN (FULL PERIOD)	OBSERVED SIGN (FULL PERIOD)	EXPECTED CHANGE ('76-'84)	OBSERVED CHANGE ('76-'84)
LARGE HUB	-	+	INCREASED ABSOLUTE VALUE	YES
MEDIUM HUB	?	-	?	?
SMALL HUB	+	-	DECREASED MAGNITUDE	YES
PASSENGERS (REVENUE PASSENGER EMPLANEMENTS)	+	+	INCREASED MAGNITUDE	YES
AVERAGE STAGE LENGTH	-	?	DECREASED ABSOLUTE VALUE	?
ANNUAL DUMMIES	?		ACHIEVE POSITIVE SIGNIFICANCE	

four-engine narrow-body

INDEPENDENT VARIABLE	PREDICTED SIGN (FULL PERIOD)	OBSERVED SIGN (FULL PERIOD)	EXPECTED CHANGE ('76-'84)	OBSERVED CHANGE ('76-'84)
LARGE HUB	+	+(?)	ALL SIGNS	
MEDIUM HUB	?	+	AMBIGUOUS	
SMALL HUB	-	-(?)	BECAUSE OF	
PASSENGERS (REVENUE PASSENGER EMPLANEMENTS)	+	+	OBSOLESCENCE	
AVERAGE STAGE LENGTH	-	-		
ANNUAL DUMMIES	POSITIVE BUT DECLINING			

three-engine wide-body

INDEPENDENT VARIABLE	PREDICTED SIGN (FULL PERIOD)	OBSERVED SIGN (FULL PERIOD)	EXPECTED CHANGE ('76-'84)	OBSERVED CHANGE ('76-'84)
LARGE HUB	+	?	INCREASED MAGNITUDE	YES
MEDIUM HUB	(-)?	-(?)	INCREASED ABSOLUTE VALUE	NO
SMALL HUB	-	-	INCREASED ABSOLUTE VALUE	?
PASSENGERS (REVENUE PASSENGER EMPLANEMENTS)	+	+	INCREASED MAGNITUDE	NO
AVERAGE STAGE LENGTH	+	+	INCREASED MAGNITUDE	NO
ANNUAL DUMMIES	=0 1963-1971 >0 1971-1984		DECREASED MAGNITUDE	

four-engine wide-body

INDEPENDENT VARIABLE	PREDICTED SIGN (FULL PERIOD)	OBSERVED SIGN (FULL PERIOD)	EXPECTED CHANGE ('76-'84)	OBSERVED CHANGE ('76-'84)
LARGE HUB	+	+	INCREASED MAGNITUDE	YES
MEDIUM HUB	-		INCREASED ABSOLUTE VALUE	YES
SMALL HUB	-(?)	+	INCREASED ABSOLUTE VALUE	YES
PASSENGERS (REVENUE PASSENGER EMPLANEMENTS)	+	?	INCREASED MAGNITUDE	?
AVERAGE STAGE LENGTH	+	+	INCREASED MAGNITUDE	YES
ANNUAL DUMMIES	=0 BEFORE 1970 >0 AFTER 1970		NO SIGNIFICANT DIFFERENCE	

PART III

Dependent variable is the percentage of aircraft of the given type in an airline fleet in a year.

two-engine narrow-body

INDEPENDENT VARIABLE	PREDICTED SIGN (FULL PERIOD)	OBSERVED SIGN (FULL PERIOD)	EXPECTED CHANGE ('76-'84)	OBSERVED CHANGE ('76-'84)
LARGE HUB	-	-	INCREASED ABSOLUTE VALUE	YES
MEDIUM HUB	?	+	?	?
SMALL HUB	+	+	INCREASED MAGNITUDE	YES
PASSENGERS (REVENUE PASSENGER EMPLANEMENTS)	-	-	INCREASED ABSOLUTE VALUE	YES
AVERAGE STAGE LENGTH	-	-	INCREASED ABSOLUTE VALUE	YES
ANNUAL DUMMIES	?		SIGNIFICANTLY POSITIVE	

