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A theory of transportation clubs with special application to the domestic aviation system

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ABSTRACT

A theory of transportation clubs
with special application to the domestic aviation system

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This dissertation employs the theory of clubs and the theory of multi-product enterprises to develop a set of three general transportation pricing and investment models. These models incorporate costs related to operating and maintaining transportation facilities, the capital investment required to provide such facilities, the congestion that arises from use of these facilities, and the adverse impacts and benefits associated with external impacts imposed on or provided to individuals who do not directly use the facilities. The models are presented in both a one-period and two-period context. In additional, the models address the sharing of transportation facilities by more than one group of users.

Among the principal findings derived from these models are a set of conditions which relate the cost characteristics of tranportation facilities to requirements for the optimal pricing of facility use. For example, in the absence of non-user externalities, for transportation facilities which are shared by multiple user groups and which experience different levels of use over time, it was determined that a cost structure

characterized by constant ray economies of scale and the absence of scope economies is required for the provision and operation of the facility to be fully and efficiently funded through user fees.

To test the extent to which the general models can be applied to real world situations, an airport club model which explicitly takes into consideration sharing of the facility by different types of transportation vehicles, which reflect differences in user preferences, was developed. Optimal pricing rules were developed for this model and tested using a sample of financial and operation data from large tower controlled U.S. airports. The empirical analysis found that ray economies of scale vary by size of airport. However, due to the discovery of a "crowding out" effect between commercial and non-commercial aircraft, no definitive findings regarding economies of scope were obtained.

CHAPTER 1: INTRODUCTION

Since the late 1960s annual investment in public capital has fallen from 4 percent of gross national product (GNP) to only about 2 percent of GNP by the late 1980s (Winston and Bosworth, 1992). Recognition of this trend, which contrasts sharply with that of the United States' major trading partners, who have increased their shares of national income going into public capital investment, has attracted much attention from both economists and politicians in recent years (Aschauer, 1989; Munnell, 1990a, 1990b; U.S. House of Representatives, 1991; Congressional Budget Office, 1991, 1992; Lynde and Richmond, 1992). Focusing on core infrastructure (e.g., highways, bridges, airports, mass transit systems, sewer and water systems, and electric and natural gas production and distribution systems) Winston and Bosworth (1992) show that the stock of such facilities has declined in comparison to the nation's GNP from 26 to 20 percent. The Joint Economic Committee of Congress estimates that for the period 1983-2000 investment in core infrastructure will experience a shortfall relative to anticipated needs of over $440 billion measured in terms of a constant 1982 dollar. Attracting further attention to this issue are the findings of several recent studies that claim such investment may yield annual returns as high as 60 percent compared to annual returns only half as large for private capital investment (Aschauer, 1989; Munnell, 1990a).

Thus, it is not surprising that in recent years significant attention has been focused on the need to increase the federal government's investment in infrastructure. Proposals calling for additional federal spending of $20 billion per year have been suggested by members of the Clinton Administration. However, there is not universal agreement on the magnitude of the need for added public infrastructure investment. Even proponents of some increase in spending in this area have begun to question the validity of the high rates of return associated with public infrastructure investment claimed by the previously mentioned studies. Also, given the history of "pork barrel" politics associated with federal public works programs, some economist have begun to question whether additional funds dedicated to public infrastructure investment will be used efficiently.

One of the more prominent members of this group of skeptics is Clifford Winston, a Senior Fellow at the Brookings Institution. Winston (1991) maintains that much of the proposed investment in transportation infrastructure can be either avoided or delayed if current construction and pricing practices are changed. Among the existing practices Winston targets for special attention are deficient pavement construction standards used on the nation's major highways, federal program funding priorities which favor new construction over maintenance, and inefficient pricing practices associated with the use of transportation infrastructure. Winston, like many others before him (Walters, 1961; Sharp, 1966; Vickery, 1969; Levine, 1969; Park, 1971; Henderson, 1974; Morrison, 1983) proposes that road and airport user fees need to be modified to take into consideration the costs associated with congestion caused by the concentration of use of major elements of the nation's transportation system during relatively short time periods, while the same facilities remain underutilized much of the remainder of each day.

The research presented in this dissertation similarly focuses on the issue of how the pricing of transportation services and the financing of transportation investment may be modified to promote the more efficient use and provision of transportation infrastructure. Unlike prior research in this area, this dissertation addresses not only the issues of congestion and peak period pricing, but also pricing issues associated with the sharing of transportation facilities by different types of users and externalities which provide justification for imposing charges on non-users in some instances while dictating the payment of compensation to non-users in other cases.

To provide the means for developing a model that is sufficiently flexible to encompass the broad range of issues addressed in this dissertation an approach significantly different from that used in most prior research into the subject of transportation infrastructure pricing and investment has been adopted. The approach used is based on the theory of clubs. Although the initial models presented in this dissertation are general, illustration of their application to current policy issues is accomplished through analysis of the domestic air transportation system.

Statement of Research Objectives

Traditionally, in the United States the problem of traffic congestion has been met by the addition of capacity to the nation's road, airport, railroad and other transportation systems. The initial development and later expansion of these systems is extremely capital intensive. Also, their use varies significantly over time, so that major portions of these systems are underutilized during most time periods. Unlike telecommunications or electric power transmission, which are services generally provided by private enterprise, transportation systems, which are mostly publicly provided and subject to the political decision-making process, are rarely priced in a manner which would encourage the spreading out of use over longer time periods. As previously mentioned, peak-load pricing has been proposed by numerous economists as at least a partial solution to transportation system capacity problems. Yet, until recently technological and political barriers have prevented its serious consideration as a solution to the problem of traffic congestion experienced by the users of urban freeways and the national air transportation system.

To a great extent the technological barriers to the implementation of peak-load pricing for transportation system use have now been overcome (Taylor-Radford, 1982; Hensher, 1991). However, problems of political acceptability still remain. Part of the political dimension of this problem can be traced to a lack of a comprehensive theoretical framework for determining how the use and cost of transportation facilities should be shared among different groups of users, as well as non-users, in order to optimize this nation's transportation infrastructure investment in terms of scale, scope of services provided, location, accessibility and environmental impacts. The models presented in this dissertation provide a general theoretical framework for addressing such a broad range of policy issues in an integrated manner. Prior research has tended to focus narrowly on one or two issues (e.g., the pricing of urban freeways or airport runways) while ignoring or assuming away other related considerations.

Club theory provides a structure which is particularly well suited for addressing how market pricing mechanisms may be used to obtain a more socially optimal allocation of public infrastructure. First, the concept of a club as a voluntary association of individuals captures the shared nature of most transportation infrastructure. Second, the recognition that the benefit of club membership is subject to diminution as the number of club members increases provides a basis for incorporating the congestibility feature of most transportation facilities.

Similarly, the theory of multi-product enterprises provides a convenient basis for modeling the cost structure of most transportation infrastructure. The large capital investment and shared use, which characterize highways, airports and other transportation infrastructure, make the concepts of ray economies of scale and economies or scope particularly useful in developing an understanding of what conditions must be satisfied in order for user charges to result in efficient levels of investment.

Organization

Chapter 2 provides a review of theoretical and empirical research upon which this dissertation is based. This literature review covers prior research from three fields of economics: transportation economics, club theory and the theory of multi-product enterprises.

Chapter 3 consists of the development of three general transportation club models. The first model presents the foundation for using club theory to identify optimal pricing and investment rules for transportation infrastructure. This is done in the context of a one-period, single capacity constrained transportation club and ignores the impact of non-user externalities. The second model replicates the first model with the exception that non-user externalities are taken into consideration. The third model expands on the prior two models in two major respects. In this last general transportation model the single club good is shared by two user groups and use of the club good over both peak and off-peak usage periods is taken into consideration. However, to keep this last model as uncomplicated as possible, the impact of non-user externalities is again ignored.

Next, in Chapter 4 the various features of the three previously developed general transportation club models are combined and customized to address the special pricing and investment considerations of airports. This model takes into consideration two club goods (i.e., airport runways and a passenger terminal), used by patrons of both scheduled commercial air carriers and general aviation over peak and off-peak traffic periods. The model also addresses both the benefits non-users of the airport derive from its existence and the adverse impacts they experience due to the airport's use. Furthermore, the model addresses how these non-user externalities should be taken into consideration in establishing airport fees and taxes in order to promote more efficient infrastructure investment. In addition, the financing implications of the degree to which the cost structure of airports is characterized by economies of scale and economies of scope is analyzed.

Chapter 5 presents the empirical analysis of the cost structure of a sample of large domestic airports. This analysis investigates the relationship between airport operating costs and both measures of airport use and airport capacity. The degree to which different size airports exhibit economies of scale and economies of scope is also investigated. This chapter concludes with a discussion of additional avenues for empirical analysis related to the pricing implications of economies of scope and non-user externalities and the data needed to conduct such research.

Finally, Chapter 6 provides a summary of findings, a discussion of their policy implications, and an agenda for further research.

CHAPTER 2: REVIEW OF PRIOR RESEARCH

General Review of Transportation Pricing Research

Most research in the area of transportation infrastructure pricing traces its ancestry to works by Pigou (1920) and Knight (1924) who employed road pricing examples as a means for addressing issues related to the inefficient pricing of industries exhibiting increasing marginal costs or decreasing marginal products. In such cases Pigou proposed the intervention of government to reconcile the difference between the social and private costs associated with use of congested facilities through the imposition of a tax as a means of redistributing traffic between overused and underused roads. Knight generally agreed with Pigou's contention that road facilities may be inappropriately priced in order to promote efficient investment in such facilities. However, unlike Pigou, who proposed that a congestion tax would have to be imposed to the extent the average costs associated with the use of facilities exhibiting constant and decreasing returns would be made equal, Knight showed that optimal use of such facilities would occur when the marginal products associated with the use of each type of facility achieved equality.

Following the work of Pigou and Knight, almost four decades elapsed until efforts were initiated to develop quantitative models of optimal transportation facility pricing and investment. The first major effort in this area is credited to Herbert Mohring and Mitchell Harwitz (1962). The analytical framework presented by Mohring and Harwitz obtains conditions for optimal traffic flow on a transportation facility through the maximization of net user benefits with respect to the travel demand. The short run optimality condition obtained by the authors is given by the following equality:

$$F(D^*) - g(D^*) = D^* \cdot \frac{dg}{dD}.$$

This condition states that total [short-run] highway derived benefits will be maximized if a level of traffic, D^*, is selected at which the difference between the value placed on a trip, $F(D^*)$, and the average travel time cost of a trip at this traffic level, $g(D^*)$, just equals the added congestion costs imposed by the marginal traveler on all users of the highway, $D^* \cdot (dg/dD)$.

The authors also derived a long-run optimality condition which equates the benefit of added highway capacity enjoyed by all users of the facility, $-D \cdot (\partial g/\partial S)$, where S is a measure of highway capacity and $\partial g(S)/\partial S < 0$ denotes a reduction in traffic congestion, to the opportunity cost associated with adding to highway capacity, $r \cdot (\partial K/\partial S)$, where K(S) is the amount of capital investment and r is the discount rate for public capital.

Furthermore, Mohring and Harwitz found that for user fees set equal to marginal congestion costs to cover the cost of adding to highway capacity, the long-run travel time cost function, g(D, S), must be homogeneous of degree zero, and that there must be neither economies nor diseconomies of scale in highway construction.

Following Mohring and Harwitz's work, interest focused on the subject of applying peak-load pricing to roads. Much of the research on this subject coincided with the development of the interstate highway system in the United States and the accompanying establishment or expansion of freeway systems in most of the nation's larger urban areas. During the same two decades, the 1960s and 1970s, the automobile became the prevailing mode of choice for most Americans while usage of public transit systems declined. This latter trend was viewed negatively by many urban planners and economists. Also, as Federal environmental rules restricting air and noise pollution, adverse impacts on environmentally sensitive lands, cultural landmarks, and areas of low cost housing were implemented, during this period interest in market-based alternatives to adding road capacity increased.

A leading advocate for the imposition of congestion taxes on users of high traffic volume roads since this time has been William Vickrey. In numerous articles (Vickrey, 1963, 1967, 1968, 1969) he presents theoretical justification for the imposition of congestion taxes on road users as a means for spreading traffic between congested and uncongested roadways. His work also addresses the use of congestion tolls to encourage highway users to divert travel from peak to off-peak traffic periods.

During the 1970s numerous efforts were made to employ econometric techniques to estimate optimal congestion tolls for urban highways (Henderson, 1974; Boardman and Lave, 1977; Keeler and Small, 1977). In one such study, Keeler and Small found that in the San Francisco Bay area road user charges were substantially below an optimal peak period toll level. They also found that urban freeways in the San Francisco Bay area exhibited constant economies of scale with respect to roadway width. Another interesting finding of this study is that a low time value results in a higher peak period optimal toll than does a high time value.

A good recent survey of road pricing research is presented by Morrison (1986). This survey presents estimates of optimal long-run congestion tolls ranging between 1.2 cents and 34.3 cents per auto-mile, and optimal short-run congestion tolls ranging between 4 cents and 38 cents per auto-mile. Morrison's article also discusses legal and political issues associated with efforts to impose congestion tolls in the United States, and he presents information on the experiences of Singapore and Hong Kong where such tolls have been implemented.

Review of Air Transportation System Pricing Research

The volume of literature dealing with air transportation system pricing and investment is not quite as rich as that dealing with highways. However, beginning with a paper by Levine (1969) increased attention has been focused on the inefficient manner in which air transportation infrastructure is priced. That paper describes how landing fees are set at most of the nation's airports on the basis of aircraft weight, which is supposed to serve as a surrogate for value of service pricing. Levine further describes the practice of setting landing fees at a level just adequate to cover the portion of airport operating and capital costs that are not covered by terminal space rents and concession charges. As a result, the fees paid by commercial carriers and general aviation generally do not cover the operating and maintenance costs they impose on airports. Even more importantly, landing fees do not reflect the congestion costs associated with airport use during high traffic periods nor the costs associated with adverse environmental impacts airport use imposes on individuals residing in their vicinity. This manner of residual pricing for use of airside facilities by commercial air carriers and general aviation results in user charges being set substantially below optimal levels. More recent articles by Walter (1978) and Golaszewski (1992) confirm these inefficient airport pricing practices continue to prevail in the United

States today.

Similarly, a recent study by the Congressional Budget Office (1992) points out that taxes paid by users of the domestic air transportation system do not generate adequate revenues to cover air traffic control system operating and capital costs nor the administrative costs associated with management of the Federal Aviation Administration. Also, the taxes imposed by the federal government on air transportation system users do not reflect the costs associated with the congestion that arises from concentrating a large share of traffic into a few hours each day. Consequently, current air transportation system user fees and taxes do not reflect either private or social marginal costs associated with system use. However, none of these studies present a theoretical basis for altering the manner in which air transportation facility use is priced.

A second body of research, though, does replicate much of the previously cited theoretical work in the pricing of highways for air transportation infrastructure. Most of this research focuses on the derivation of optimal pricing and investment rules for airport runways (Carlin and Park, 1970; Park, 1971; Morrison, 1982, 1983). Like much of the highway pricing research during the 1970s, the article by Carlin and Park determines the optimality of marginal cost pricing for runway use, but then proceeds to discuss institutional factors which would likely thwart imposition of such a pricing system. Park (1971) further explores alternative means for implementing optimal airport tolls through investigation of the impacts of assessing such charges on air carriers versus as a "head-tax" on passengers. This analysis found imposition of congestion tolls directly on the air carriers is superior to an added "tax" on passengers because the added carrier charge would result in higher aircraft load factors.

Morrison derives optimal pricing rules for both uncongested airports (1982) and congested airports (1983). He also estimates optimal toll levels in these two cases. For the uncongested airport case he finds a Ramsey type pricing system to be optimal. A major finding of the second article is that current weight-based fees do not vary by time of day and consequently tend to result in the misallocation of traffic between peak and off-peak periods of air transportation service demand.

Review of Club Theory Research

As defined by Sandler and Tschirhart (1980) a club is a voluntary group deriving mutual benefit from sharing production costs, the members' characteristics, and/or a good characterized by excludable benefits. They also trace the roots of club theory to Pigou (1920) and Knight (1924) whose works have been previously cited as the foundation for research into the issue of congestion pricing for transportation facilities. Thus, a common source is established for the application of club theory to the development of a theory of transportation facility pricing and investment. However, to date there have been only a few efforts to treat transportation pricing and investment issues from a club theory perspective (Oakland, 1972; Littlechild and Thompson, 1977; Berglas and Pines, 1981).

The first formal development of club theory is credited to James Buchanan (1965). He presented the club concept as a bridging of the gap between purely private and purely public goods. The principal result of Buchanan's initial club model is that there exist goods members of society consume jointly which are subject to congestion beyond some finite size of the sharing group. Consequently, the optimal size group of consumers for such goods falls somewhere between one and the total population. Buchanan derived this result by maximizing the utility of a representative member of a homogenous group of consumers of the club good simultaneously with respect to the quantity of the club good to be provided and the number of members of the sharing group.

Buchanan's model, which only takes into consideration the interests of a representative club good consumer, is commonly characterized as presenting a within-club perspective. Subsequent research by Ng (1973) extends the treatment of club goods to encompass an overall societal perspective in which both consumer and non-consumer preferences are taken into consideration. However, both Buchanan's and Ng's models suffer from the treatment of the size of the group of club good consumers as a discrete variable. This problem results from the assumption that membership of the group of club good consumers is characterized by homogeneous preferences and that every member of the group has to consume the same amount of the club good.

The problem of discrete club size was solved by Oakland (1972) who developed a model in which the amount of club good consumption is permitted to vary among club members. The allowing of club members to possess a heterogeneous array of preferences yielded a toll, or utilization rate, condition. This condition provides the basis for determination of optimal pricing rules for shared goods which are used in varying amounts by members of the consuming group.

A further significant modification of the club good model by Oakland consists of replacement of the group size variable as an argument in the utility functions of club members with a congestion function. Employing this form of the club model Oakland expresses the utility of a representation club member as a negative function of congestion, which in turn is expressed as a negative function of total club good use and as a positive function of club good size, capacity or quantity.

Using this form of the club model Oakland and others (DeSerpa, 1978; Sandler and Tschirhart, 1980, 1984) show that expressing congestion as a ratio of club good use to the quantity of the club good (i.e., a congestion function that is homogeneous of degree zero with respect to club good use and quantity) leads to the finding that the club can be fully financed from user fees if the club's cost structure is characterized by constant economies of scale. This form of the club model possesses particularly attractive features for application to the analysis of transportation systems where a traffic volume to transportation facility capacity ratio serves as the principal argument for the congestion, or delay, function.