three-engine narrow-body

INDEPENDENT VARIABLE	PREDICTED SIGN (FULL PERIOD)	OBSERVED SIGN (FULL PERIOD)	EXPECTED CHANGE ('76-'84)	OBSERVED CHANGE ('76-'84)
LARGE HUB	+	+	INCREASED MAGNITUDE	?
MEDIUM HUB	+	?	INCREASED MAGNITUDE	+(?)
SMALL HUB	-	-	INCREASED ABSOLUTE VALUE	YES
PASSENGERS (REVENUE PASSENGER EMPLANEMENTS)	+	?	INCREASED MAGNITUDE	?
AVERAGE STAGE LENGTH	-	?	DECREASED ABSOLUTE VALUE	?
ANNUAL DUMMIES	+		SIGNIFICANTLY POSITIVE	

four-engine narrow-body

INDEPENDENT VARIABLE	PREDICTED SIGN (FULL PERIOD)	OBSERVED SIGN (FULL PERIOD)	EXPECTED CHANGE ('76-'84)	OBSERVED CHANGE ('76-'84)
LARGE HUB	-		AIRCRAFT TYPE OBSOLETE IN LATE 1970S	
MEDIUM HUB	-			
SMALL HUB	-			
PASSENGERS (REVENUE PASSENGER EMPLANEMENTS)	+			
AVERAGE STAGE LENGTH	+			
ANNUAL DUMMIES	POSITIVE BUT DIMINISHING			

three-engine wide-body

INDEPENDENT VARIABLE	PREDICTED SIGN (FULL PERIOD)	OBSERVED SIGN (FULL PERIOD)	EXPECTED CHANGE ('76-'84)	OBSERVED CHANGE ('76-'84)
LARGE HUB	+	?	INCREASED MAGNITUDE	?
MEDIUM HUB	-	-	INCREASED ABSOLUTE VALUE	?
SMALL HUB	-	-	INCREASED ABSOLUTE VALUE	?
PASSENGERS (REVENUE PASSENGER EMPLANEMENTS)	+	+	INCREASED MAGNITUDE	NONE
AVERAGE STAGE LENGTH	+	?	INCREASED MAGNITUDE	?
ANNUAL DUMMIES	=0 BEFORE 1971 >0 AFTER 1971		SIGNIFICANTLY DIFFERENT FROM REGULATION	

four-engine wide-body

INDEPENDENT VARIABLE	PREDICTED SIGN (FULL PERIOD)	OBSERVED SIGN (FULL PERIOD)	EXPECTED CHANGE ('76-'84)	OBSERVED CHANGE ('76-'84)
LARGE HUB	+	+	INCREASED MAGNITUDE	YES
MEDIUM HUB	-	-	INCREASED ABSOLUTE VALUE	NO
SMALL HUB	-	?	INCREASED ABSOLUTE VALUE	?
PASSENGERS (REVENUE PASSENGER EMPLANEMENTS)	+	?	INCREASED MAGNITUDE	?
AVERAGE STAGE LENGTH	+	+	INCREASED MAGNITUDE	YES
ANNUAL DUMMIES	=0 BEFORE 1970 >0 AFTER 1970		SIGNIFICANTLY DIFFERENT	

Analysis of Empirical Results

The predictions ventured in the previous section were only partly correct, as can be established by consulting table 10. For two-engine narrow-body aircraft, the signs of the coefficients for large and small hubs and passengers per day emplaned at each are as predicted for both the full sample and the sub-periods. They are also significantly different from zero in almost all equations, whether the dependent variable is number of aircraft or of an aircraft type in a fleet. The coefficients for medium hubs are seldom significant and, as predicted, of varying sign.

The predictions regarding the signs of the coefficients in the equations for three-engine narrow-body jets are almost completely wrong. The number of large hubs and the average number of passengers per day at large hubs have significant, positive coefficients. The coefficient of the average number of passengers per day served at small hubs is insignificantly different from zero in all equations. The coefficient of the number of small hubs is negative where significantly different from zero.

Four-engine narrow-body jets, for which no prediction was ventured, have the same pattern of sign and significance as was predicted for larger jets.