Aside from the work by Oakland, few other attempts have been made to explicitly address transportation pricing and investment issues from a club theory perspective. Berglas and Pines (1981) presented what they claimed was a unified club, local public good and transportation model. Among their findings, they claimed that for a heterogeneous population Pareto optimally required a distribution of the population over a set of segregated clubs. Sandler and Tschirhart (1984), though, show that this finding resulted from Berglas and Pines' assumption that club members must fully finance provision of the club good. Sandler and Tschirhart also show that Berglas and Pines' findings only apply to the case of replicable clubs in which every member of the population belongs to some club. Sandler and Tschirhart claim this condition does not hold for transportation facilities, which are generally non-replicable, and as a result, leave some members of society excluded from club membership. In this case, they claim heterogeneous club membership is optimal. The issue of whether segregated or mixed club membership is optimal is of particular importance in identifying under what conditions economies of scope are associated with the use of transportation facilities.

In another paper, Littlechild and Thompson (1977) use club theory to explore the sharing of airport runway capital costs among different types of aircraft. Employing a game theory model they show that in the absence of congestion optimal landing fees should reflect both variable operating and maintenance costs associated with different types of aircraft plus a share of the common costs associated with runway capital costs. In the conclusion to this article the authors suggest a number of possible extension to their model. Among these extensions the authors suggest the club approach may be applied to a network of airports as well as to single airports. They also suggest that the model could be modified to incorporate the impact of externalities. However, they recognize that this modification would require making passengers the decision makers in the model rather than the airlines.

Review of Multiproduct Enterprise Research

Recent research related to the economics of multiproduct industries and network externalities provides additional support for expanding the theory of transportation system pricing and investment. Given that most transportation facilities are used to provide a wide variety of services, single output models are incapable of adequately addressing those pricing and investment issues related to the sharing of transportation facilities and systems by a population characterized by heterogeneous travel preferences. Also, evaluation of conditions under which cross-subsidization among different elements of a transportation system may be justified requires the consideration of network externalities.

The most comprehensive treatment of multiproduct industry economics to date is provided by Baumol, Panzar and Willig (1988). Although ostensibly concerned with the presentation of the theory of contestable markets, this work also serves as a treatise on theoretic and empirical issues associated with the economics of multiproduct industries. Most of the concepts of multiproduct industry cost analysis used in this dissertation are derived from this source or from other works by these authors or others with whom they have collaborated on doing related research (Baumol and Bradford, 1970; Panzar, 1976; Panzar and Willig, 1977, 1981; Willig, 1979; Bailey and Friedlaender, 1982).

Among the multiproduct industry cost concepts presented by Baumol, Panzar and Willig used in this dissertation are multiproduct (ray) economies of scale, average incremental cost, product-specific economies of scale, and economies of scope. For each of these cost concepts the authors present measures which provide a basis for conducting empirical research.

The measure developed for ray economies of scale is $S_n(Y) = C(Y)/\Sigma_i Y_i \bullet C_i(Y)$, where C(Y) is the cost associated with producing a vector of outputs, Y, and $C_i(Y)$ is the marginal cost associated with producing output i. In the single output case this measure becomes simply the ratio of average cost to marginal costs. As in the single product case, $S_n(Y)$ may take values greater than, equal to or less than one which signify increasing, constant or decreasing ray economies of scale, respectively.

Baumol, Panzar and Willig define product-specific economies of scale in terms of the ratio of the average incremental cost associated with producing a specific product to the marginal cost associated with producing that product, i.e., $S_i(Y) = AIC(Y_i)/C_i(Y)$, where $AIC(Y_i)$ denotes the average incremental cost associated with producing output Y_i. In this measure, average incremental cost is defined as the difference between the cost of jointly producing the entire vector of outputs and the cost of producing all outputs except output i divided by the quantity of output i that is produced, i.e., $AIC(Y_i) = [C(Y) - C(Y_{n-i})]/Y_i$. Values for $S_i(Y)$ greater than, equal to or less than one denote increasing, constant or decreasing product-specific economies of scale, respectively.

When it is less costly to produce n outputs jointly than to produce the outputs separately, or at least not all together, economies of scope are said to exist. The degree of scope economies, denoted $SC_i(Y)$, exhibited by a multiproduct production process may be measured by the following ratio:

$$SC_i(Y) = [C(Y_i) + C(Y_{n-i}) - C(Y)]/C(Y),$$

where $C(Y_i)$ is the cost of producing output set i, $C(Y_{n-i})$ is the cost of producing the remainder of outputs in vector Y and C(Y) is the cost of producing the entire vector of n outputs jointly. Economies (diseconomies) of scope are said to exist when $SC_i(Y) > (<) 0$.

The last of these multiproduct cost concepts is particularly important in determining under what conditions the sharing of transportation facilities by multiple user groups is advantageous and when it is not advantageous. Panzar and Willig (1981) suggest that economies of scope arise from the existence of a quasi-public factor of production in an industry's input requirement set. They also show that the existence of economies of scope is necessary and sufficient for the joint production of outputs by firms in the industry to result.

Industries offering services over an interconnected network, which may be thought of as a quasi-public good, generally exhibit production costs characterized by economies of scope. Also, as shown by Artle and Averous (1973), services offered over a network yield external benefits to users which increase with the size of the network. This feature of network industries provides justification for cross-subsidization among elements of the network. An additional interesting feature of this article is that the optimality condition derived by the authors associated with the addition of a new user to the network resembles a combined club model type membership and provision condition. These results are presented in the context of the national telephone network. However, the authors maintain that similar findings could be expected for other industries which offer their services over an interconnected network, such as the motor carrier and air transportation industries.

Thus, both club theory and the theory of multiproduct industries offer ideas which can be used to expand the analysis of transportation infrastructure pricing and investment issues. This is done through the presentation of three general transportation models in Chapter 3.

CHAPTER 3:GENERAL TRANSPORTATION CLUB MODELS

Previous transportation infrastructure pricing and investment models have focused almost exclusively on the use of congestion taxes as a means for more efficiently allocating the use of transportation way facilities (i.e., urban freeways or airport runways, and for financing the expansion of these facilities). And although much prior research has addressed both the temporal and spacial dimensions of the problem, models addressing these dimensions of the problem in the context of scope economies have only recently begun to appear (Brueckner and Lee, 1991; Sandler and Tschirhart, 1993). Furthermore, existing models ignore the interaction between way and non-way (i.e., terminal, communication and traffic control) facilities in the provision of transportation services, and they fail to consider how the sharing of facilities by multiple user groups affect the determination of conditions required for efficient pricing and resource allocation. Finally, although prior models implicitly recognize the existence of that portion of the population that consists of nonusers of the transportation infrastructure, they do not provide a means for addressing the pricing and investment implications of the external impacts of transportation facility existence and use on these individuals.

The models presented in this chapter develop a framework for addressing the omissions of existing transportation pricing and investment models cited above. Another major departure from prior work in this area, is that the models presented in this chapter approach the derivation of optimality conditions from a comprehensive social welfare maximization perspective rather than the perspective of net user benefit maximization or user cost minimization, which have been the dominant approaches employed by others since the pioneering work of Mohring and Harwitz (1962). Consequently, the approach followed here can be viewed as providing a theoretical foundation for the more applied approaches employed by prior researchers.

The remainder of this chapter presents three general transportation club models. The first model replicates the findings of Mohring and Harwitz for a single transportation facility that serves a single group of users, who are homogeneous in their tastes and preferences, and who are subject to a binding capacity constraint. The second model expands the analysis by taking into consideration non-user externalities. The third model further extends consideration to multiple time periods and user groups.

One-period, One User Group, Capacity Constrained Single Transportation Club Model without Non-user Externalities

For this model the total population of the transportation facility's service area, P, is divided between two internally homogeneous groups. One group of M individuals consists of those members of the service area population who each use the transportation facility v^m times during a single time period. The other group consists of the remainder of the service area population, P-M individuals, who do not use the transportation facility. The utilities of representative members of the two groups increase with the consumption of a composite private good, y, which serves as a numeraire good, i.e., for non-users of the transportation facility $\partial U^l/\partial y^l > 0$ and for users of the facility $\partial U^m/\partial y^m > 0$. Also, non-users of the transportation facility are affected neither beneficially nor adversely by the existence of the facility or by its use by others, i.e., $U^l = U^l(y^l, 0, 0)$. The utility of a representative member of the group of transportation facility users, i.e., $U^m = U^m[y^m, v^m, c(F^m, X)]$, where $F^m = v^m \cdot M$, increases with his or her own use of the facility, i.e., $\partial U^m/\partial v^m > 0$, while it decreases as the facility becomes more congested, i.e., $\partial U^m/\partial c < 0$.

The transportation facility is subject to congestion, $c(F^m, X)$, which increases with the total volume of use, or traffic flow, F^m, and decreases with the provision of added capacity, X, i.e., $\partial c/\partial F^m > 0$ and $\partial c/\partial X < 0$. Total use of the transportation facility during the period is constrained by the capacity of the facility, i.e., $F^m \leq X$. Also, the cost of providing and operating the transportation facility, C = C(X,

F^m), increases both with the size of the facility and with the volume of use, i.e., $\partial C(.)/\partial X > 0$ and $\partial C(.)/\partial F^m > 0$.

The model that results from these assumptions consists of the maximization of an equally weighted Benthamite social welfare function subject to a societal budget constraint and to the transportation facility capacity constraint. The objective function for this model is

$$W = (P-M) \cdot U^l(y^l, 0, 0) + M \cdot U^m[y^m, v^m, c(F^m, X)]. \tag{1}$$

The societal budget constraint,

$$I = (P-M) \cdot y^l + M \cdot y^m + C(X, F^m), \tag{2}$$

indicates the total income of the service area population, I, is spent on consumption of the private good by members of both segments of the population, as well as for the provision and operation of the transportation facility. The second constraint,

$$F^m \leq X, \tag{3}$$

requires the volume of traffic served by the transportation facility not exceed the traffic carrying capacity of the facility.

The Lagrangean function, comprised of the objective function and the two constraints,

$$\begin{aligned}\text{Max. } L = {} & (P-M)\cdot U^{l}(y^{l},0,0) + M\cdot U^{m}[y^{m},v^{m},c(F^{m},X)] \\ & + \lambda\cdot[I-(P-M)\cdot y^{l} - M\cdot y^{m} - C(X,F^{m})] \\ & + \mu\cdot(X-F^{m}),\end{aligned} \tag{4}$$

is optimized with respect to the consumption of the composite private good by both transportation facility users and non-users, the size of the group of users, the capacity of the transportation facility, the number of trips taken by each user, and the two Lagrange multipliers.

Optimization of the Lagrangean function results in seven first-order conditions. First, optimization with respect to the quantities of the composite private good consumed by representative members of both the user and non-user groups results in the equality of the marginal utility of the private good for the entire transportation facility service area population,

$$\frac{\partial U^{l}}{\partial y^{l}} = \frac{\partial U^{m}}{\partial y^{m}} = \lambda. \tag{5}$$

This equality condition is dependent on the form of the social welfare function, which for this model has the utility functions for all members of the population equally weighted. The significance of this result is that maximization of the welfare of society requires the marginal rate of social substitution be equal across all members of society (see Boadway and Bruce 1984, pp. 139-42), i.e., $(\partial W/\partial U^{l})(\partial U^{l}/\partial y^{l})$ =

$(\partial W/\partial U^m)(\partial U^m/\partial y^m)$. This condition provides a standard unit of measure for the conditions derived from the optimization of the Lagrangean function with respect to the size of the transportation facility user group, the capacity of the transportation facility, and the number of trips made by each member of the user group. Given that the composite private good is designated the numeraire good in this model, this unit of measure can be thought of as the social marginal utility of income.

Optimization of the Lagrangean function with respect to the number of members in the group of transportation facility users yields what is commonly referred to in club theory as a membership condition,

$$\frac{U^m(.)}{\partial U^m/\partial y^m} - \frac{U^l(.)}{\partial U^l/\partial y^l} = -\frac{\partial U^m/\partial c}{\partial U^m/\partial y^m} \cdot \frac{\partial c}{\partial F^m} \cdot F^m + \frac{\partial C(.)}{\partial F^m} \cdot \frac{F^m}{M} + \frac{\mu}{\lambda} \cdot \frac{F^m}{M} + (y^m - y^l). \tag{6}$$

This condition states that the benefit a marginal user derives from the transportation facility, which is given by the expression on the left-hand-side (LHS) of the equation, equals the marginal costs imposed by that individual's use of the facility and a reallocation of income between the user and non-user groups, which is given by the right-hand-side (RHS) of the equation. Given the number of users of the transportation facility is positive, this condition holds with equality.

More specifically, the benefit a marginal user derives from the transportation facility is expressed as the difference between the utilities of a user and non-user measured in terms of the marginal utility all members of the population derive from their last unit of consumption of the composite private good. The costs imposed by the marginal user of the transportation facility consists of three components. First, the additional usage of the facility increases congestion experienced by all users. Second, the cost required to operate and maintain the transportation facility increases as the user group is increased by one member. Third, there is an added cost associated with increasing capacity of the transportation facility to accommodate the marginal user.

The last RHS term in equation (6) represents a change in the amount of the private good consumed, which can be thought of as a reallocation of income, by the marginal user of the transportation facility. This condition is required to maintain equality between the marginal rates of social substitution for all members of the population by maintaining the marginal utility derived from the private good for the marginal transportation facility user. As explained by Cornes and Sandler (1986, p. 178) this change will be positive if the private good and use of the transportation facility are viewed as complements by the marginal transportation facility user. On the other hand, the change will be negative if these two goods are viewed as substitutes by the marginal user of the transportation facility.

Optimization of the Lagrangean function with respect to the size of the transportation facility yields a provision condition for the club good, the transportation facility,

$$M \cdot \frac{\partial U^m / \partial c}{\partial U^m / \partial y^m} \cdot \frac{\partial c}{\partial X} = \frac{\partial C(.)}{\partial X} - \frac{\mu}{\lambda}. \qquad (7)$$

This condition shows that optimal provision of the transportation facility occurs when the sum of benefits derived by all users of the facility, given by the LHS of the equation, equals the marginal cost associated with a change in the size, or capacity, of the facility, minus the benefits associated with expanding the facility's capacity, given by the ratio of the two Lagrange multipliers. Since the capacity of the facility is assumed to be positive, this condition holds with equality.

Optimization of the Lagrangean function with respect to the number of trips taken by each member of the transportation facility users group results in a toll, or usage, condition for the transportation facility,

$$\frac{\partial U^m/\partial v^m}{\partial U^m/\partial y^m} = -M \cdot \frac{\partial U^m/\partial c}{\partial U^m/\partial y^m} \cdot \frac{\partial c}{\partial F^m} + \frac{\partial C(.)}{\partial F^m} + \frac{\mu}{\lambda}. \tag{8}$$

This condition states that the benefit derived from one additional trip made using the transportation facility, given by the LHS of the equation, equals the additional costs associated with the increased traffic congestion that trip imposes on all users of the facility, plus the additional operating and maintenance costs occasioned by that trip, plus the benefits that would be derived from relaxing the constraint on the traffic carrying capacity of the facility through added capital investment. Since the number of trips made by each member of the group of transportation facility users is assumed positive, this condition holds with equality.

Finally, given that the capacity constraint is an inequality, optimization of the Lagrangean function with respect to that constraint's multiplier yields the Kuhn-Tucker conditions,

$$X - F^m \geq 0 \tag{9}$$

$$\mu \geq 0 \tag{10}$$

$$\mu \cdot (X - F^m) = 0. \tag{11}$$

These conditions indicate that when the traffic volume is strictly less than the capacity of the transportation facility, the Lagrange multiplier, μ, equals 0. However, if the traffic volume is constrained by the capacity of the facility, then the Lagrange multiplier takes on a positive value and equation (9) holds with equality. This latter case where the constraint becomes of consequence gives rise to the need for users of the transportation facility to take into consideration the cost of new capital investment, represented by the last RHS terms in the provision and toll conditions, as well as the costs associated with operating and maintaining the transportation facility.

Optimization of the Lagrangean function with respect to the other Lagrange multiplier, λ, returns the societal budget constraint, equation (2), which is assumed to hold with equality.

Equations (5) through (11) establish the conditions required for the optimal use and provision of the transportation facility. However, from a public policy perspective, what is even more important is their implications for the pricing of use of the facility and the financing of investment in facility capacity.

Transportation facility financing considerations

Given this model assumes only users of the transportation facility benefit from its existence, it is logical to ask whether the facility can be financed solely from user fees. If one assumes that users of the facility are willing to pay an amount equal to the benefits they derive from the facility, then the toll per use of the facility, t^m, would equal the marginal rate of substitution between making a trip and consumption of the composite private good when membership of the users group, the number of trips made by each user group member, and the capacity of the transportation facility are simultaneously optimized. Given these assumptions, full financing of the transportation facility by users yields the following condition,

$$F^m \cdot \frac{\partial U^m / \partial v^m}{\partial U^m / \partial y^m} = F^m \cdot t^m = C(F^m, X). \tag{12}$$

To determine what conditions must be satisfied for full user financing to be feasible, it is necessary to take into consideration both the toll condition, equation (8), and the provision condition, equation (7). First, multiplication of the RHS of the toll condition by the optimal total number of trips made using the transportation facility, F^m, and substitution of the resulting expression for the LHS of equation (12), gives equation (13),

$$-M \cdot \frac{\partial U^m / \partial c}{\partial U^m / \partial y^m} \cdot \frac{\partial c}{\partial F^m} \cdot F^m + \frac{\partial C(.)}{\partial F^m} \cdot F^m + \frac{\mu}{\lambda} \cdot F^m = C(F^m, X). \tag{13}$$

This equation states that the sum of marginal congestion costs and marginal operating and maintenance costs associated with use of the transportation facility, plus the marginal benefits that would result from adding capacity to the facility, must equal the total cost of providing, operating and maintaining the facility at the optimal levels of use and capacity.

Next, in order to relate the toll and provision conditions, it is necessary to make an assumption about how congestion of the transportation facility is dependent on the total use and the capacity of the facility. Typically, the planning and design of transportation facilities consists of two major steps. First, planners forecast travel demand for a horizon date 20 or more years in the future. Then, based on the function the proposed transportation improvement is intended to serve a "level of service" standard is adopted. This level of service standard is often expressed as a ratio of the forecasted traffic, adjusted for vehicle mix, to the design capacity of the proposed transportation facility at the planning horizon date. This ratio is commonly referred to as the volume to capacity ratio. As presented both in the Highway Capacity Manual published by the Transportation Research Board (1985) and Ashford and Wright (1992), Airport Engineering, 3rd Edition, delay time costs, or congestion costs, are generally modeled as a function of the volume to capacity ratio either in deterministic or stochastic form. Thus, the congestion function in this model, in the absence of non-user externalities, can be assumed to be homogeneous of degree zero in traffic flow and capacity, i.e., $c(F^m, X) = c(F^m/X)$, and by

Euler's theorem,

$$\frac{\partial c}{\partial F^m} \cdot F^m = -\frac{\partial c}{\partial X} \cdot X. \tag{14}$$

This condition states that when use and provision of the transportation facility are in equilibrium the congestion caused by the last trip taken on the facility will just be offset by the final unit of traffic capacity provided by the facility.

Now, combining equations (13) and (14) with the transportation facility provision condition shows that for the facility to be solely financed by user fees the transportation facility must exhibit constant economies of scale. First, substituting the RHS of equation (14) into equation (13) one obtains equation (15),

$$M \cdot \frac{\partial U^m/\partial c}{\partial U^m/\partial y^m} \cdot \frac{\partial c}{\partial X} \cdot X + \frac{\partial C(.)}{\partial F^m} \cdot F^m + \frac{\mu}{\lambda} \cdot F^m = C(F^m, X). \tag{15}$$

Then, substituting the RHS of equation (7), the provision condition, into the first LHS term of equation (15), the condition for ray constant economies of scale is obtained,

$$\frac{\partial C(.)}{\partial X} \cdot X + \frac{\partial C(.)}{\partial F^m} \cdot F^m - \frac{\mu}{\lambda} \cdot (X - F^m) = C(F^m, X). \tag{16}$$

This shows that the transportation facility cost function is homogeneous of degree one with respect to its utilization and capacity. This condition obtains because the last term on the

LHS of equation (16) equals the Kuhn-Tucker condition derived in equation (11), which equals zero. Alternatively, dividing the RHS of equation (16) by its LHS yields the following ratio form condition for ray constant economies of scale, as presented in Bailey and Friedlaender (1982),

$$\frac{C(F^m, X)}{[\partial C(.)/\partial F^m] \cdot F^m + [\partial C(.)/\partial X] \cdot X} = 1. \tag{17}$$

Therefore, if all benefits associated with use of the transportation facility accrue only to the population of users, and if the facility is characterized by a cost structure that exhibits constant ray economies of scale, pricing each use of the facility equal to the marginal rate of substitution between use of the facility and the composite private good will result in adequate revenues to cover all costs associated with provision of transportation services by the facility. Furthermore, letting $t^m(*)$ stand for the optimal usage toll, one sees in equation (18) that if the facility exhibits constant ray economies of scale this toll will equal the average cost associated with providing the transportation service, as well as the marginal cost associated with the taking of one more trip,

$$F^m \cdot \frac{\partial U^m/\partial v^m}{\partial U^m/\partial y^m} = F^m \cdot t^m = C(F^m, X)$$

$$\Rightarrow t^m(*) = \frac{C(F^m, X)}{F^m} = -M \cdot \frac{\partial U^m/\partial c}{\partial U^m/\partial y^m} \cdot \frac{\partial c}{\partial F^m} + \frac{\partial C(.)}{\partial F^m} + \frac{\mu}{\lambda}. \tag{18}$$

Or more precisely, substituting from the provision condition, equation (7), for the ratio of Lagrange multipliers, as shown in equation (19), one sees that the optimal toll must take into consideration both the costs and benefits, given by the last two RHS terms, respectively, associated with expansion of the transportation facility when its use is at capacity,

$$t^m(*) = -M \cdot \frac{\partial U^m/\partial c}{\partial U^m/\partial y^m} \cdot \frac{\partial c}{\partial F^m} + \frac{\partial C(.)}{\partial F^m} + \frac{\partial C(.)}{\partial X} - M \cdot \frac{\partial U^m/\partial c}{\partial U^m/\partial y^m} \cdot \frac{\partial c}{\partial X}. \tag{19}$$

Alternatively, if the transportation facility exhibits increasing economies of scale, setting the toll equal to the marginal rate of substitution between use of the facility and the composite private good will not yield revenues adequate to cover the cost of providing the service. In this case the RHS of equation (16) becomes strictly greater than the LHS of the equation. Therefore, if the transportation facility cost function exhibits increasing economies of scale, the average cost associated with transportation facility provision and use will exceed the marginal cost arising from one more trip. On the other hand, setting the toll in this manner when the transportation facility exhibits decreasing economies of scale will yield a revenue surplus.

Summarizing the results of this model one can state,

Proposition 1: In the absence of non-user externalities, full user financing of a transportation facility requires a cost structure for the facility characterized by constant ray economies of scale.

Generally, transportation facilities do exhibit constant economies of scale over a broad range of output levels. Thus, full user financing is feasible in many cases. However, if non-user externalities associated with the provision and use of a transportation facility do exist, then as the next model shows optimal pricing requires internalization of the costs and benefits associated with the transportation facility impacts experienced by those individuals who do not use the facility.

<u>One-period, One User Group, Capacity Constrained Transportation Facility Club Model with Non-user Externalities</u>

All of the assumptions upon which this second model is based are the same as those for the first model, with one exception. Non-users of the transportation facility are assumed to be adversely affected by use of the transportation facility while at the same time benefiting from its existence, i.e., $\partial U^l/\partial F^m < 0$ and $\partial U^l/\partial X > 0$. The rationale for this change is that users of a transportation facility often cause air and noise pollution that adversely affect people who do not use the facility. On the other hand, the existence of a transportation facility, such as an airport or freeway, often benefits non-users by increasing economic activity in the service area and by making the service area more accessible to friends, relatives, customers and suppliers.

As a result of this one new assumption, the objective function from the first model is modified to make the utility function of the representative member of the group of transportation facility non-users dependent on both the total number of trips made using the facility and on the traffic carrying capacity of the facility,

$$W = (P-M)\cdot U^l(y^l, 0, 0, F^m, X) + M\cdot U^m[y^m, v^m, c(F^m, X), 0, 0]. \quad (1A)$$

Also, as expressed above, the utility functions of both transportation facility users and non-users are assumed to be of the same functional form. The differences among the arguments included in the two utility functions reflect the distinguishing characteristics of members of the two groups. Since by definition members of the group of non-users are assumed to not directly use the airport, their utility functions reflect no impact from the trip and congestion arguments. Similarly, although users of the airport may also experience either adverse or beneficial impacts resulting from the use and existence of the airport, the direct influence of the airport usage and capacity arguments is omitted to emphasize more explicitly the distinction between the two segments of the population.

The societal budget constraint and the transportation facility capacity constraint remain the same as presented in equations (2) and (3) in the first model. Thus, the Lagrangean function for this model is only slightly modified relative to the first model's Lagrangean function, equation (4),

$$\begin{aligned} \text{Max. } L = \ & (P-M)\cdot U^{l}(y^{l},0,0,F^{m},X) + M\cdot U^{m}[y^{m},v^{m},c(F^{m}, X),0,0] \\ & + \lambda\cdot[I - (P-M)\cdot y^{l} - M\cdot y^{m} - C(F^{m}, X)] \qquad (4A) \\ & + \mu\cdot(X - F^{m}) \end{aligned}$$

The first-order conditions for the marginal utility of the composite private good and for the capacity constraint in this model are the same as for the first model. However, since the external impacts of transportation facility existence and use depend on the number of facility users, M, the number of trips made by each user, v^{m}, and on the capacity of the facility, X, the membership, provision, and toll conditions all require modification.

The revised membership condition now includes a fourth cost factor, which is equal to the disbenefits non-users experience as a result of an additional transportation facility user. This additional cost is reflected in the first RHS term of equation (6A),

$$\frac{U^m(.)}{\partial U^m/\partial y^m} - \frac{U^l(.)}{\partial U^l/\partial y^l} =$$

$$- (P - M) \cdot \frac{\partial U^l/\partial F^m}{\partial U^l/\partial y^l} \cdot \frac{F^m}{M} - \frac{\partial U^m/\partial c}{\partial U^m/\partial y^m} \cdot \frac{\partial c}{\partial F^m} \cdot F^m \qquad (6A)$$

$$+ \frac{\partial C(.)}{\partial F^m} \cdot \frac{F^m}{M} + \frac{\mu}{\lambda} \cdot \frac{F^m}{M} + (y^m - y^l).$$

The remainder of this equation is the same as the membership condition for the first model. The added cost associated with expanding the membership of the transportation facility user group implies that the benefit a new member derives from using the transportation facility must be greater in this case than in the model without non-user externalities.

The benefits associated with expansion of the transportation facility also increase as the result of taking into consideration the value non-users place on the existence of the facility. This change from the provision condition in the first model is reflected by the first LHS term in equation (7A),

$$(P - M) \cdot \frac{\partial U^l / \partial X}{\partial U^l / \partial y^l} + M \cdot \frac{\partial U^m / \partial c}{\partial U^m / \partial y^m} \cdot \frac{\partial c}{\partial X} = \frac{\partial C(.)}{\partial X} - \frac{\mu}{\lambda}. \qquad (7A)$$

The benefits derived from an additional trip made using the transportation facility also must increase. This change results from the need to offset the disbenefits experienced by non-users when traffic on the facility increases. The added cost associated with an increase in transportation facility use is reflected by the first RHS term in the revised toll condition presented in equation (8A),

$$\frac{\partial U^m / \partial v^m}{\partial U^m / \partial y^m} = -(P - M) \cdot \frac{\partial U^l / \partial F^m}{\partial U^l / \partial y^l} - M \cdot \frac{\partial U^m / \partial c}{\partial U^m / \partial y^m} \cdot \frac{\partial c}{\partial F^m} + \frac{\partial C(.)}{\partial F^m} + \frac{\mu}{\lambda}. \qquad (8A)$$

These revisions made to the first model to accommodate the impacts the existence and use of the transportation facility have on non-users result in several significant implications for the financing of this type of public infrastructure.

Transportation facility financing considerations

The existence of non-user externalities does not change the nature of the congestion function for the transportation facility. The assumption that the congestion function is homogeneous of degree zero still holds. However, incorporation of non-user externalities in this model does change the condition required for full user financing of the transportation facility.

Letting $t^m(**)$ denote the per trip toll, the requirement that users fully finance the provision and operation of the transportation facility now reflects the need to provide for compensation to non-users to offset the adverse impacts associated with transportation facility use. This revised full user financing condition is presented in equation (13A),

$$t^m(**) \cdot F^m = \frac{\partial U^m/\partial v^m}{\partial U^m/\partial y^m} \cdot F^m = C(F^m, X)$$

$$= -(P - M) \cdot \frac{\partial U^l/\partial F^m}{\partial U^l/\partial y^l} \cdot F^m - M \cdot \frac{\partial U^m/\partial c}{\partial U^m/\partial y^m} \cdot \frac{\partial c}{\partial F^m} \cdot F^m \qquad (13A)$$

$$+ \frac{\partial C(.)}{\partial F^m} \cdot F^m + \frac{\mu}{\lambda} \cdot F^m.$$

In this equation the first RHS term reflects payments users of the transportation facility would have to make to non-users in order for the adverse impacts associated with transportation facility use to be internalized.

Next, using the zero degree homogeneity of the congestion function and the provision condition, equation (7A), one finds that full user financing of the transportation facility no longer implies a facility cost function that is homogeneous of degree one. This is shown by equation (16A),

$$\frac{\partial C(.)}{\partial F^m} \cdot F^m + \frac{\partial C(.)}{\partial X} \cdot X - (P - M) \cdot \left[\frac{\partial U^l/\partial F^m}{\partial U^l/\partial y^l} \cdot F^m + \frac{\partial U^l/\partial X}{\partial U^l/\partial y^l} \cdot X \right] \qquad (16A)$$

$$= C(F^m, X).$$

This equation implies that depending on the net value non-users of the transportation facility place on the external impacts the facility has on them, the cost function for the facility could exhibit increasing, constant or decreasing ray economies of scale. In the case where the value of the adverse impacts associated with use of the transportation facility exceed the value of the benefits associated with the existence of the facility, full user financing requires a cost function that exhibits increasing ray economies of scale. This condition results because then the third LHS term in equation (16A) is positive which implies the cost of providing and operating the transportation facility exceeds the sum of the first two LHS terms in that equation. Consequently, the degree of homogeneity of the transportation facility cost function in this case is less than one. Furthermore, this implies the transportation facility would be smaller than in the case where non-user externalities are absent. On the other hand, if the net value non-users place on external impacts of the transportation facility is positive, then the cost function would have to exhibit decreasing ray economies of scale for full user financing to be feasible, and the facility would be larger than in the case of no non-user externalities.

Finally, combining the provision and toll conditions for this model, equations (7A) and (8A) respectively, one obtains the optimal per trip toll condition for the non-user externality case,

$$t^m(**) = \frac{\partial U^m/\partial v^m}{\partial U^m/\partial y^m}$$

$$= -(P - M)\cdot\left[\frac{\partial U^l/\partial F^m}{\partial U^l/\partial y^l} + \frac{\partial U^l/\partial X}{\partial U^l/\partial y^l}\right] - M\cdot\frac{\partial U^m/\partial c}{\partial U^m/\partial y^m}\cdot\frac{\partial c}{\partial F^m}$$

$$+ \frac{\partial C(.)}{\partial F^m} + \frac{\partial C(.)}{\partial X} - M\cdot\frac{\partial U^M/\partial c}{\partial U^m/\partial y^m}\cdot\frac{\partial c}{\partial X}. \qquad (19A)$$

This optimal toll condition equals the condition derived in the first model, equation (19), with the exception of the first RHS term. This term represents the net value of the external impacts of the transportation facility on non-users.

Therefore, the introduction of non-user externalities into the one-period transportation model results in the following modification to the findings of the first model.

Proposition 2: In the case where the adverse impacts associated with use of the transportation facility are greater than the benefits associated with the existence of the facility, the optimal toll for transportation facility users will increase over what it would be in the non-externality case. If the net value of external impacts is positive, then the converse will be true.

The previous two models show the basis for setting the toll for use of a transportation facility in the context of a single time period when the facility serves a single homogeneous group of users. Comparison of the two models also shows how the optimal toll condition changes when non-user externalities are taken into consideration. However, most transportation facilities are not dedicated to the exclusive service of a single group of users. Neither are most transportation facilities used uniformly every hour of the day. These factors are taken into consideration in the next model.

Two-period, Two User Group, Capacity Constrained Single Transportation Facility Club Model without Non-user Externalities

This third model expands upon the first by including two time periods and a second group of transportation facility users. This is done to permit consideration of peak-load pricing issues and to investigate the implications of the sharing of a transportation facility by a heterogeneous population. These changes make the model more representative of how transportation facilities are actually used. Modifying the model to include two time periods reflects the uneven use transportation facilities experience during different hours of the day, during different days of the week, and during different weeks of the year. These variations in use result in different levels of traffic congestion during different time periods. Consequently, the benefits derived and the costs imposed by a marginal user of a transportation facility similarly vary according to when that individual makes use of the facility.

Also, most transportation facilities are shared by a variety of users. Most highways and airports, as well as many railroad lines, serve both passenger and freight traffic. Even those facilities that are dedicated exclusively to either passenger or freight service serve populations of users that vary in their service requirements and preferences. For example, urban freeways carry passengers traveling by a wide variety of transportation modes (e.g., private automobile, bus, van, taxi and limousine). These vehicle choices can be taken to reflect differences in the preferences of their occupants with respect to the value they place on trip characteristics, such as travel time, waiting time, privacy, comfort, and convenience. Similarly, airports serve business travelers and those traveling for pleasure, individuals and families, the young and the old, users of commercial airlines and owners of private aircraft. Thus, modification of the model to incorporate two groups of users enhances its generality.

Reflecting these changes, the population of the transportation facility's service area is now distributed among three groups, two user groups consisting of M and N individuals, and the remainder of the population, P-M-N in size, that does not use the transportation facility. Also, the utility functions of representative members of the two user groups are modified to depend explicitly on trips taken during each of two time periods, a peak-load traffic period denoted by the subscript 'p' and an off-peak traffic period denoted by the subscript 'o', i.e., $U^i = U^i[y^i, v_o^i, v_p^i, c(.)]$ for $i = m,n$. Again, the utility functions of the representative members of each of the three population groups are of the same functional form. However, the manner in which the functions' arguments impact utility varies to reflect the distinctive characteristics of each group. (See Appendix A, Part 1 for an alternative treatment of the non-user group.)

Similarly, the transportation facility congestion and cost functions are expanded to accommodate both peak and off-peak traffic flow variables for members of the two user groups, i.e., $c(F_o^m, F_p^m, F_o^n, F_p^n, X)$ and $C(F_o^m, F_p^m, F_o^n, F_p^n, X)$, where $F_o^m = v_o^m \cdot M$, $F_p^m = v_p^m \cdot M$, $F_o^n = v_o^n \cdot N$ and $F_p^n = v_p^n \cdot N$. Finally, the model now includes both peak period and off-peak period capacity constraints which require that the weighted sums of trips made by members of both user groups each period not exceed the capacity of the transportation facility, i.e., $F_p^m + k \cdot F_p^n \leq X$ and $F_o^m + k \cdot F_o^n \leq X$, where k is a factor representing a ratio between measures of transportation facility occupancy for members of group N to members of group M. These changes made to the one-period, one-user group model yield the objective function presented in equation (1B),

$$W = (P-M-N)\cdot U^{l}(y^{l}, 0, 0, 0) + M\cdot U^{m}[y^{m}, v_{o}^{m}, v_{p}^{m}, c(F_{o}^{m}, F_{p}^{m}, F_{o}^{n}, F_{p}^{n}, X)] + N\cdot U^{n}[y^{n}, v_{o}^{n}, v_{p}^{n}, c(F_{o}^{m}, F_{p}^{m}, F_{o}^{n}, F_{p}^{n}, X)]. \quad (1B)$$

This objective function is again subject to a societal budget constraint,

$$I = (P-M-N)\cdot y^{l} + M\cdot y^{m} + N\cdot y^{n} + C(F_{o}^{m}, F_{p}^{m}, F_{o}^{n}, F_{p}^{n}, X). \quad (2B)$$

This constraint requires the total income earned by all members of the transportation facility's service area population be expended on the acquisition of private goods by members of the three groups and for the provision and operation of the transportation facility.

Maximization of the objective function is also constrained by the capacity of the transportation facility. This constraint applies separately to the peak and off-peak time periods and thus requires satisfaction of the conditions presented in equations (3B.1) and (3B.2) during the respective periods,

$$F_{p}^{m} + k\cdot F_{p}^{n} \leq X, \quad (3B.1)$$

and

$$F_{o}^{m} + k\cdot F_{o}^{n} \leq X. \quad (3B.2)$$

The Lagrangean function for this model,

$$\begin{aligned}\text{Max. } W = & (P-M-N)\cdot U^{l}(y^{l}, 0, 0, 0) \\ & + M\cdot U^{m}[y^{m}, v_{o}^{m}, v_{p}^{m}, c(F_{o}^{m}, F_{p}^{m}, F_{o}^{n}, F_{p}^{n}, X)] \\ & + N\cdot U^{n}[y^{n}, v_{o}^{n}, v_{p}^{n}, c(F_{o}^{m}, F_{p}^{m}, F_{o}^{n}, F_{p}^{n}, X)] \\ & + \lambda\cdot [I - (P-M-N)\cdot y^{l} - M\cdot y^{m} - N\cdot y^{n} \\ & - C(F_{o}^{m}, F_{p}^{m}, F_{o}^{n}, F_{p}^{n}, X)] \\ & + \mu\cdot [X - F_{p}^{m} - k\cdot F_{p}^{n}] + \delta\cdot [X - F_{o}^{m} - k\cdot F_{o}^{n}],\end{aligned} \tag{4B}$$

is optimized with respect to the consumption of the composite private good by members of all three segments of the population, the number of members in each of the two transportation facility user groups, the capacity of the transportation facility, the number of trips taken during each time period by members of the two user groups, and the three Lagrange multipliers.