For wide-bodied aircraft, the predictions are largely confirmed. The coefficients on the large hub variables are uniformly positive and generally significant. The coefficients of the small hub variables are negative but seldom significant. The medium-hub variables are negative and usually significant. These results are quite striking.

Finally, the change of regimes test reported in table 9 yields some striking results. For the regressions where the dependent variable is the numbers of aircraft of each type employed by the carriers during the period, the tests indicate that the relationship between route characteristics and number of aircraft selected of a given type changed in a statistically significant fashion.

In those regressions where the dependent variable is the percentage of aircraft of a given type in the airlines fleet, application of the same structural tests yields results that are different. In fact, these tests indicate that the relationship of the relative composition of airlines' fleets to their routes did not change for three-engine narrow-body and three-engine wide-body jets subsequent to deregulation. In other words, airline fleets tended to contain about the same proportions of three-engine jets after deregulation. This finding is at variance with predictions that would have been made about the airline fleets on the basis of the economic analysis of airlines prior to deregulation. However, three varieties of aircraft show changed relationships between aircraft fleet proportions and route characteristics. In the case of four-engine narrow-body aircraft this finding can be explained by the technological obsolescence of the class. In the case of two-engine narrow-body aircraft, the utilization of these craft on lower density spokes may in fact mean that they are needed in increased proportions since deregulation.

Since flight frequency was identified as the prime competitive weapon under regulatory constraint, airlines would have been expected to have fleets with small aircraft over-represented relative to large aircraft. This is not reflected in the empirical results. In fact, these results support the thesis of this dissertation that the major effects of airline deregulation on airline allocation of capital have not been upon the choice of aircraft in general but on the route structures within which the aircraft are employed.

Summary of Empirical Results

In summary, these regressions indicate that the model presented in chapter 3 has significant explanatory power. The changes in aircraft utilization patterns in the period from 1974 to 1984 clearly reflects the effects of deregulation. In particular the restructuring of airline networks into hub-and-spoke systems is reflected.

In the post-deregulation scheme of things, wide-bodied aircraft are used predominantly for long-haul, inter-hub transfers. The smaller aircraft are used to carry passengers on the spokes where passenger densities are lowest. All other things equal, as passenger densities and/or route distance increase, three-engine jets (i.e. Boeing 727) displace smaller varieties of aircraft on the spokes. Such aircraft are also employed on the less dense inter-hub flights (e.g., Chicago to Charlotte, N.C.).

CHAPTER 5

CONCLUSION AND SUGGESTIONS FOR FURTHER RESEARCH

This dissertation has been concerned with some elements of the structure of the airline industry which make it unique. These idiosyncratic features result in industry conduct and performance not easily explained within the framework of conventional models of economic behavior. An alternative analytical framework was provided above. This framework was then tested empirically using two distinct data sets. These empirical results were largely consistent with the predictions of the model developed here.

This chapter reviews the unique elements of the airline industry's structure, the predictions of deregulated industry performance, and the specific shortcomings of these a priori models. These models are then compared with the superior predictive performance of the alternative model developed here. Finally, the empirical tests of the model are reviewed and conclusions drawn from the results advanced. In addition, some possible empirical and theoretical extensions of this investigation are suggested.

The Structure of the Industry

As outlined in chapter I, the passenger airline industry has a number of unique structural elements which make it both rewarding and difficult to analyze economically. An important feature throughout the first half century of the industry's history was pervasive regulation of price and route entry. Since the late 1970s, much of the behavior of airlines has taken the form of adjustment to the changes caused by elimination of the price and entry regulation of the industry.

Two related elements of the industry structure also help to make it unique. The first is the nature of its product. The "product" of the airline industry consists of point-to-point transportation offered at a particular time of day. Any product is one of a class of related products, each consisting of a flight between the same two points but originating at a different time of day.

This is true because the opportunity cost of air transport is not merely the cash price paid for such transport but also the opportunity cost of time of travel. Travel time itself includes several elements including the actual point-to-point time, the delay occasioned by flights not departing at the preferred time, and delays caused by not being able to take a preferred flight because it is full.