Optimization of the above Lagrangean function results in the following first-order conditions. First, as shown in equation (5B),

$$\frac{\partial U^{l}}{\partial y^{l}} = \frac{\partial U^{m}}{\partial y^{m}} = \frac{\partial U^{n}}{\partial y^{n}} = \lambda, \tag{5B}$$

the addition of the second user group results in the inclusion of one more term in the marginal utility condition for the private good. The interpretation of this condition remains the same as in equation (5) of the first model, i.e., that the marginal rates of social substitution be equal across the entire population.

Next, optimization of the Lagrangean function with respect to the sizes of the two transportation facility user groups yields two membership conditions which are presented in equations (6B.1) and (6B.2). For members of group M,

$$\frac{U^m(.)}{\partial U^m/\partial y^m} - \frac{U^l(.)}{\partial U^l/\partial y^l} =$$

$$- \frac{\partial U^m/\partial c}{\partial U^m/\partial y^m} \cdot \frac{\partial c}{\partial F_p^m} \cdot F_p^m - \frac{\partial U^m/\partial c}{\partial U^m/\partial y^m} \cdot \frac{\partial c}{\partial F_o^m} \cdot F_o^m$$

$$- \frac{N}{M} \cdot \frac{\partial U^n/\partial c}{\partial U^n/\partial y^n} \cdot \frac{\partial c}{\partial F_p^m} \cdot F_p^m - \frac{N}{M} \cdot \frac{\partial U^n/\partial c}{\partial U^n/\partial y^n} \cdot \frac{\partial c}{\partial F_o^m} \cdot F_o^m \qquad (6B.1)$$

$$+ \frac{\partial c(.)}{\partial F_p^m} \cdot \frac{F_p^m}{M} + \frac{\partial c(.)}{\partial F_o^m} \cdot \frac{F_o^m}{M} + \frac{\mu}{\lambda} \cdot \frac{F_p^m}{M} + \frac{\delta}{\lambda} \cdot \frac{F_o^m}{M}$$

$$+ (y^m - y^l),$$

and for members of group N,

$$\frac{U^n(.)}{\partial U^n/\partial y^n} - \frac{U^l(.)}{\partial U^l/\partial y^l} =$$

$$- \frac{\partial U^n/\partial c}{\partial U^n/\partial y^n} \cdot \frac{\partial c}{\partial F_p^n} \cdot F_p^n - \frac{\partial U^n/\partial c}{\partial U^n/\partial y^n} \cdot \frac{\partial c}{\partial F_o^n} \cdot F_o^n \qquad (6B.2)$$

$$- \frac{M}{N} \cdot \frac{\partial U^m/\partial c}{\partial U^m/\partial y^m} \cdot \frac{\partial c}{\partial F_p^n} \cdot F_p^n - \frac{M}{N} \cdot \frac{\partial U^m/\partial c}{\partial U^m/\partial y^m} \cdot \frac{\partial c}{\partial F_o^n} \cdot F_o^n$$

$$+ \frac{\partial C(.)}{\partial F_p^n} \cdot \frac{F_p^n}{N} + \frac{\partial C(.)}{\partial F_o^n} \cdot \frac{F_o^n}{N} + \frac{\mu}{\lambda} \cdot k \cdot \frac{F_p^n}{N} + \frac{\delta}{\lambda} \cdot k \cdot \frac{F_o^n}{N}$$

$$+ (y^n - y^l).$$

Like equation (6) in the first model, these conditions indicate that membership in each of the two user groups is optimized when the benefits derived by the marginal users, given by the LHS of each equation, are just equal to the costs those individuals' use of the transportation facility impose on all other users, plus any redistribution of the private good required to maintain the equality of the marginal rate of social substitution among all members of the population. However, the RHS of each of these membership conditions consists of nine rather than the four terms derived in the first model. In this case the first two RHS terms in each equation represent the additional congestion costs the marginal user of the transportation facility imposes on members of his or her own group during the peak and off-peak periods, respectively. The third and fourth RHS terms similarly represent peak and off-peak period congestion costs imposed by the marginal user on members of the other user group. The fifth and sixth RHS terms equal the additional peak and off-peak period operating costs associated with the increased use of the facility. Whereas the seventh and eighth RHS terms represent the additional capital investment necessitated by increased peak period and off-peak period use of the transportation facility when traffic during either of the periods reaches or exceeds the facility's capacity. Finally, like in equation (6), the last term accounts for adjustments in the allocation of the private good, or income, between the marginal users and non-users. Since each group of users is assumed to contain at least one member, the conditions hold with equality.

Similarly, optimal provision of the transportation facility requires recognition of the benefits derived by members of both user groups from the reduction in congestion that would result from facility expansion. As shown in equation (7B),

$$M \cdot \frac{\partial U^m/\partial c}{\partial U^m/\partial y^m} \cdot \frac{\partial c}{\partial X} + N \cdot \frac{\partial U^n/\partial c}{\partial U^n/\partial y^n} \cdot \frac{\partial c}{\partial X} = \frac{\partial C(.)}{\partial X} - \frac{\mu}{\lambda} - \frac{\delta}{\lambda}, \tag{7B}$$

the LHS of the provision condition now consists of the sum of benefits received by members of the two user groups which result from the reduction in traffic congestion when the capacity of the transportation facility is expanded. Similarly, the RHS of the revised provision condition now includes three terms. As in equation (7), the first term represents the marginal cost associated with expansion of the facility's capacity. The other two terms consist of ratios of the peak period and off-peak period capacity constraint Lagrange multipliers to the budget constraint Lagrange multiplier. These two ratios of Lagrange multipliers are interpreted to represent the marginal benefits associated with relaxing the capacity constraints for each of the two time periods measured in terms of the marginal utility of the private good. If the capacity of the transportation facility is not being fully used during either of the periods, then the magnitude of the corresponding ratio of Lagrange multipliers for that period is zero.

Optimization of the Lagrangean function with respect to use of the transportation facility results in four toll conditions. These conditions, one for members of each user group during each time period, are presented in equations (8B.1) through (8B.4). For members of group M the peak period toll condition is

$$\frac{\partial U^m/\partial v_p^m}{\partial U^m/\partial y^m} = -M\cdot\frac{\partial U^m/\partial c}{\partial U^m/\partial y^m}\cdot\frac{\partial c}{\partial F_p^m} - N\cdot\frac{\partial U^n/\partial c}{\partial U^n/\partial y^n}\cdot\frac{\partial c}{\partial F_p^m} + \frac{\partial C(.)}{\partial F_p^m} + \frac{\mu}{\lambda}, \tag{8B.1}$$

and the off-peak period toll condition is

$$\frac{\partial U^m/\partial v_o^m}{\partial U^m/\partial y^m} = -M\cdot\frac{\partial U^m/\partial c}{\partial U^m/\partial y^m}\cdot\frac{\partial c}{\partial F_o^m} - N\cdot\frac{\partial U^n/\partial c}{\partial U^n/\partial y^n}\cdot\frac{\partial c}{\partial F_o^m} + \frac{\partial C(.)}{\partial F_o^m} + \frac{\delta}{\lambda}. \tag{8B.2}$$

Similarly, for members of group N the peak period toll condition is

$$\frac{\partial U^n/\partial v_p^n}{\partial U^n/\partial y^n} = -N\cdot\frac{\partial U^n/\partial c}{\partial U^n/\partial y^n}\cdot\frac{\partial c}{\partial F_p^n} - M\cdot\frac{\partial U^m/\partial c}{\partial U^m/\partial y^m}\cdot\frac{\partial c}{\partial F_p^n} + \frac{\partial C(.)}{\partial F_p^n} + \frac{\mu}{\lambda}\cdot k, \tag{8B.3}$$

and the off-peak period toll condition is

$$\frac{\partial U^n/\partial v_o^n}{\partial U^n/\partial y^n} = -N\cdot\frac{\partial U^n/\partial c}{\partial U^n/\partial y^n}\cdot\frac{\partial c}{\partial F_o^n} - M\cdot\frac{\partial U^m/\partial c}{\partial U^m/\partial y^m}\cdot\frac{\partial c}{\partial F_o^n} + \frac{\partial C(.)}{\partial F_o^n} + \frac{\delta}{\lambda}\cdot k. \tag{8B.4}$$

Each of the toll conditions follows the same general form. The term on the LHS of each equation equals the marginal rate of substitution between use of the transportation facility and consumption of the composite private good. Or alternatively, the LHS of each equation represents the additional benefit a user of the transportation facility derives from taking one more trip during a given time period. Given the assumptions that members of the two user groups differ in terms of their tastes and preferences and that travel during the two time periods is represented separately in the utility functions of the representative user group members, the four equations will not generally be equal.

Similarly, the RHS of each of the toll conditions consists of four terms. The first RHS term in each case represents the increased congestion cost an additional trip by a member of one of the user groups imposes on the members of his or her own group. The second RHS term equals the increase in congestion cost the same trip imposes on members of the other user group. The third RHS term equals the increase in transportation facility operating cost associated with the added trip. Finally, the last RHS term represents the benefit the individual making the additional trip would derive from expansion of the transportation facility if it is already being used to capacity during the time period when the individual wants to make the trip. This last RHS term equals zero if the facility is not being used to capacity during the time period when the desire for additional travel arises. This may be expected to be the case most of the time for the off-peak period. However, when demand for the use of the transportation facility during the peak traffic period becomes exceptionally high the overflow will often spill over into the off-peak period and cause the capacity of the facility to be reached during that period as well. Finally, the weighting of the last RHS term by the factor k in the two toll conditions for members of group N reflects the prior assumption that members of the two groups do not use the transportation facility with the same intensity. For example, in traveling on an urban freeway members of group M may travel alone whereas members of group N carpool.

The last set of first-order conditions derived for this model results from differentiating the Lagrangean function with respect to each of the Lagrange multipliers. For the multiplier λ the result is the societal budget constraint in implicit form which is assumed to hold with equality. But for μ and δ, the Lagrange multipliers for the peak period and off-peak period capacity constraints, respectively, which are not assumed to hold with equality, one derives the following Kuhn-Tucker conditions. For the peak traffic period,

$$X - v_p^m \cdot M - k \cdot v_p^n \cdot N = X - F_p^m - k \cdot F_p^n \geq 0 \qquad (9B.1)$$

$$\mu \geq 0 \qquad (10B.1)$$

$$\mu \cdot (X - F_p^m - k \cdot F_p^n) = 0, \qquad (11B.1)$$

and for the off-peak traffic period,

$$X - v_o^m \cdot M - k \cdot v_o^n \cdot N = X - F_o^m - k \cdot F_o^n \geq 0 \qquad (9B.2)$$

$$\delta \geq 0 \qquad (10B.2)$$

$$\delta \cdot (X - F_o^m - k \cdot F_o^n) = 0. \qquad (11B.2)$$

Equations (9B.1) and (9B.2) hold with equality when the transportation facility is being used to capacity during the period which corresponds with each of these constraints. Otherwise, if excess capacity exists during either of the time periods, then the corresponding Lagrange multiplier equals zero signifying there is no benefit to be derived by users of the transportation facility during that period from expanding the capacity of the facility.

The first-order conditions for the two-period, two user group model show several differences from those derived for the one-period, one user group model. However, in all cases, the differences can be characterized as the expansion of terms in the first model to reflect the finer differentiations of the population and the division of time into distinct periods. The more significant findings associated with the first-order conditions derived from this model are revealed by looking at their implications relative to the financing of the transportation facility. With the expansion of the model, the issues of economies of scale and economies of scope both must be considered to determine when full user financing of the transportation facility is feasible.

Transportation facility financing considerations

Full user financing of the transportation facility in the context of this model requires that payments from members of both user groups for travel made during the two time periods entirely cover both operating and capital costs. Letting t_i^j represent the toll paid per trip during period i by a member of group j, full user financing of the transportation facility requires satisfaction of the condition presented in equation (12B),

$$F_p^m \cdot t_p^m + F_o^m \cdot t_o^m + F_p^n \cdot t_p^n + F_o^n \cdot t_o^n = C(F_p^m,\ F_o^m,\ F_p^n,\ F_o^n,\ X). \qquad (12B)$$

If one again assumes users of the transportation facility are willing to make payments equal to the benefit they derive from each trip, substitution from the various toll conditions, equations (8B.1) through (8B.4), for the t_i^j terms in equation (12B) yields equation (13B),

$$\begin{aligned}
&-\left[M \cdot \frac{\partial U^m/\partial c}{\partial U^m/\partial y^m} + N \cdot \frac{\partial U^n/\partial c}{\partial U^n/\partial y^n}\right] \cdot \left[\frac{\partial c}{\partial F_p^m} \cdot F_p^m + \frac{\partial c}{\partial F_o^m} \cdot F_o^m + \frac{\partial c}{\partial F_p^n} \cdot F_p^n + \frac{\partial c}{\partial F_o^n} \cdot F_o^n\right] \\
&+ \left[\frac{\partial C(.)}{\partial F_p^m} \cdot F_p^m + \frac{\partial C(.)}{\partial F_o^m} \cdot F_o^m + \frac{\partial C(.)}{\partial F_p^n} \cdot F_p^n + \frac{\partial C(.)}{\partial F_o^n} \cdot F_o^n\right] \qquad (13B) \\
&+ \left[\frac{\mu}{\lambda} \cdot F_p^m + \frac{\delta}{\lambda} \cdot F_o^m + \frac{\mu}{\lambda} \cdot k \cdot F_p^n + \frac{\delta}{\lambda} \cdot k \cdot F_o^n\right] \\
&= C(F_p^m,\ F_o^m,\ F_p^n,\ F_o^n,\ X).
\end{aligned}$$

Next, to relate the toll and provision conditions in this model, it is necessary to make an assumption about how congestion of the transportation facility is dependent on the total use and the capacity of the facility when multiple user groups and time periods are involved. As previously explained in the one-period, one user group model, the key relationship employed in planning for new transportation facilities or for the expansion of existing facilities is the desired ratio between forecasted use of the facility and the capacity of the facility at some future date.

The prior model assumed a single homogeneous group of users that implicitly also assumed the transportation facility would serve a single type of transportation vehicle. However, the use of most transportation facilities is shared by a variety of transportation vehicles, which due to differences in their size and operating characteristics contribute differently to the congestion of the facility as their number and share of the total traffic flow increase. This model explicitly recognizes that in practice the volume-to-capacity ratio used in planning transportation facility improvements must take into consideration vehicle mix as well as vehicle count. Furthermore, this model provides the basis for relating individual use of the transportation facility to the flow of transportation vehicles served by the facility since assumption of multiple user groups distinguished on the basis of their members' utility functions encompasses differences in mode and vehicle preferences.

In practice, as explained in standard transportation engineering references, such as the Highway Capacity Manual (1985) and Airport Engineering (Ashford and Wright, 1992), volume-to-capacity ratios for mixed use facilities are determined by weighting the contribution of different types of vehicles to congestion of the facility in terms of a standard design vehicle. For example, for highway planning purposes the contributions of different size trucks and busses to traffic congestion are measured as multiples of the contribution of a standard automobile. In this model the factor k reflects the difference in contribution to transportation facility congestion attributable to members of the two user groups.

Also, consideration of two time periods within a single congestion function reflects how traffic in one period can and does affect traffic in other periods. This is particularly true when extreme congestion during peak traffic periods can result in travel delays during subsequent time periods. For example, congestion at a major hub airport often results in air traffic controllers ordering approaching aircraft to slow their speed, or in the worst cases, prohibiting additional aircraft destined for the congested airport from taking off.

Thus, in the two-period, two user group case, as in the single user group case, in the absence of non-user externalities, the model's congestion function can be assumed to be homogeneous of degree zero in traffic flow and capacity, i.e., $c(F_p^m, F_o^m, F_p^n, F_o^n, X) = c[(F_p^m + F_o^m + k \cdot F_p^n + k \cdot F_o^n)/X]$. Consequently, by Euler's theorem the following equality can be expected to hold,

$$\frac{\partial c}{\partial F_p^m} \cdot F_p^m + \frac{\partial c}{\partial F_o^m} \cdot F_o^m + \frac{\partial c}{F_p^n} \cdot F_p^n + \frac{\partial c}{\partial F_o^n} \cdot F_o^n = - \frac{\partial c}{\partial X} \cdot X. \tag{14B}$$

Now, substituting the RHS of equation (14B) into the LHS of equation (13B) one obtains equation (15B),

$$\begin{aligned} &\left[M \cdot \frac{\partial U^m / \partial c}{\partial U^m / \partial y^m} + N \cdot \frac{\partial U^n / \partial c}{\partial U^n / \partial y^n}\right] \cdot \left[\frac{\partial c}{\partial X} \cdot X\right] \\ &+ \left[\frac{\partial C(.)}{\partial F_p^m} \cdot F_p^m + \frac{\partial C(.)}{\partial F_o^m} \cdot F_o^m + \frac{\partial C(.)}{\partial F_p^n} \cdot F_p^n + \frac{\partial C(.)}{\partial F_o^n} \cdot F_o^n\right] \\ &+ \left[\frac{\mu}{\lambda} \cdot F_p^m + \frac{\delta}{\lambda} \cdot F_o^m + \frac{\mu}{\lambda} \cdot k \cdot F_p^n + \frac{\delta}{\lambda} \cdot k \cdot F_o^n\right] = C(F_p^m, F_o^m, F_p^n, F_o^n, X). \end{aligned} \tag{15B}$$

The first LHS term in equation (15B) equals the LHS of the provision condition for the model, equation (7B). Thus, substituting the RHS from the provision condition into equation (15B) and regrouping terms yields the condition for ray constant economies of scale presented in equation (16B),

$$\begin{aligned} &\frac{\partial C(.)}{\partial F_p^m} \cdot F_p^m + \frac{\partial C(.)}{\partial F_o^m} \cdot F_o^m + \frac{\partial C(.)}{\partial F_p^n} \cdot F_p^n + \frac{\partial C(.)}{\partial F_o^n} \cdot F_o^n + \frac{\partial C(.)}{\partial X} \cdot X \\ &- \frac{\mu}{\lambda} \cdot (X - F_p^m - k \cdot F_p^n) - \frac{\delta}{\lambda} \cdot (X - F_o^m - k \cdot F_o^n) \\ &= C(F_p^m, F_o^m, F_p^n, F_o^n, X). \end{aligned} \tag{16B}$$

But by the complementary slackness conditions presented in equations (11B.1) and (11B.2) the last two LHS terms of equation (16B) equal zero. Consequently, the condition for ray constant economies of scale, which implies a transportation facility cost function that is homogeneous of degree one, is again obtained, i.e.,

$$\frac{\partial C(.)}{\partial F_p^m} \cdot F_p^m + \frac{\partial C(.)}{\partial F_o^m} \cdot F_o^m + \frac{\partial C(.)}{\partial F_p^n} \cdot F_p^n + \frac{\partial C(.)}{\partial F_o^n} \cdot F_o^n + \frac{\partial C(.)}{\partial X} \cdot X \qquad (17B)$$

$$= C(F_p^m, F_o^m, F_p^n, F_o^n, X).$$

Therefore, full user financing of the transportation facility is feasible if the toll charged for each trip during each time period is set equal to its marginal cost. However, since the facility provides service jointly to two groups of users over two time periods, the existence of a cost structure characterized by ray constant economies of scale does not provide adequate information to reveal whether each toll is separately optimal. Optimal pricing of the transportation facility requires that each group's toll per time period equal both the marginal cost and the average incremental cost associated with each trip type. Thus, letting $t_i^j(*)$ denote the optimal toll for trips made during period i by members of group j, the conditions for optimal pricing of the transportation facility are presented in equations (18B.1) through (18B.4).

For members of group M the peak period optimal toll condition is,

$$t_p^m(*) = \frac{C(F_p^m, F_o^m, F_p^n, F_o^n, X) - C(0, F_o^m, F_p^n, F_o^n, X')}{F_p^m}$$

$$= -M\cdot \frac{\partial U^m/\partial c}{\partial U^m/\partial y^m}\cdot \frac{\partial c}{\partial F_p^m} - N\cdot \frac{\partial U^n/\partial c}{\partial U^n/\partial y^n}\cdot \frac{\partial c}{\partial F_p^m} + \frac{\partial C(.)}{\partial F_p^m} + \frac{\mu}{\lambda}, \quad (18B.1)$$

where $X' \leq X$ represents the transportation facility capacity required to serve all users except members of group M during the peak period. For the off-peak period the optimal toll condition is,

$$t_o^m(*) = \frac{C(F_p^m, F_o^m, F_p^n, F_o^n, X) - C(F_p^m, 0, F_p^n, F_o^n, X'')}{F_o^m}$$

$$= -M\cdot \frac{\partial U^m/\partial c}{\partial U^m/\partial y^m}\cdot \frac{\partial c}{\partial F_o^m} - N\cdot \frac{\partial U^n/\partial c}{\partial U^n/\partial y^n}\cdot \frac{\partial c}{\partial F_o^m} + \frac{\partial C(.)}{\partial F_o^m} + \frac{\delta}{\lambda}, \quad (18B.2)$$

where $X'' \leq X$ represents the transportation facility capacity required to serve all users except members of group M during the off-peak period. Similarly, for members of group N the optimal peak period toll condition is,

$$t_p^n(*) = \frac{C(F_p^m, F_o^m, F_p^n, F_o^n, X) - C(F_p^m, F_o^m, 0, F_o^n, X''')}{F_p^n}$$

$$= -N\cdot \frac{\partial U^n/\partial c}{\partial U^n/\partial y^n}\cdot \frac{\partial c}{\partial F_p^n} - M\cdot \frac{\partial U^m/\partial c}{\partial U^m/\partial y^m}\cdot \frac{\partial c}{\partial F_p^n} + \frac{\partial C(.)}{\partial F_p^n} + k\cdot \frac{\mu}{\lambda}, \quad (18B.3)$$

where $X''' \leq X$ represents the transportation facility capacity required to serve all users except members of group N during the peak traffic period. And for the off-peak period the optimal toll condition is,

$$t_o^n(*) = \frac{C(F_p^m, F_o^m, F_p^n, F_o^n, X) - C(F_p^m, F_o^m, F_p^n, 0, X'''')}{F_o^n}$$

$$= -N \cdot \frac{\partial U^n/\partial c}{\partial U^n/\partial y^n} \cdot \frac{\partial c}{\partial F_o^n} - M \cdot \frac{\partial U^m/\partial c}{\partial U^m/\partial y^m} \cdot \frac{\partial c}{\partial F_o^n} + \frac{\partial C(.)}{\partial F_o^n} + k \cdot \frac{\delta}{\lambda}. \qquad (18B.4)$$

where $X'''' \leq X$ represents the transportation facility capacity required to serve all users except members of group N during the off-peak traffic period.

From these conditions one can ascertain that the transportation facility's cost function must exhibit neither economies of scope nor diseconomies of scope, as well as be characterized by ray constant economies of scale, for marginal cost pricing to be optimal. To show this one must consider opportunities for sharing the transportation facility both within one time period and between time periods.

Focusing first on the within time period case, one finds that if the incremental costs associated with serving the two user groups separately relative to the costs associated with serving the two groups jointly is subadditive then economies of scope exist. (See Appendix A, Part 2 for proof of the relationship between subadditive incremental costs and economies of scope.) For the peak traffic period this condition becomes

$$F_p^m \cdot t_p^m(*) + F_p^n \cdot t_p^n(*) =$$

$$F_p^m \cdot \left[\frac{C(F_p^m, F_o^m, F_p^n, F_o^n, X) - C(0, F_o^m, F_p^n, F_o^n, X')}{F_p^m} \right] \tag{19B}$$

$$+ F_p^n \cdot \left[\frac{C(F_p^m, F_o^m, F_p^n, F_o^n, X) - C(F_p^m, F_o^m, 0, F_o^n, X''')}{F_p^n} \right]$$

$$< C(F_p^m, F_o^m, F_p^n, F_o^n, X),$$

where $X' + X''' > X$. This implies that if the two groups share some of the capacity of the transportation facility during the peak traffic period, then the condition for intra-period economies of scope results, i.e.,

$$C(0, F_o^m, F_p^n, F_o^n, X') + C(F_p^m, F_o^m, 0, F_o^n, X''') - C(F_p^m, F_o^m, F_p^n, F_o^n, X) > 0. \tag{20B}$$

By similar reasoning it can be shown that economies of scope would exist under the same conditions during the off-peak traffic period. For both time periods, the key factor that must exist for economies of scope to arise from the joint use of the transportation facility is the ability of the facility to accommodate joint use without substantial conflict occurring between the two groups. If substantial conflict does arise, then the simultaneous accommodation of the two user groups may necessitate the expansion of the transportation facility so that the sum of the capacities required to serve the two user groups on a stand alone basis is less than the required capacity under joint use, i.e., $0 < X' + X''' < X$. In this case, again focusing on the peak traffic period, the sum of intra-period incremental costs would exceed the cost associated with providing service jointly, i.e.,

$$F_p^m \cdot t_p^m(*) + F_p^n \cdot t_p^n(*) =$$

$$F_p^m \cdot \left[\frac{C(F_p^m, F_o^m, F_p^n, F_o^n, X) - C(0, F_o^m, F_p^n, F_o^n, X')}{F_p^m}\right]$$

$$+ F_p^n \cdot \left[\frac{C(F_p^m, F_o^m, F_p^n, F_o^n, X) - C(F_p^m, F_o^m, 0, F_o^n, X''')}{F_p^n}\right] \quad (21B)$$

$$> C(F_p^m, F_o^m, F_p^n, F_o^n, X).$$

Under these conditions, the inequality in equation (20B) is reversed signifying the transportation facility exhibits diseconomies of scope, i.e.,

$$C(0, F_o^m, F_p^n, F_o^n, X') + C(F_p^m, F_o^m, 0, F_o^n, X''') - C(F_p^m, F_o^m, F_p^n, F_o^n, X) < 0. \quad (22B)$$

An example of a situation under which diseconomies of scope could arise is the mixing of automobile and truck traffic on a highway characterized by high traffic volume and steep grades. Due to differences in acceleration rates and stopping distance requirements, the mixing of the two vehicle types under the described conditions would likely require additional investment in climbing lanes and a larger number of through lanes to achieve the same level of service and level of safety as highway facilities designed to serve automobile and truck traffic on a mutually exclusive basis. Similarly, highly congested airports that serve both commercial air carriers and general aviation aircraft often have to invest in more peak period runway capacity than would be required to serve the two types of traffic on an exclusive basis. This additional investment is required to allow increased aircraft spacing during take-offs and landings to prevent the smaller general aviation aircraft from being adversely affected by air turbulence caused by the larger commercial carrier aircraft.

Even when during peak usage periods a transportation facility is characterized by diseconomies of scope, it is possible on an inter-period basis for economies of scope to exist. As for the intra-period case, the degree of inter-period economies of scope depends on the relationship between the sum of incremental costs associated with serving peak and off-peak period traffic and the joint costs associated with serving all traffic over both time periods. When excess capacity exists during the off-peak traffic period, and some element of the transportation facility is used during both the peak and off-peak traffic periods, the sum of per period incremental costs will be less than the two period joint cost. To illustrate this one begins by focusing on a single group of users over the two time periods. For example, for members of group M,

$$F_p^m \cdot t_p^m(*) + F_o^m \cdot t_o^m(*) =$$

$$F_p^m \cdot \left[\frac{C(F_p^m, F_o^m, F_p^n, F_o^n, X) - C(0, F_o^m, F_p^n, F_o^n, X')}{F_p^m}\right] + F_o^m \cdot \left[\frac{C(F_p^m, F_o^m, F_p^n, F_o^n, X) - C(F_p^m, 0, F_p^n, F_o^n, X''')}{F_o^m}\right] < C(F_p^m, F_o^m, F_p^n, F_o^n, X), \quad (23B)$$

where $X' + X''' > X$.

This subadditivity of incremental costs relative to the joint cost associated with serving members of group M over both time periods directly yields the condition for inter-period economies of scope, i.e.,

$$C(F_p^m, 0, F_p^n, F_o^n, X'') + C(0, F_o^m, F_p^n, F_o^n, X') - C(F_p^m, F_o^m, F_p^n, F_o^n, X) > 0. \quad (24B)$$

Similar conditions will result in inter-period economies of scope relative to use of the transportation facility by members of group N.

Now, turning to the issue of serving each group of users on an exclusive basis over the two time periods versus serving them jointly with a single transportation facility, economies of scope exist if the sum of the group specific incremental costs are subadditive with respect to the cost associated with serving both groups of users jointly, i.e.,

$$\left[C(F_p^m, F_o^m, F_p^n, F_o^n, X) - C(0, 0, F_p^n, F_o^n, X^n)\right]$$
$$+ \left[C(F_p^m, F_o^m, F_p^n, F_o^n, X) - C(F_p^m, F_o^m, 0, 0, X^m)\right] \quad (25B)$$
$$< C(F_p^m, F_o^m, F_p^n, F_o^n, X),$$

where X^m and X^n are the transportation capacities required to serve members of group M and group N, respectively, on a stand alone basis. This condition occurs when the sum of the stand alone transportation facility capacities is greater than the capacity required to serve the members of both groups jointly, i.e., $X^m + X^n > X$, which implies some sharing of transportation facility capacity when joint use occurs. This subadditivity of group specific incremental costs directly yields the condition for economies of scope, i.e.,

$$C(F_p^m, F_o^m, 0, 0, X^m) + C(0, 0, F_p^n, F_o^n, X_n) - C(F_p^m, F_o^m, F_p^n, F_o^n, X) > 0. \quad (26B)$$

Finally, if conditions required for inter-period economies of scope exist for each group of users, $X' + X''' > X$ and $X'' + X'''' > X$, and if the conditions for inter-group economies of scope also hold, $X_p^m + X_o^m > X^m$, where X_p^m and X_o^m are the user group M stand alone peak period and off-peak period transportation facility capacities, and $X_p^n + X_o^n > X^n$, where X_p^n and X_o^n are the user group N stand alone peak period and off-peak period transportation facility capacities, then overall economies of scope among the two user groups over the two time periods also exists, i.e.,

$$C(F_p^m,0,0,0,X_p^m) + C(0,F_o^m,0,0,X_o^m) + C(0,0,F_p^n,0,X_p^n) + C(0,0,0,F_o^n,X_o^n) - C(F^{p^n},F_o^m,F_p^n,F_o^n,X) > 0. \tag{27B}$$

When these conditions hold, the sum of group and period specific incremental costs will be less than the cost associated with providing all transportation services jointly. In this case pricing usage of the transpotation facility on a marginal cost basis will not generate adequate revenues from user fees to fully fund the provision and operation of the facility. These findings yield the following proposition:

Proposition 3: Both ray constant economies of scale and the absence of economies of scope are required for marginal cost pricing to result in the optimal provision of capacity for the shared transportation facility.

On the other hand, usage fees set equal to marginal costs would yield more than adequate revenues to fund provision and operation of the transportation facility when the facility exhibits a cost structure characterized by overall diseconomies of scope and ray constant economies of scale. When neither overall economies of scope or diseconomies of scope characterize the cost structure of the facility findings regarding the optimality of marginal cost pricing of facility use are ambiguous. Such a situation would arise when heavy use of the facility during the peak traffic period results in diseconomies of scope and light traffic during the off-peak traffic period results in economies of scope. In this situation marginal cost pricing would not be optimal, but it could encourage traffic to shift from the peak period to the off-peak period, which would result in an improvement of efficiency in use of the facility.

Additional insight into the optimal pricing of shared transportation facilities which experience variable usage over different time periods is obtained by comparing intra-period optimal tolls between the user groups and by comparing inter-period optimal tolls for each group. The intra-period toll comparison for the peak traffic is

$$t_p^m(*) - t_p^n(*) = -\left[M \cdot \frac{\partial U^m/\partial c}{\partial U^m/\partial y^m} \cdot + N \cdot \frac{\partial U^n/\partial c}{\partial U^n/\partial y^n}\right] \cdot \left[\frac{\partial c}{\partial F_p^m} - \frac{\partial c}{\partial F_p^n}\right] + \left[\frac{\partial C(.)}{\partial F_p^m} - \frac{\partial C(.)}{\partial F_p^n}\right] + [1-k] \cdot \frac{\mu}{\lambda}, \tag{28B}$$

and for the off-peak traffic period the comparison is

$$t_o^m(*) - t_o^n(*) = -\left[M\cdot \frac{\partial U^m/\partial c}{\partial U^m/\partial y^m}\cdot + N\cdot \frac{\partial U^n/\partial c}{\partial U^n/\partial y^n}\right]\cdot\left[\frac{\partial c}{\partial F_o^m} - \frac{\partial c}{\partial F_o^n}\right]$$

$$+\left[\frac{\partial C(.)}{\partial F_o^m} - \frac{\partial C(.)}{\partial F_o^n}\right] + [1-k]\cdot \frac{\delta}{\lambda}. \qquad (29B)$$

Both of these equations show that the difference in the tolls charged members of the two transportation facility user groups will arise from three sources. First, differences in the marginal congestion caused by trips taken by members of the two groups would justify different per trip tolls. The difference in marginal operating and maintenance costs imposed by an additional trip taken by members of the two groups provides the second source of justification for differential pricing. The difference in capital costs assignable to members of the two user groups provides the third source of justification for differential pricing within periods.

Similarly, sources of differential pricing for use of the transportation facility between periods by members of the same group can be seen by taking the difference between equations (18B.1) and (18B.2) for members of group M and by taking the difference between equations (18B.3) and (18B.4) for members of group N. These conditions are presented in equations (30B) and (31B), respectively.

$$t_p^m(*) - t_o^m(*) = -\left[M\cdot\frac{\partial U^m/\partial c}{\partial U^m/\partial y^m} + N\cdot\frac{\partial U^n/\partial c}{\partial U^n/\partial y^n}\right]\cdot\left[\frac{\partial c}{\partial F_p^m} - \frac{\partial c}{\partial F_o^m}\right] + \left[\frac{\partial C(.)}{\partial F_p^m} - \frac{\partial C(.)}{\partial F_o^m}\right] + \left[\frac{\mu}{\lambda} - \frac{\delta}{\lambda}\right] \tag{30B}$$

$$t_p^n(*) - t_o^n(*) = -\left[M\cdot\frac{\partial U^m/\partial c}{\partial U^m/\partial y^m} + N\cdot\frac{\partial U^n/\partial c}{\partial U^n/\partial y^n}\right]\cdot\left[\frac{\partial c}{\partial F_p^n} - \frac{\partial c}{\partial F_o^n}\right] + \left[\frac{\partial C(.)}{\partial F_p^n} - \frac{\partial C(.)}{\partial F_o^n}\right] + k\cdot\left[\frac{\mu}{\lambda} - \frac{\delta}{\lambda}\right] \tag{31B}$$

The differences between peak period and off-peak period tolls for members of the two user groups again both arise from three sources. First, since congestion is assumed to be an increasing function of traffic flow, higher volumes of traffic during the peak period than during the off-peak period dictates that tolls charged for peak period use of the facility exceed tolls charged for off-peak period use. Differences in marginal operating and maintenance costs associated with use of the transportation facility during the two periods provides a second potential justification for differential pricing. However, in this case, since a large portion of operating and maintenance costs are unrelated to traffic volume, this potential source of differential pricing for trips taken by members of the same user group during different time periods can be expected to contributed little or no justification for inter-period toll differences. Third, differences in marginal benefits associated with the expansion of the transportation facility for the two time periods provides another potential justification for charging different tolls during peak traffic periods versus off-peak periods. Furthermore, in those cases when traffic is capacity constrained during the peak period, while traffic is not at capacity during the off-peak period, only users of the facility during the peak period should bear any of the cost of facility expansion.

Thus, extension of the model to include multiple time periods and multiple user groups shows that justification does exist for charging different rates for use of transportation facilities at different times. In addition, charging different tolls to different types of users during the same time period is similarly justified. This model also establishes that the cost function associated with the provision and operation of a transportation facility must exhibit both ray constant economies scale and zero economies of scope for financing of the facility solely by users to be feasible.

This third model completes the presentation of the general theory of transportation clubs. In the next chapter application of this theory to the special case of air transportation is presented.

CHAPTER 4: AIRPORT PRICING AND INVESTMENT MODEL

The previous chapter yielded a general transportation pricing and investment model which is based on the theory of clubs. The current chapter extends the general transportation club model to the special case of airport infrastructure pricing and investment. The model developed below incorporates two transportation club goods (i.e., airport runways and a passenger terminal) which are used by two groups of travelers (i.e., those who use scheduled commercial air carriers and those who use general aviation services) over peak and off-peak traffic periods.