Of these, only the first--the point-to-point transit time--is truly exogenous in the short run. It is determined by the the technological characteristics of the aircraft available. Aircraft availability is the second element of the structure of airline transportation that makes the airline industry unique. Because of the lumpiness of airline capital--that is, aircraft--airlines are faced with a choice of several varieties of aircraft. The lumpiness of airline capital makes it impossible for airlines to offer custom-tailored "products." Instead airlines must offer products which provide lowest opportunity cost of air travel.

The combination of these three elements before deregulation resulted in a voluminous literature about the industry structure. This body of theoretical and empirical literature will be discussed next.

Previous Economic Analysis of Airlines

Two empirical observations were seminal in the analysis of airline performance under CAB regulation. First, it was recognized that, despite fares set above competitive levels and the protection from competitive pressures provided by CAB entry restrictions, airlines did not earn economic profits. Indeed, they frequently earned no profits at all. In addition, observation of less regulated intrastate carriers in California and Texas revealed that these carriers were able to earn profits with lower fares than CAB-regulated carriers. This was caused by the substantially lower costs of the intrastate carriers.

Providing an explanation of these observations consistent with profit maximizing behavior was an important challenge of the economic literature of the early 1970s. The key element in the explanation eventually adopted was the nature of the opportunity costs faced by air travelers and the absence of price competition in the airline industry. Since airlines could not freely compete in price of service, they competed on the other element of air travelers' cost of air travel: travel time. Specifically, competition took the form of offering increased flight frequency, a competitive variable not subject to regulation. This had the effect of increasing airline average costs, since fewer passengers were carried on each individual flight, thereby increasing the per-passenger share of flight costs which are fixed once the route and type of aircraft employed are determined.

This theory provided the basis for a series of predictions regarding airline behavior subsequent to removal of regulation. With airlines free to compete on price of service, it was predicted that flight frequency would fall and airlines would increase their utilization of larger aircraft. There were two hidden weaknesses of this theory, however. First, it was generally assumed that airlines would not substantially alter their route structures except to expand them. A second assumption was that airlines would charge a single fare for any particular class of service after receiving pricing freedom. Both of these assumptions proved false after deregulation. The consequences of this are considered in the next section.

A Theory of Airline Behavior

The third chapter presents a theoretical framework for understanding the responses of airlines to deregulation. Its basis is a model of how airlines might determine flight frequency in particular markets, and is an extension of work by Steven Salop (1984). The model forms the building block upon which an understanding of the principles of airline fleet selection can be constructed.

An important extension of Salop's model is one utilized to explain the practice of hub-and-spoke networks. In this framework, hub-and-spoke networking can be interpreted as a problem of joint production. In addition, a form of price discrimination, where customers are distinguished by both their differing destinations and differing opportunity cost of time, is illustrated. As is common in joint production and price discrimination models, the result is higher levels of provision of the good. The ability to spread the fixed costs of production across several different classes of consumers yields these increases in production. This leads to the conclusion that the effect of the adoption of hubbing and spoking on airline flight frequencies is to increase flight frequency from an origin, ceteris paribus. This conclusion is contrary to the expectations held before deregulation but is a natural consequence of the model employed.

This result is a generalization of the result of Morrison and Winston discussed above(1984). In this model, the decision to hub and spoke involves balancing revenue losses caused by decreased convenience of service with the lowered costs of joint production. Airlines are the only passenger transportation mode where the cost savings in both cash and time are generally enough to offset the increased time cost of not proceeding directly to a destination. There is some evidence that for surface freight transportation, particularly less than truckload shipment, can enjoy economies with a network of the hub-and-spoke variety.

In general, the theoretical results derived in the third chapter point to a very different interpretation of the consequences of deregulation than was previously held. In particular, the model of this dissertation indicates that a) deregulation should lead to increased flight frequencies as airlines adjust their networks to the more efficient hub-and-spoke structure, and b) the requirements of frequency of service imply that smaller aircraft will not be displaced by larger aircraft as was predicted in previous models.