The significance of the airport model is two-fold. First, it illustrates the versatility of the general model through its application to issues relevant to the special case of air transportation. Second, the airport model provides a real world application of club theory to the practical problems associated with making more efficient use of transportation infrastructure at a time when transportation planners and engineers are finally beginning to accept that it is not possible to address infrastructure congestion solely through the addition of new capacity.

The recently released Federal Aviation Administration (FAA) 1991-92 Aviation System Capacity Plan strongly supports this second point through its advocacy of greater reliance on pricing mechanisms in the management of use of airport infrastructure in the United States (FAA, 1991). Similar supporting evidence and arguments are presented in a more broadly focused study by the Congressional Budget Office, Paying for Highways, Airways and Waterways: How Can Users Be Charged? (CBO, 1992).

The specific theoretical and practical issues addressed in this chapter include:

(1) What criteria should be employed to establish how airport costs are shared among different groups of users?

(2) What conditions justify requiring non-users of the airport to contribute to the financing of airport construction and operation?

(3) Under what conditions should airport user fees be used to compensate non-users for adverse environmental impacts associated with the existence and operation of the airport?

(4) What conditions must exist for the sharing of airport facilities by multiple user groups to be mutually beneficial?

(5) What criteria should be employed in establishing an efficient schedule of demand sensitive user fees?

However, to provide a basis for understanding the relevance of these issues, it is first necessary to describe the United States domestic air transportation system. This background discussion will include a description of the nation's system of airports, the financing of airport operations and capital improvements, and the relationship between the engineering of airports and their operating and construction costs.

Therefore, this chapter consists of the following five sections. Section one presents an overview of the domestic system of airports and problems associated with the current operation of this system. In section two, current airport service pricing practices and sources of funds for financing airport capital improvements are described. In section three, the relationship between the engineering characteristics of airport runways and terminals and the construction and operating costs associated with these elements of airport infrastructure are discussed. In section four, an airport club model is presented. Finally, the last section discusses the policy implications of this model regarding how the pricing of airport services and the allocation of investment capital may be modified to improve the efficiency of the domestic air transportation system.

Description of the Domestic System of Airports

As of June 30, 1990, the Unites States domestic air transportation system consisted of 17,451 civil landing areas (i.e., airports, heliports and seaplane bases). However, only about one-third of these airports (5,598) are available for public use. The remainder (11,853) are classified as private use facilities which have been constructed and are maintained by corporations and individuals for their own use.

Approximately three-fourths (4,169) of the airports available for public use are owned and operated by governmental or quasi-governmental organizations, generally city or county governments or regional transportation authorities. The other 1,429 public use airports are privately owned.

Of the airports available for public use, 3,285 are included in the National Plan of Integrated Airport Systems (NPIAS), which determines eligibility for federal funding of capital improvements. Of these NPIAS airports 568 serve commercial aircraft while the remaining 2,717 provide only general aviation service (FAA, 1991: 1-3).

This chapter focuses primarily on those airports which provide commercial air service and those general aviation facilities located in close proximity to major commercial airports, referred to as reliever airports. Although they represent less than 10 percent of all domestic airports, they provide all of the nation's commercial air service and serve the vast majority of general aviation operations as well. Similarly, these airports account for the majority of capital investment needs for the domestic air transportation system and they account for most of the social costs associated with travel delays attributable to the congestion of the domestic air transportation system.

Even among the commercial service and reliever airports, severe traffic congestion problems are experienced by only a relative few. These problem airports are generally those classified by the Federal Aviation Administration (FAA) as large hubs, meaning each accounts for at least one percent of annual revenue passenger enplanements in the United States. In 1990, these 27 busiest airports accounted for 72.42 percent of all U.S. passenger enplanements (FAA Airport Activity Statistics, 1990).

As shown in Table 4.1, the concentration of air passenger operations in the United States has remained relatively stable over the past decade. However, the costs associated with traffic congestion at large hub airports has increased substantially during this period because the number of people travelling by air has increased by over 60 percent. Furthermore, forecasts of air transportation demand through the end of the century indicate the problem is likely to get worse with passenger enplanements predicted to grow by another 40 percent and aircraft operations predicted to grow by another

Table 4.1: U.S. Passenger Enplanements by Airport Size, 1979 - 1989

Part A: Enplaned Passengers (1,000)

Year	Large Hub	Medium Hub	Small Hub	All Hub Airports	Non-hub	Total
1979	221,614	49,341	25,717	287,671	11,363	299,034
1980	197,549	51,779	23,357	272,685	8,724	281,409
1981	186,048	50,233	19,934	256,215	9,568	265,783
1982	194,703	55,550	19,443	269,696	8,055	277,751
1983	220,501	53,455	20,957	294,913	8,808	303,721
1984	238,617	58,343	22,288	319,249	8,522	327,771
1985	264,513	65,765	24,344	354,621	8,720	363,341
1986	294,406	68,801	27,201	390,408	9,600	400,008
1987	316,271	70,851	30,304	417,426	9,390	426,816
1988	321,750	68,423	31,493	421,666	9,750	431,416
1989	313,777	76,092	30,033	419,901	9,753	429,655

Part B: Percent of Emplaned Passengers

Year	Large Hub	Medium Hub	Small Hub	All Hub Airports	Non-hub	Total
1979	71.1	16.5	8.6	96.2	3.8	100.0
1980	70.2	18.4	8.3	96.9	3.1	100.0
1981	70.0	18.9	7.5	96.4	3.6	100.0
1982	70.1	20.0	7.0	97.1	2.9	100.0
1983	72.6	17.6	6.9	97.1	2.9	100.0
1984	72.8	17.8	6.8	97.4	2.6	100.0
1985	72.8	18.1	6.7	97.6	2.4	100.0
1986	73.6	17.2	6.8	97.6	2.4	100.0
1987	74.1	16.6	7.1	97.8	2.2	100.0
1988	74.6	15.9	7.3	97.8	2.2	100.0
1989	73.0	17.7	7.0	97.7	2.3	100.0

Source: Federal Aviation Administration, Aiport Activity Statistics of Certificated Route Air Carriers, 1979 - 1989.

30 percent (FAA, 1991: 1-2).

A measure of the magnitude of the economic cost associated with airport congestion is the number of airports experiencing more than 20,000 hours of annual aircraft delay, which equates to $32 million of aircraft cost for each airport so affected. In 1990, the number of airports experiencing at least this amount of aircraft delay was 23. This number is expected to increase to 40 by the year 2000. Thus, by 2000, aircraft operators alone will suffer over $1.2 billion in delay costs unless substantial measures are taken to relieve congestion at the nation's busiest airports (FAA, 1991).

Three types of delay may be encountered by passengers and aircraft operators at airports: taxi-in delay, gate-hold delay, and taxi-out delay. Nearly 80 percent of all flights are delayed from 1 to 14 minutes during the taxi-in or taxi-out phases of airport operations. While only 5 percent of flights experience a gate-hold delay (FAA, 1991: 1-11).

Statistics on the number of aircraft operations delayed more than 15 minutes have been collected by FAA air traffic controllers since 1984. According to this delay reporting system, known as the Air Traffic Operations Management System (ATOMS), weather is the principal cause of aircraft delay, followed by air traffic control (ATC) center capacity constraints, and then by airport terminal constraints. During 1990, 404,367 flights experienced delays exceeding 15 minutes.

Weather was recorded as the cause of 53 percent of these aircraft delays, while airport traffic volume, which exceeded either ATC or terminal area capacities, accounted for 36 percent.

As shown in Table 4.2, the relative significance of weather as a cause of delay has decreased over the period from 1985 to 1990 from 68 to 53 percent, while the share of delays associated with air traffic volume have tripled from 12 to 36 percent. Also, from 1987 to 1990 the share of all flights experiencing delays of at least 15 minutes has increased from 8.0 to 10.3 percent. Thus, not only has the number of flight delays at the nation's airports increased in recent years, but more importantly, the portion of these delays attributable to runway, taxiway, and terminal capacity problems has increased dramatically.

One major factor that has contributed to the increase in traffic related delays is the deregulation of commercial air transportation. Prior to deregulation, the Civil Aeronautics Board (CAB) regulated air carrier rates and routes. This regulation limited carriers' ability to adjust flight schedules and service areas. Also, regulation of rates limited the ability of carriers to compete on the basis of price, while at the same time by guaranteeing profits regulation removed carriers' incentives to manage operations in a cost effective manner. Consequently, most commercial carriers competed for

Table 4.2: Percent of Aircraft Delay Greater than 15 Minutes Experienced at U.S. Airports by Cause, 1985 - 1990

Cause of Delay	1985	1986	1987	1988	1989	1990
Weather	68	67	67	70	57	53
Terminal Volume	12	16	11	9	29	36
ATC Center Volume	11	10	13	12	8	2
Closed Runways or Taxiways	6	3	4	5	3	4
NAS Equipment	2	3	4	3	2	2
Other	1	1	1	1	1	3
Total Operations Delayed (1000)	334	418	325	322	392	404

Notes:
ATC stands for air traffic control.
NAS stands for National Airspace System.

Source: Federal Aviation Administration, 1991 - 92 Aviation System Capacity Plan passengers on the basis of service, which translated into the minimization of travel times between origin and destination airports through the offering of non-stop service.

Deregulation of air passenger service beginning in 1978 significantly changed the incentive system for commercial carrier managers. The elimination of rate and route regulation resulted in price competition among carriers, plus both existing and new carriers were permitted to adjust routes, service areas and schedules at will following a short transition period. These changes in the business environment put pressure on airline managers to cut operating costs. One of the primary results of this change was the reconfiguration of routes from a direct point-to-point system of routes to a hub-and-spoke system of routes.

Under this new arrangement carriers established hub operations at selected airports which serve as gathering and transfer points for their operations. To facilitate this change required that landings and departures at hub airports be coordinated so as to minimize the time passengers are required to wait between connecting flights. As a result, air traffic at hub airports both increased and flight schedules became more concentrated which increased congestion during peak activity
periods.

In reviewing the changes brought about by deregulation, a recent Transportation Research Board study makes the following two observations.

> First, ... the public sector's response to the increased demand for airway and airport capacity that was stimulated by deregulation has been inadequate. Second, ... given the difficulties with expanding the supply of airway and airport capacity, the existing system should be used more efficiently. Assets have been used more efficiently by the private sector in aviation by greater reliance on the price mechanism, [and] this approach deserves experimentation in the public sector (TRB, 1991: 202-203).

However, to date the use of demand sensitive pricing as a means for modifying how airport infrastructure is used or as a means for generating additional funds for airport expansion has been rare. Only, the Port Authority of New York and New Jersey (PANY), which operates John F. Kennedy, LaGuardia and Newark airports, and Massport, which operates Logan airport in Boston, have attempted to modify their airport usage fees as a means to reduce airport congestion. In 1968, PANY raised peak-period landing fees for small aircraft in order to encourage the shifting of general aviation activity to off-peak times of the day. In 1988, Massport took an even more aggressive approach by raising landing fees for all general aviation use of Logan Airport in an effort to divert smaller aircraft to reliever airports in the area.

Both of these experiments with congestion pricing faced legal challenges from general aviation aircraft operators. In the PANY case the United States District Court found in favor of the Port Authority, ruling that "the defendants were justified in distinguishing classes of aircraft, on the grounds of safety and that the fee was meant to induce aircraft operators to use other times of the day or other facilities (CBO, 1992: 44)." On the other hand, Massport's attempt at congestion pricing was found to unduly discriminate against small aircraft and was terminated. However, in ruling in the Massport case, the administrative law judge indicated that a fee structure of the sort employed at the PANY airports would likely be acceptable (CBO, 1992: 44-45).

However, to date neither Massport nor any other major airport in the United States, aside from the three PANY facilities, have adopted peak-period pricing as a means for alleviating airport congestion. To some extent this may be attributed to some remaining confusion over the legality of such fees. Specifically, the U.S. Supreme Court's decision in the case of Evansville Vanderburgh Airport Authority District et al. versus Delta Airlines et al. states that airports may not charge aeronautical users more than the airport's historic cost for providing capacity. This ruling would appear to allow congestion pricing if the revenues raised through the assessment of such fees are invested in airport capacity improvements. However, given the current state of airport financial management in which airport revenues are often intermingled with other municipal funds and under which fees assessed aircraft operators generally are not directly related to the cost of providing aviation services leaves the legal status of such fees in question. Also, tradition and long-term contractual arrangements between airports and air carriers, plus the role of the federal government in providing funding for capital improvements, has inhibited the incorporation of congestion pricing into airport fee structures.

To gain a better understanding of how existing airport fees promote the inefficient investment in and use of airport infrastructure, one needs to explore current pricing and financial practices of the domestic airport industry. The next section describes these practices.

Financing and Pricing of Airport Services

The federal government shares with local governments the responsibility for financing airport capital improvements in the United States. Operating costs, on the other hand, are generally funded locally through user fees, rent payments, concession fees, special taxes, or general fund appropriations.

Federal funding of airport capital improvements began in 1946 with Congress' authorization of the Federal-Aid Airport Program. Through this program the federal government has provided matching grants ranging from 50 percent to 94 percent. Types of projects eligible for federal assistance include: the development of new airports; the construction or upgrading of runways, taxiways and aprons; the construction, expansion or rehabilitation of public-use terminal areas; and noise abatement projects (CBO, 1984: 5).

The primary source of revenue for this federal program has been excise taxes on passenger tickets, freight waybills and general aviation fuel. Since 1970, these tax revenues have been deposited in the Airport and Airway Trust Fund which serves as the funding mechanism for both airport capital grants and for investment in the national air traffic control system. Currently, the 10 percent tax on the price of domestic airline tickets provides the major share of revenues for the trust fund. During 1991, the passenger ticket tax generated $4.3 billion and accounted for 88 percent of total aviation tax revenues (CBO, 1992: 35). Other sources of aviation trust fund revenues during 1991 include $222 million from a 6.25 percent tax an the value of freight waybills, $140 million from a 15 cent per gallon tax on aviation gasoline and a 17.5 cent per gallon tax on aviation jet fuel, and $217 million from a $6 per passenger departure tax on all international flights originating in the United States (CBO, 1992: 36-37).

From 1960 through 1982 cumulative public and private investment in the nation's airports totaled $25.1 billion (in 1982 dollars), of which federal grants accounted for about one-third, or $9 billion. During the 1980s federal annual trust fund appropriations for airport improvements increased to about $800 million per year. Still the majority of the costs of airport capital improvements and all airport operating costs remain the responsibility of local airport management. Funds needed to cover these local cost responsibilities are derived from a variety of sources.

Most large commercial airports raise funds for investment purposes by issuing either general obligation bonds, which are backed by the full faith, credit and taxing power of the issuing government, or revenue bonds, which are backed solely by revenues generated from airport operations. Options for financing capital improvements at small general aviation airports are more limited. Due to their limited ability to raise revenues through user fees, the issuance of revenue bonds is often not feasible. Consequently, funding of improvements for these facilities must be provided from issuing general obligation bonds or through direct appropriations from the general funds of the government jurisdiction which owns the airport. Similarly, commercial airports generally possess adequate sources of revenue to cover operating costs without requiring support from the general fund revenues of their owning jurisdictions. However, many general aviation airports require operating subsidies (CBO, 1984: 17-28).

Since traffic congestion experienced by large commercial airports is the primary focus of this chapter, it is instructive to explore further how present practices associated with the pricing of airport airside services contributes to the problem. Most United States commercial airports follow one of two approaches in setting fees for the use of airport runways, taxiways, apron areas, terminal gates, and baggage handling areas. These two approaches are known as residual cost pricing and compensatory pricing.

Under the residual cost pricing approach the airlines that use the airport assume a significant portion of the airport's financial risk by agreeing to pay any costs associated with operating the airport that are not covered by fees collected from other sources, such as terminal space rentals and concessions. Alternatively, under the compensatory approach the airport owner assumes the major financial risk associated with operating the airport and charges airlines fees and rental rates adequate to recover the actual cost associated with the provision of airport services (CBO, 1984: 19).

These two approaches to the pricing of airport services have significantly different implications for airport infrastructure investment. These differences are reflected in (1) an airport's ability to accumulate retained earnings usable for funding capital projects, (2) the nature and extent of the role airlines play in making capital investment decisions, and

(3) the length of term of airline airport use agreements (CBO, 1984: 22).

For example, under the residual cost pricing approach airport operators are guaranteed that the cost of airport operation will be covered. However, in exchange for the airlines assuming much of the airport's financial risk, airport operators generally must grant the airlines "majority-in-interest" rights which gives them a significant degree of control over airport investment decisions. Furthermore, since most airport capital improvements are initially funded through the issuance of bonds, long-term use agreements are required to obtain a higher rating for these securities and to guarantee an adequate revenue stream to retire the debt. Thus, under this pricing approach the discretion of airport operators to respond to changing service demands is often sacrificed in exchange for financial security (CBO, 1984: 23-26).

On the other hand, under the compensatory pricing approach airport operators have no guarantee that revenues generated from operations will cover expenses. But neither is their ability to accumulate funds for future investment as restricted as under the residual pricing approach. Consequently, this pricing approach affords airport operators greater discretion in planning capital improvements. Also, the term of usage agreements is generally shorter than at airports that employ the residual pricing approach. However, since revenue generated by the airlines is needed to retire airport debt, airport operators still need to obtain airline support before undertaking major investment projects.

From an economic efficiency perspective, both of these approaches to pricing the use of airport services by commercial carriers and general aviation operators present problems. For example, under both approaches landing fees are generally set on the basis of gross aircraft weight, which serves as a surrogate measure for the wear imposed on runways, taxiways and apron areas due to aircraft use. However, by using gross weight as the method of cost allocation the fees do not reflect how efficiently the aircraft are being used because no distinction is made on the basis of load-factor. Neither do fees set in this manner account for extra aircraft operating costs and passenger travel time costs which result when airports become congested. Nor do weight based landing fees adequately reflect the cost associated with the investment in extra airside capacity added to accommodate peak period traffic. Furthermore, general aviation aircraft are often exempted from having to pay these fees, or when they do have to pay such fees, they are generally charged substantially below the level of cost they impose on the airport (FAA, 1987).

Similarly, the federal excise tax on passenger tickets does not distinguish between passengers traveling during peak versus off-peak traffic periods. Furthermore, because the ticket tax is assessed as a percentage of the ticket price, the amount of tax varies significantly among different flights and even among different passengers on the same flight. Since the advent of deregulation, the associated increase in price competition among airlines has further accentuated the inefficient nature of the ticket tax. Specifically, as ticket prices are reduced on the most highly contested routes congestion increases while tax revenues decrease. In addition, although the majority of federal trust fund revenues is generated by traffic at the nation's busiest airports, a disproportionate share of capital improvement grants is awarded to general aviation facilities.