Empirical Models of Airline Behavior

The fourth chapter of this dissertation presented tests of its theoretical framework. Two distinct sets of data are used. In the first set, the airlines behavior at the level of individual routes is investigated. The number of aircraft of different types employed is the dependent variable regressed against the route characteristics of a randomly chosen set of American airline routes for two years, 1974 and 1984. In another set of regressions the average number of seats per flight on a route is employed as the dependent variable. The results tend to provide confirmation for the theory constructed here. There was a clear movement towards employing aircraft whose characteristics make them especially suitable for the "spokes" of a hub-and-spoke network.

In the second set of regressions, the gross fleet composition of major airlines is regressed against the route characteristics of those airlines. This is done in three ways. The first utilizes the absolute numbers of each of several aircraft types. In the second the relative frequency of different aircraft varieties is the dependent variable in the regressions. Additionally, the average number seats in the airline's fleet is employed as the dependent variable.

These regressions confirm some of the theoretical predictions about airline fleet composition. The regression employing absolute fleet numbers as dependent variable indicates both that the relationship between route characteristics and fleet composition changed with deregulation and that the direction of the change is toward larger numbers of aircraft in fleets. In the regressions employing relative fleet composition, there is less indication of a changed relationship between the route structures of airlines and the relative proportions of different types of aircraft in their fleets. In particular, the early prediction that smaller jets would disappear with service competition in terms of flight frequency was never borne out.

Welfare Implications and Suggestions for Additional Research

What implications may be drawn from the results of this research? One is that regulation did not necessarily induce airlines to make inefficient choices of aircraft. Instead, the inefficiencies were generated through the airline's inability to create efficient route structures while subject to entry regulation.

Thus far this dissertation has not directly discussed the welfare implications of airline deregulation. Implicitly, the argument of the previous paragraph is that the welfare consequences of regulation were less significant than previously believed. A further statement about the welfare consequences of deregulation can in fact be made. Salop's model (1978), which forms the basis for the theoretical model of this dissertation, also permits the evaluation of social welfare in a monopolistically competitive industry. This welfare evaluation indicates that the number of varieties of the good offered will be excessive from a social point of view. The model of Panzar (1979) is specifically intended to evaluate the behavior of the deregulated airline industry. It also suggests that airlines will offer more than the socially optimal number of flights. The theory of hubbing and spoking developed here implies that an even greater number of flights will be offered than is indicated by the simple, monopolistically competitive models. Thus, it is a likely consequence of deregulation that an excessive number of flights will be offered. The relatively weak welfare results presented by the authors cited can be considered strengthened.

In addition, the mathematical similarity of the hub-and-spoke model presented here to the price discrimination results also presented in chapter 3 indicates that the distributional consequences of deregulation have been insufficiently considered. In fact, this model provides an alternative to Levine's (1987) explanation of how the incumbent airlines with significantly higher costs were able to prevail in competition with lower cost, new entrants. Their ability to earn rents through the hub-and-spoke system and the advantages conferred by their more extensive route systems in hubbing and spoking surely contribute to their success. Thus, despite the significant benefits of deregulation, the picture is perhaps not so rosy as its proponents would have it. Air carriers continue to earn some rents in the deregulated environment.

At least three possibilities for building on this work present themselves. In the case of the empirical results reported here, two useful extensions might be made. First, the route level results reported here might be duplicated with another sample to confirm the results reported. A second step would be to find a superior proxy for the opportunity cost of air traveler's time. Per capita income was seldom statistically significant, despite strong theoretical expectations regarding income's role in determining the cost of time and its implications for flight scheduling.

On a theoretical level, the assumption that the population of potential airline travelers is uniformly distributed throughout the course of a day is used here and elsewhere for want of an alternative. The problem of rivalrous airline scheduling where demand assymetries exist is worthy of attention, on both theoretical and empirical grounds.

Appendix A

Data Types and Sources

As discussed in chapter 3, an airline's demand for aircraft can be explained in terms of the demand characteristics of the markets served and the economic and regulatory environment. The variables presented in the theory are not represented exactly by any data sources readily available. In order to perform econometric estimates proxies must be found for four distinct varieties of variables.