Thus, the present system of airport finance in the United States largely fails to promote the efficient use of airport infrastructure. Setting usage fees on the basis of average historic cost rather than on the basis of current marginal cost encourages the overinvestment in new capacity. Ignoring differences in the operating characteristics of different types of airport users when pricing airport services discourages the efficient use of existing airport facilities. Finally, the separation of service pricing and investment decision-making prevents the operation of market mechanisms as a means for better coordinating the use of and investment in airport infrastructure.

The airport club model developed in section four of this chapter provides a theoretical basis for a more efficient system of airport infrastructure finance. However, before proceeding with development of this model, it is first necessary to explore the relationship between the engineering and economic considerations that influence modern airport design.

Economic Implications of Airport Engineering and Design

All commercial airports and most large general aviation airports consist of a large number of interrelated design elements, i.e., access roads, parking areas, lighting and communication systems, emergency facilities, aircraft hangers, runways, taxiways, terminal buildings, etc. However, to simplify the analysis, the theoretical airport model presented in this chapter is reduced to the two most basic elements of infrastructure required to provide air passenger service, i.e., runways and a terminal building. Also, these two elements of infrastructure provide the airport with its fundamental economic characteristics.

The engineering of runways incorporates five geometric design features that influence the type and amount of aircraft traffic an airport can serve. These determinants of airport capacity are: the number of runways, runway orientation, runway length, runway width and pavement depth. The number and orientation of runways are the primary design features that determine how many aircraft an airport can serve during a given time period. Whereas runway length, runway width and pavement depth determine the size of aircraft that can use the airport.

The primary determinant of the maximum number of aircraft operations that can be handled by an airport in a given time period is its number of runways. However, an airport's maximum operating capacity is also influenced by various aspects of runway orientation, i.e., the spacing between runways, orientation relative to the direction of prevailing winds, by whether runways are parallel or intersecting, by distance to the terminal and by the spacing of exit ramps and taxiways. For example, under visual flight rules (VFR) a single runway airport which serves only large commercial jet aircraft can handle a maximum of 51 operations per hour under ideal conditions. If the number of runways at this airport are doubled with a spacing of at least 4,300 feet, then the airport can handle 103 VFR operations per hour. However, if the spacing between two adjacent parallel runways is only 2,500 feet, then the airport's maximum operating capacity is restricted to only 94 VFR operations per hour.

Furthermore, under inclement weather conditions when aircraft must operate according to instrument flight rules (IFR), the impact of runway spacing on airport capacity becomes even more pronounced. In this case adding a second parallel runway with a spacing of 4,300 feet again about doubles capacity up to 99 operations per hour. However, at 2,500 foot spacing airport capacity increases by only 20 percent from 50 to 60 operations per hour (Ashford and Wright, 1992: 206-207).

Airport capacity is also affected by the mix of aircraft using the facility and by whether take-offs and landings occur on the same runway or on separate runways. When large and small aircraft use the same runways, the spacing of aircraft must be increased to prevent small aircraft from being adversely effected by wing-tip vortices generated by larger jet aircraft. Using the same runways for take-offs and landings may further reduce airport capacity and result in substantial departure delays at busy airports since landing aircraft take priority over those waiting to take-off.

On the other hand, separating large and small aircraft can result in a substantial increase in airport capacity. For example, an airport with two parallel runways separated by at least 4,300 feet can handle up to 126 operations per hour when both runways are used by all sizes of aircraft. However, separation of large and small aircraft traffic on different runways can increase the same airport's capacity to 149 operations per hour.

Runway length, runway width and pavement depth also influence airport capacity when measured in terms of passenger enplanements rather than in terms of aircraft operations.

For example, under normal conditions, a Boeing 737-500 aircraft with maximum capacity of 132 passengers requires a runway length of at least 6,650 feet for take-offs, while a Boeing 747-400 aircraft with maximum capacity of 660 passengers requires a runway of at least 11,100 feet for take-offs. Thus, lengthening runways from 6,650 feet to 11,100 feet (67 percent) can yield up to a 500 percent increase in the number of passengers the airport can theoretically handle. However, there are practical limits to the degree of scale economies that can be realized from this type of infrastructure investment. Foremost, few air transportation markets can support use of aircraft as large as the Boeing 747-400. Thus, for most of an airport's traffic the runways would be substantially overbuilt. Also, runway extensions generally require corresponding additions to runway width and pavement depth to accommodate the increased wheel base and weight of the larger aircraft (Ashford and Wright, 1992: 71-79).

Therefore, most commercial airports exhibit either constant or decreasing economies of scale with respect to the number of runways they have in operation. On the other hand, due both to the peaked nature of flight operations and the fact that airports often construct runways to accommodate flight operations under less than ideal conditions, a substantial amount of excess capacity exists during most time periods. Consequently, to spread the cost associated with an airport's investment in runways, most commercial airports serve general aviation, air freight and military traffic, as well as provide service to commercial passenger carriers. The accommodation of air freight and military aircraft increases runway utilization during off-peak traffic periods, plus provides additional use of long runways which are well suited for serving aircraft carrying heavy payloads or requiring extra length for high speed landings. Accommodation of general aviation aircraft further increases off-peak runway utilization. Thus, most commercial airports are characterized by subadditive runway costs. This implies at least some degree of economies of scope with respect to the provision of runway capacity (Baumel, Panzar and Willig, 1988: 71-72).

The relationship between the design and economic character of airport terminals is less well understood than for runways. The primary consideration in the design of most modern airport terminals is the accommodation of passenger needs. These needs fall in three areas: circulation, processing and holding space (Ashford and Wright, 1992: 287).

First, to provide efficient circulation, airport terminal designers generally strive to minimize the distance passengers must travel between landside access and aircraft boarding areas and to minimize conflicts between arriving and departing passengers. Second, depending on whether the airport serves only domestic or both domestic and international flights, terminal space must be allocated to a variety of passenger processing functions, which include: airline ticketing, passenger check-in, baggage check-in, baggage pick-up, gate check-in, incoming and outgoing customs, immigration control, health control, and security. Third, depending on the role played by the airport in the national air transportation system in terms of the number and size of markets served, areas must be designed to accommodate a variety of passenger and visitor needs while they wait for flights. Among the types of facilities that must be accommodated within these holding areas are: waiting areas at aircraft boarding gates, passenger service areas which include wash rooms, public telephones, nurseries, storage lockers, first aid stations, and flight information displays, and concessions which include bars, restaurants, vending machines, newsstands, tax and duty-free shops, retail shops, hotel reservation and car rental areas, and areas in which to purchase insurance, exchange currencies and access automatic teller machines.

Thus, because of the wide variety of functions airport terminals must serve, the relationship between terminal size and the number of passengers served per time period is not as precise as the relationship between the number of runways and capacity measured in terms of the number of aircraft that can be served. And, even though most commercial airports serve a variety of different sized aircraft, airport terminal designers generally resort to using measures of aircraft accommodation rather than passenger accommodation as the starting point for determining terminal space requirements. As a result, the number of gates required to serve originating and terminating flights often serves as the basis for measuring airport terminal capacity (Landrum and Brown, 1992: 3-3).

In this regard, the design of airport terminals may be thought of as proceeding from the airside/terminal interface, i.e., the aircraft boarding gates, and working backward toward the terminal/landside interface. In this process the determination of terminal space requirements begins with forecasting the number of aircraft gates that will be required at some future planning horizon to accommodate approximately 90 percent of anticipated peak period flight demand.

However, following this approach will not necessarily result in a unique number of boarding gates. Factors which introduce variation into the process include the mix of aircraft which must be accommodated, whether gates will be used by more than one size of aircraft, and whether air carriers possess exclusive usage rights to specific gates or whether gates are open to all carriers.

Another important determinant of airport terminal capacity is whether passenger processing is handled in a centralized or decentralized manner. Factors influencing this decision include the volume of flights, the number of air carriers served, the split of traffic among domestic, international, scheduled and charter flights, physical site characteristics, available modes of landside access and type of financing (Ashford and Wright, 1992: 293). The interplay of all of these factors requires designers of airport terminals to make a number of critical trade-offs. For example, the greater the number of aircraft the terminal is designed to accommodate during peak traffic periods, the larger the number of gates that will be required. This will result in passengers making connections, along with their baggage, having to travel greater distances within the terminal between flights which as a consequence increases gate occupancy times. Similarly, the degree of air carrier concentration at an airport will influence the number of aircraft that must be accommodated during peak traffic periods. As the degree of concentration increases the number of required gates will increase to facilitate the transfer of passengers and baggage between connecting flights, and consequently, so will gate occupancy times. Thus, as most domestic air carriers have restructured flight operations into a hub-and-spoke configuration since the deregulation of air passenger transportation, gate requirements at major airports have increased.

These and other trade-offs often result in substantial airport terminal excess capacity during off-peak traffic periods. This suggests there is potential for substantial economies of scope with respect to the variety of passenger transportation demands that may be accommodated by airport passenger terminals. In particular, as air carriers continue to adjust to the new economic opportunities and challenges presented by deregulation they are finding some route segments are best served by hub-and-spoke type operations, whereas direct point-of-origin to point-of-destination type flights serve other markets better. This continued restructuring of air carrier routes lends itself to an associated rescheduling of non-hubbing flights to off-peak traffic periods.

The impact of rescheduling direct point-to-point flights to off-peak periods would not only allow a reduction in the number of boarding gates required to meet peak period needs, but it would also allow a reduction in terminal space requirements for most passenger processing and holding activities, which in turn would reduce circulation space requirements. On the other hand, direct flights are most viable for routes carrying a high percentage of business travelers whose time preferences for using airport terminals corresponds very closely with present hub-and-spoke operation peak traffic periods. This suggests that as with runways, a terminal usage pricing system sensitive to variations in demand could result in a more efficient utilization of facilities.

Thus, the design of airport terminals does not lend itself to the same form of precise numeric measures of ultimate capacity as does the design of runways. Rather, airport terminal designers generally resort to empirically determined level of service criteria in developing space requirements for the various passenger processing and holding areas of the terminal which in turn result in the determination of circulation area requirements.

Having described the relationships between the major design considerations and the associated aircraft and passenger service characteristics of airport runways and terminals, it is now possible to develop a theoretical model which will provide a basis for testing hypotheses related to the existence of economies of scale and economies of scope associated with commercial airport design and use. The above provided information also provides the basis for empirically testing the hypotheses suggested by the model. Both the model and testable hypotheses are presented in the next section. Testing of selected hypotheses suggested by the model is the focus of Chapter 5.

Airport Club Model

Model specification

The airport club model represents a special case of the two-period, two user group general transportation facility model presented in Chapter Three. Principal modifications to that model required to obtain the airport club model include:

the incorporation of arguments in the utility function for the representative member of the non-user portion of the population to permit consideration of the impacts of externalities, the inclusion of two club goods -- a runway club good and a terminal club good, and the explicit recognition of transportation vehicles, i.e., airplanes, as the means by which airport users obtain transportation service.

In this model the population of the airport service area is divided among two user groups and a group of individuals who do not use the airport. One group of airport users, consisting of M individuals, uses scheduled commercial air carriers to meet its transportation needs. Each member of this group is assumed to take v_p^m trips during peak traffic periods and v_o^m trips during off-peak traffic periods. The other group of airport users, consisting of N individuals, uses only general aviation services, e.g., private aircraft or air taxis. Members of this second group each take v_p^n peak traffic period trips and v_o^n off-peak traffic period trips. The remaining members of the airport service area population, P-M-N individuals, do not use the airport but they do benefit from its existence, while they are adversely affected by its use.

Airport service is assumed to be provided through the provision of two club goods. One club good, the airport's runways, is used by both groups of airport users. The size, or capacity, of this club good, X_1, reflects the number of aircraft take-offs and landings accommodated by the airport during a giving time period. The other club good, the airport terminal is used only by individuals who patronize scheduled commercial air carriers. As explained above, the model will adopt the convention of representing terminal size, X_2, in terms of the airport's number of aircraft gate positions.

Two different types of aircraft are assumed to serve the members of the two user groups. The aircraft serving patrons of scheduled commercial air carriers is assumed to carry an average payload of A passengers per trip, while the average payload for the type of aircraft used in providing general aviation service equals B passengers per trip.

Both the airport runways and the airport terminal are subject to congestion. Congestion of the airport's runways is assumed to be a function of the number of landings and take-offs made by both types of aircraft during the two time periods and the capacity of the runways, i.e., $c_1 = c_1(F_p^m, F_o^m, F_p^n, F_o^n, X_1)$, where $F_p^m = v_p^m \bullet M/A$, $F_o^m = v_o^m \bullet M/A$, $F_p^n = v_p^n \bullet N/B$ and $F_o^n = v_o^n \bullet N/B$. Congestion of the airport terminal, on the other hand, is assumed only to be a function of use by patrons of scheduled commercial air carriers during the two time periods and the size of the terminal, i.e., $c_2 = c_2(F_p^m, F_o^m, X_2)$. In both cases congestion increases with use and decreases as capacity is expanded. Also, both the runways and the terminal are assumed to be subject to capacity constraints, i.e., $F_p^m + k \cdot F_p^n \leq X_1$, $F_o^m + k \cdot F_o^n \leq X_1$, $F_p^m \leq X_2$ and $F_o^m \leq X_2$, where k represents the runway occupancy time ratio between a size B aircraft and a size A aircraft.

The costs associated with the provision, operation and maintenance of the airport's runways are assumed to be a function of use by each group of users during each of the two time periods and the total runway capacity of the airport, i.e. $C_1 = C_1(F_p^m, F_o^m, F_p^n, F_o^n, X_1)$. All first partial derivatives of the runway cost function are assumed to be positive. The costs associated with provision, operation and maintenance of the airport terminal are assumed to be a function of peak and off-peak period use by patrons of scheduled commercial air service and the size of the terminal, i.e., $C_2 = C_2(F_p^m, F_o^m, X_2)$. Again, all first partial derivatives of this cost function are assumed to be positive.

Utility for a user of scheduled commercial air service is a function of the quantity of a composite private good consumed by that individual, y^m, the number of visits to the airport during each of the two time periods, and the runway and airport terminal congestion functions, i.e.,

$$U^m = U^m[y^m, v_p^m, v_o^m, c_1(\cdot), c_2(\cdot), 0, 0, 0].$$

Utility for a user of general aviation services is a function of the quantity of the composite private good consumed by that individual, y^n, the number of visits to the airport during each of the two time periods, and the runway congestion function, i.e.,

$$U^n = U^n[y^n,\ v_p^{\ n},\ v_o^{\ n},\ c_1(\cdot),\ 0,\ 0,\ 0,\ 0].$$

Utility for a representative individual who does not use the airport is a function of the composite private good consumed by that individual, y^l, the amounts of air traffic at the airport during each time period, and the runway capacity of the airport, which serves as a measure of airport size, i.e.,

$$U^l = U^l[y^l,\ 0,\ 0,\ 0,\ 0,\ F_p^{\ m} + h\bullet F_p^{\ n},\ F_o^{\ m} + h\bullet F_o^{\ n},\ X_1],$$

where h represents a factor which measures the environmental impacts of general aviation aircraft in terms of a typical commercial aircraft.

The utility functions for members of all three groups are assumed to be of the same functional form. However, they differ in regards to how the various function arguments affect the utility members of the three groups derive from the airport's existence and use. In this manner, the distinguishing characteristics of members of the different groups are emphasized. For example, the utility functions for members of the two groups of airport users could include the arguments representing the beneficial and adverse environmental impacts associated with the airport's existence and use. However, to emphasize the distinction between users and non-users these arguments have been omitted from the utility functions of airport users.

The marginal utilities of the members of the different groups of individuals are the same as presented in the general transportation facility models. Airport users derive positive marginal utility from their own use of the airport, i.e., $\partial U^m/\partial v_p{}^m > 0$, $\partial U^m/v_o{}^m > 0$, $\partial U^n/\partial v_p{}^n > 0$ and $\partial U^n/\partial v_o{}^n > 0$, while the marginal utility of airport users decreases as runway and terminal congestion increases, i.e., $\partial U^m/\partial c_1 < 0$, $\partial U^m/\partial c_2 < 0$ and $\partial U^n/\partial c_1 < 0$. The marginal utilities of those individuals who do not use the airport are positive with respect to the provision of runway capacity, i.e., $\partial U^l/\partial X_1 > 0$, and negative with respect to airport use during each of the two time periods, i.e, $\partial U^l/\partial(F_p{}^m + h\bullet F_p{}^n) < 0$ and $\partial U^l/\partial(F_o{}^m + h\bullet F_o{}^n) < 0$.

The first-order conditions for this model are derived by maximizing a quasi-concave Benthamite Social Welfare function,

$$\begin{aligned} W = {} & (P-M-N)\cdot U^l(y^l, 0, 0, 0, 0, F_p^m + h\cdot F_p^n, F_o^m + h\cdot F_o^n, X_1) \\ & + M\cdot U^m[y^m, v_p^m, v_o^m, c_1(F_p^m, F_o^m, F_p^n, F_o^n, X_1), c_2(F_p^m, F_o^m, X_2), 0, 0, 0] \qquad (1) \\ & + N\cdot U^n[y^n, v_p^n, v_o^n, c_1(F_p^m, F_o^m, F_p^n, F_o^n, X_1), 0, 0, 0, 0], \end{aligned}$$

in which the utility functions of representative members of the three components of the airport service area population are weighted only by each group's membership size.

Maximization of the objective function is carried out subject to a societal budget constraint,

$$I = (P-M-N)\cdot y^l + M\cdot y^m + N\cdot y^n + C_1(F_p^m, F_o^m, F_p^n, F_o^n, X_1) + C_2(F_p^m, F_o^m, X_2), \quad (2)$$

which requires that the total income of the airport service area population, I, be expended on the purchase of private goods and for the provision, operation and maintenance of the airport runways and terminal.

Also, maximization of the objective function is carried out subject to a peak period runway capacity constraint,

$$F_p^m + k\cdot F_p^n \leq X_1, \quad (3)$$

an off-peak period runway capacity constraint,

$$F_o^m + k\cdot F_o^n \leq X_1, \quad (4)$$

a peak period airport terminal capacity constraint,

$$F_p^m \leq X_2, \quad (5)$$

and an off-peak period airport terminal capacity constraint,

$$F_o^m \leq X_2. \quad (6)$$

Optimization of this model yields the following first-order conditions.

First-order conditions

First, optimization of the model with respect of the amount of private good consumed by representative members of each of the three segments of the airport service area population yields the condition that the marginal rate of social substitution must be equal across the entire population,

$$\frac{\partial U^l}{\partial y^l} = \frac{\partial U^m}{\partial y^m} = \frac{\partial U^n}{\partial y^n} = \lambda \qquad (7)$$

Furthermore, this condition represents the valuation each population member places on the marginal unit of the private good consumed when the social welfare function is simultaneously maximize with respect to group membership, airport facility provision, and airport facility utilization. As a result, this condition provides a common unit of measure for comparing how different members of the population value the provision and use of airport facilities.