The first is aircraft types. Two distinct sources of data were consulted to develop models of aircraft utilization. The aircraft data for the route level estimates presented in chapter 3 comes from the July 1974 and July 1984 editions of The Official Airline Guide, North American Edition. A random sample of domestic airlines' routes was constructed from these editions of the Guide and utilized to construct statistics on the utilization of various types of aircraft on those routes. In addition, the hubbing variable was constructed by assigning a value of one to all routes listed as providing connecting flights on the sampled route.

Population and per capita income variables were constructed by using either The State and Metropolitan Data Book, 1986 edition, The City and County Data Book, 1977 edition, or the Rand-McNally Commercial Atlas, 1986 edition. For route terminals (i.e. either origins or destinations) which were elements of Standard Metropolitan Statistical areas, the population and per capita income of the SMSA was utilized. For terminals which were not so classified, the population and per capita income of the surrounding county was employed.

The route distance variable was also derived form multiple sources. For many major cities, the 1974 edition of the OAG provided a table of domestic airline mileages, routes not listed in this source were taken from either Offical Table of Distances, Continental U.S., Alaska, Hawaii, and Puerto Rico, Direct Line Distances, U.S. Edition, or as a last resort Rand-McNally Standard Highway Mileage Guide.

The final variable in the route level regressions was the vacation variable. The vacation spot dummy was created by assigning a value of one to all routes with a terminal in Florida, Hawaii, coastal California, or the desert Southwest (i.e., Nevada, Arizona, and New Mexico.) A continuous vacation variable was the per capita expenditures on lodging at either the origin or destination. The source of these continuous variables was either The Statistical Abstract or County Business Patterns both published by the U.S. Census Bureau.

For the second set of regressions the primary source of data was The Handbook of Airline Statistics, published biannually between 1963 and 1973, with a supplement published for the years 1974 and 1975. This data source was supplemented for years after 1976 by The Inventory and Age of Aircraft Trunks and Locals, prepared by the Office of Economic Analysis of the CAB and the Air Transport Association's Annual Report for 1983 and 1984. In these data sources different models of aircraft were classified according to their body style (i.e., either narrow-bodied or wide-bodied.) In addition, aircraft are classified by type and number of engines. These data were collected for the period 1963-1984 and consisted of the inventory of each of the CAB-defined types of aircraft in carrier fleets as of December 31 of a given year. The initial year chosen was 1963 to minimize the disturbance to airline fleet composition consequent to the introduction of jet aircraft in the late 1950s (c.f. Yance, op. cit). Nineteen eighty-four was chosen as an upper bound by limits in data availability and the necessity to have sufficient sample years subsequent to deregulation. Since no single data source reported all years, the carrier fleet series were constructed only for carriers still existing and defined as "majors" in 1984. Where a merger had resulted in the creation of a new "major ," the fleets and other statistics were combined for the entire sample period.

The descriptive statistics used to characterize the route structure of the carriers were constructed from Airport Activity Statistics of Certificated Route Carriers reported annually for the years 1963-1984. In using this data, the conventions of the FAA in classifying airports as large,medium, and small hubs and as non-hubs depending on the percentage of U.S. airline passenger emplanements, was adopted.[1] Airline route structures were characterized by the numbers of each hub classification that they served and the average number of passengers served per day in each of these classifications.

An additional variable used in the two stage least squares estimates of chapter 4 was the average stage length of airlines. This was reported in The Handbook of Airline Statistics before 1976 and in Air Carrier Traffic Statistics, also published by the CAB beginning in 1976.

Each set of regressions reported below has a distinct source of data. Thus two independent tests of the hypothesis are provided by these results.

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1 Large hubs have more than 1% of US passenger emplanements. Medium hubs have between 0.99% and 0.50% of U.S. passenger emplanements. Small hubs have between 0.49% and 0.25% of emplanements. Non-hubs emplane fewer than 0.25% of U.S. airline passengers.

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