Second, optimization of the model with respect to the number of users of scheduled air carrier service, M, and the number of users of general aviation services, N, yields two conditions which define the socially optimal levels of airport patronage by members of the two groups. The first of these membership conditions shows that use of scheduled commercial air transportation service should expand up to the point where the benefits derived by the marginal member of this group of airport patrons just equals the costs that individual imposes on members of the service area population that do not use the airport, the costs he or she imposes on other users of scheduled commercial air carrier service, the costs he or she imposes on users of general aviation service, the additional airport runway and passenger terminal operating and capital costs associated with this last unit of patronage and an adjustment to the marginal users income to maintain the equality of the marginal utility of income for all population members, i.e.,

$$
\begin{aligned}
\frac{U^m(.)}{\partial U^m/\partial y^m} - \frac{U^l(.)}{\partial U^l/\partial y^l} = &- (P-M-N)\cdot \frac{\partial U^l/\partial(F_p^m + h\cdot F_p^n)}{\partial U^l/\partial y^l}\cdot \frac{F_p^m}{M} \\
&- (P-M-N)\cdot \frac{\partial U^l/\partial(F_o^m + h\cdot F_p^n}{\partial U^l/\partial y^l}\cdot \frac{F_o^m}{M} \\
&- M\cdot \frac{\partial U^m/\partial c_1}{\partial U^m/\partial y^m}\cdot \frac{\partial c_1}{\partial F_p^m}\cdot \frac{F_p^m}{M} - M\cdot \frac{\partial U^m/\partial c_1}{\partial U^m/\partial y^m}\cdot \frac{\partial c_1}{\partial F_o^m}\cdot \frac{F_o^m}{M} \\
&- M\cdot \frac{\partial U^m/\partial c_2}{\partial U^m/\partial y^m}\cdot \frac{\partial c_2}{\partial F_p^m}\cdot \frac{F_p^m}{M} - M\cdot \frac{\partial U^m/\partial c_2}{\partial U^m/\partial y^m}\cdot \frac{\partial c_2}{\partial F_o^m}\cdot \frac{F_o^m}{M} \qquad (8) \\
&- N\cdot \frac{\partial U^n/\partial c_1}{\partial U^n/\partial y^n}\cdot \frac{\partial c_1}{\partial F_p^m}\cdot \frac{F_p^m}{M} - N\cdot \frac{\partial U^n/\partial c_1}{\partial U^n/\partial y^n}\cdot \frac{\partial c_1}{\partial F_o^m}\cdot \frac{F_o^m}{M} \\
&+ \frac{\partial C_1(.)}{\partial F_p^m}\cdot \frac{F_p^m}{M} + \frac{\partial C_1(.)}{\partial F_o^m}\cdot \frac{F_o^m}{M} + \frac{\partial C_2(.)}{\partial F_p^m}\cdot \frac{F_p^m}{M} + \frac{\partial C_2(.)}{\partial F_o^m}\cdot \frac{F_o^m}{M} \\
&+ \frac{\mu_1}{\lambda}\cdot \frac{F_p^m}{M} + \frac{\delta_1}{\lambda}\cdot \frac{F_o^m}{M} + \frac{\mu_2}{\lambda}\cdot \frac{F_p^m}{M} + \frac{\delta_2}{\lambda}\cdot \frac{F_o^m}{M} + (y^m - y^l)
\end{aligned}
$$

Whereas, the LHS of this first-order condition can readily be interpreted as the benefit the marginal user of commercial air carrier service derives from use of the airport, the RHS (or cost side) of the condition merits further explanation. The first two RHS terms represent the environmental costs borne by non-users associated with additional use of the airport by individuals using scheduled commercial air carrier service during peak and off-peak traffic periods, respectively. Dissecting the first of these terms, the cost imposed on airport non-users is shown to equal the product of the number of non-users, P-M-N, the representative non-user's marginal rate of substitution between additional peak period flight activity and consumption of the composite private good, $(\partial U^l/\partial F^m_p)/(\partial U^l/\partial y^l)$, and the average number of peak period flights attributable to a representative member of the group of users of scheduled commercial air carrier service, F^m_p/M.

The third and fourth RHS terms equal the added congestion users of scheduled commercial air carriers experience during peak and off-peak traffic periods, respectively, when this type of airport use increases. Again dissecting the peak period term, one finds the added own-group congestion cost associated with the use of scheduled commercial air service consists of the product of the marginal user's marginal rate of substitution between runway congestion and the composite private good, $(\partial U^m/\partial c_1)/(\partial U^m/\partial y^m)$, the partial derivative of the runway congestion function with respect to the number of peak period scheduled commercial air carrier flights, $\partial c_1/\partial F^m{}_p$, and the number of peak period scheduled commercial air carrier flights, $F^m{}_p$. Similarly, the fifth and sixth RHS terms equal the marginal passenger terminal congestion costs associated with added scheduled commercial air carrier use during peak and off-peak traffic periods, respectively. And, the seventh and eighth RHS terms equal the marginal runway congestion costs expansion of scheduled commercial air carrier use imposes on users of general aviation services at the airport during peak and off-peak traffic periods, respectively.

The next four RHS terms pertain to the added airport runway and passenger terminal operating and maintenance costs associated with increased use of the airport by patrons of scheduled commercial air carrier service. The first of these is the marginal runway operating and maintenance costs associated with an increase in peak period scheduled commercial air carrier use, which is equal to the product of the marginal runway operating and maintenance costs with respect to the number of peak period scheduled commercial air carrier flights, $\partial C_1(.)/\partial F^m{}_p$, and the average number of such flights per member of the group of users of scheduled commercial air transportation service, $F^m{}_p/M$. The other three operating and maintenance cost terms have a similar interpretation.

Next, the thirteenth through the sixteenth RHS terms, pertain to the marginal runway and passenger terminal capital costs that would arise from peak and off-peak use of the airport by one more user of scheduled commercial air transportation service. For example, the thirteenth RHS term is the marginal cost associated with runway capacity expansion needed to accommodate an increase in peak period scheduled commercial air service usage, and the other three capital cost terms have similar interpretations. However, generally, the capital cost terms pertaining to off-peak traffic periods would equal zero since most airports experience capacity problems only during peak traffic periods.

As explained in Chapter Three, the last RHS term represents an income adjustment required to maintain the equality among the marginal utilities of the private good, or income, for the three segments of the airport service area population.

The membership condition for users of general aviation services follows the same pattern as for users of scheduled commercial air transportation service. However, this second membership condition,

$$\frac{U^n}{\partial U^n/\partial y^n} - \frac{U^l}{\partial U^l/\partial y^l} =$$

$$- (P\text{-}M\text{-}N) \cdot \frac{\partial U^l/\partial(F_p^m + h \cdot F_p^n)}{\partial U^l/\partial y^l} \cdot h \cdot \frac{F_p^n}{N} \tag{9}$$

$$- (P\text{-}M\text{-}N) \cdot \frac{\partial U^l/\partial(F_o^m + h \cdot F_o^n)}{\partial U^l/\partial y^l} \cdot h \cdot \frac{F_o^n}{N}$$

$$- \frac{M}{N} \cdot \frac{\partial U^m/\partial c_1}{\partial U^m/\partial y^m} \cdot \frac{\partial c_1}{\partial F_p^n} \cdot F_p^n - \frac{M}{N} \cdot \frac{\partial U^m/\partial c_1}{\partial U^m/\partial y^m} \cdot \frac{\partial c_1}{\partial F_o^n} \cdot F_o^n$$

$$- \frac{\partial U^n/\partial c_1}{\partial U^n/\partial y^n} \cdot \frac{\partial c_1}{\partial F_p^n} \cdot F_p^n - \frac{\partial U^n/\partial c_1}{\partial U^n/\partial y^n} \cdot \frac{\partial c_1}{\partial F_o^n} \cdot F_o^n$$

$$+ \frac{\partial c_1(.)}{\partial F_p^n} \cdot \frac{F_p^n}{N} + \frac{\partial c_1(.)}{\partial F_o^n} \cdot \frac{F_o^n}{N} + \frac{\mu_1}{\lambda} \cdot k \cdot F_p^n + \frac{\delta_1}{\lambda} \cdot k \cdot F_o^n$$

$$+ (y^n - y^l),$$

excludes congestion costs, operating and maintenance costs, and capital costs terms for the passenger terminal. This is because users of general aviation services are assumed to not use the passenger terminal.

Third, optimization of the airport model with respect to runway and passenger terminal capacity variables yields the following two infrastructure provision conditions. The provision condition for airport runways,

$$(P-M-N)\cdot\frac{\partial U^l/\partial X_1}{\partial U^l/\partial y^l}+M\cdot\frac{\partial U^m/\partial c_1}{\partial U^m/\partial y^m}\cdot\frac{\partial c_1}{\partial X_1}+N\cdot\frac{\partial U^n/\partial c_1}{\partial U^n/\partial y^n}\cdot\frac{\partial c_1}{\partial X_1}$$
$$=\frac{\partial C_1(\cdot)}{\partial X_1}-\frac{\mu_1}{\lambda}-\frac{\delta_1}{\lambda}, \tag{10}$$

requires that the population weighted sum of the marginal rates of substitution between runway capacity and the composite private good equal the marginal cost associated with runway expansion minus the peak period and off-peak period benefits which would result from runway expansion, i.e. capacity shadow prices. Similarly, the provision condition for the airport passenger terminal,

$$M\cdot\frac{\partial U^m/\partial c_2}{\partial U^m/\partial y^m}\cdot\frac{\partial c_2}{\partial X_2}=\frac{\partial C_2(\cdot)}{\partial X_2}-\frac{\mu_2}{\lambda}-\frac{\delta_2}{\lambda}, \tag{11}$$

requires that the aggregate marginal value users of scheduled commercial air transportation service place on the reduction in terminal congestion equal the marginal cost associated with terminal capacity expansion minus the peak period and off-peak traffic period benefits which would result from expansion of airport passenger terminal capacity. For both runways and the passenger terminal the additional benefits associated with capacity expansion for the off-peak traffic period will generally be zero.

Fourth, four toll conditions are derived from maximization of the model with respect to airport peak period and off-peak period usage rates by members of the two user groups. For each of these toll conditions, the benefit derived from an additional trip through the airport is equated to the sum of changes in environmental costs experienced by the segment of the population that does not use the airport, congestion costs experienced by airport users, airport operating and maintenance costs, and airport capital costs. More precisely, for an increase in peak traffic period trips by a user of scheduled commercial air carrier service, the toll condition,

$$
\begin{aligned}
\frac{\partial U^m/\partial v_p^m}{\partial U^m/\partial y^m} = &- (P-M-N)\cdot \frac{\partial U^l/\partial (F_p^m + h\cdot F_p^n)}{\partial U^l/\partial y^l}\cdot \frac{1}{A} \\
&- M\cdot \frac{\partial U^m/\partial c_1}{\partial U^m/\partial y^m}\cdot \frac{\partial c_1}{\partial F_p^m}\cdot \frac{1}{A} - M\cdot \frac{\partial U^m/\partial c_2}{\partial U^m/\partial y^m}\cdot \frac{\partial c_2}{\partial F_p^m}\cdot \frac{1}{A} \\
&- N\cdot \frac{\partial U^n/\partial c_1}{\partial U^n/\partial y^n}\cdot \frac{\partial c_1}{\partial F_p^m}\cdot \frac{1}{A} + \frac{\partial C_1(\cdot)}{\partial F_p^m}\cdot \frac{1}{A} \\
&+ \frac{\partial C_2(\cdot)}{\partial F_p^m}\cdot \frac{1}{A} + \frac{\mu_1}{\lambda}\cdot \frac{1}{A} + \frac{\mu_2}{\lambda}\cdot \frac{1}{A},
\end{aligned}
\qquad (12)
$$

equates the marginal rate of substitution between a trip through the airport and the composite private good to the sum of eight RHS cost terms. The first RHS term, which represents the adverse impact of additional peak traffic period airport scheduled commercial air carrier activity, equals the product of the size of the non-user population, P-M-N, the marginal rate of substitution between the number of all peak traffic period flights expressed in terms of equivalent scheduled commercial air carrier flights and the composite private good, $(\partial U^l/\partial(F^m_p + h \cdot F^n_p)) / (\partial U^l/\partial y^l)$, and the inverse of the average passenger load for scheduled commercial air carrier flights, 1/A. The second RHS term represents the added delay time cost experienced by users of scheduled commercial air carrier service resulting from increased peak period runway congestion. This equals the product of the number of users of scheduled commercial air carrier service, M, the marginal rate of substitution between runway congestion and the composite private good, $(\partial U^m/\partial c_1) / (\partial U^m/\partial F^m)$, the marginal change in runway congestion attributable to a change in the number of peak period scheduled commercial air carrier flights, and the inverse of the average passenger load for scheduled commercial air carrier flights, 1/A. Similarly, the third RHS term represents the increased cost experienced by users of scheduled commercial air carrier service resulting from increased peak period congestion of the passenger terminal, and the fourth RHS term equals the increased cost experienced by users of general aviation service resulting from additional peak period runway use by scheduled commercial air carriers. The fifth and sixth RHS terms represent the marginal increase in runway and passenger terminal operating and maintenance costs, respectively, that would result from an increase in peak traffic period use of scheduled commercial air carrier service. Finally, the seventh and eighth RHS terms represent the increase in runway and passenger terminal capital cost, respectively, that would result from an increase in peak traffic period use of the airport by travelers using scheduled commercial air carriers.

The toll condition for off-peak traffic period use of the airport by users of scheduled commercial air carrier service,

$$\frac{\partial U^m/\partial v_o^m}{\partial U^m/\partial y^m} = -(P-M-N)\cdot\frac{\partial U^l/\partial(F_o^m + h\cdot F_o^n)}{\partial U^l/\partial y^l}\cdot\frac{1}{\bar{A}}$$
$$- M\cdot\frac{\partial U^m/\partial c_1}{\partial U^m/\partial y^m}\cdot\frac{\partial c_1}{\partial F_o^m}\cdot\frac{1}{\bar{A}} - M\cdot\frac{\partial U^m/\partial c_2}{\partial U^m/\partial y^m}\cdot\frac{\partial c_2}{\partial F_o^m}\cdot\frac{M}{\bar{A}}$$
$$- N\cdot\frac{\partial U^n/\partial c_1}{\partial U^n/\partial U^n}\cdot\frac{\partial c_1}{\partial F_o^m}\cdot\frac{1}{\bar{A}} + \frac{\partial c_1(\cdot)}{\partial F_o^m}\cdot\frac{1}{\bar{A}} \qquad (13)$$
$$+ \frac{\partial c_2(\cdot)}{\partial F_o^m}\cdot\frac{1}{\bar{A}} + \frac{\delta_1}{\lambda}\cdot\frac{1}{\bar{A}} + \frac{\delta_2}{\lambda}\cdot\frac{1}{\bar{A}},$$

includes the same number and type of costs on the RHS as the condition for peak period airport use by members of this group of travelers. However, the values attributable to the runway and passenger terminal capital cost terms in this condition will be small, or zero, for most airports because generally most airports have excess off-peak period capacity.

The toll condition for peak period use of the airport by users of general aviation services,

$$\frac{\partial U^n/\partial v^n_p}{\partial U^n/\partial y^n} = -(P\text{-}M\text{-}N)\cdot\frac{\partial U^l/\partial(F^m_p + h\cdot F^n_p)}{\partial U^l/\partial y^l}\cdot h\cdot\frac{1}{B}$$

$$-M\cdot\frac{\partial U^m/\partial c_1}{\partial U^m/\partial y^m}\cdot\frac{\partial c_1}{\partial F^n_p}\cdot\frac{1}{B} - N\cdot\frac{\partial U^n/\partial c_1}{\partial U^n/\partial y^n}\cdot\frac{\partial c_1}{\partial F^n_p}\cdot\frac{1}{B} \qquad (14)$$

$$+\frac{\partial c_1(.)}{\partial F^n_p}\cdot\frac{1}{B} + \frac{\mu_1}{\lambda}\cdot k\cdot\frac{1}{B},$$

also includes terms representing the cost imposed on that portion of the population that does not use the airport, the increased delay costs experienced by members of both groups of airport users when general aviation activity increases, the increased runway operating and maintenance cost that would arise from increased general aviation activity, and the increased runway capital investment that would be required to adequately accommodate an increase of general aviation use at the airport. The toll condition for off-peak period general aviation activity,

$$\frac{\partial U^n/\partial v^n_o}{\partial U^n/\partial y^n} = -(P\text{-}M\text{-}N)\cdot\frac{\partial U^l/\partial(F^m_o + h\cdot F^n_o)}{\partial U^l/\partial y^l}\cdot h\cdot\frac{1}{B}$$

$$-M\cdot\frac{\partial U^m/\partial c_1}{\partial U^m/\partial y^m}\cdot\frac{\partial c_1}{\partial F^n_o}\cdot\frac{1}{B} - N\cdot\frac{\partial U^n/\partial c_1}{\partial U^n/\partial y^n}\cdot\frac{\partial c_1}{\partial F^n_o}\cdot\frac{1}{B} \qquad (15)$$

$$+\frac{\partial c_1(.)}{\partial F^n_o}\cdot\frac{1}{B} + \frac{\delta_1}{\lambda}\cdot k\cdot\frac{1}{B},$$

mirrors the condition for peak period general aviation airport use, but as with the off-peak period toll condition for scheduled commercial carrier use of the airport, the magnitude of the capital cost factor is expect to be small, or zero, for most airports.

The major difference between these two latter toll conditions and the first two is the omission of terms related to congestion cost, operating and maintenance cost, and capital cost associated with the airport passenger terminal. These terms do not appear in the toll conditions for general aviation use of the airport because users of this type of air transportation service are assumed to not use the terminal.

The remaining five first-order conditions result from maximization of the airport model with respect to the lagrange multipliers for the peak traffic period runway constraint, μ_1, for the off-peak traffic period runway capacity constraint, δ_1, for the peak traffic period passenger terminal capacity constraint, μ_2, for the off-peak period passenger terminal capacity constraint, δ_2, and for the societal budget constraint, λ. The conditions associated with the capacity constraints are expressed in Kuhn-Tucker form.

The first order conditions for peak traffic period runway capacity,

$$X_1 - F_p^m + k \cdot F_p^n \geq 0 \qquad (16)$$

$$\mu_1 \geq 0 \qquad (17)$$

$$\mu_1 \cdot (X_1 - F_p^m - k \cdot F_p^n) = 0, \qquad (18)$$

and for off-peak period runway capacity,

$$X_1 - F_o^m - k \cdot F_o^n \geq 0 \qquad (19)$$

$$\delta_1 \geq 0 \qquad (20)$$

$$\delta_1 \cdot (X_1 - F_o^m - k \cdot F_o^n) = 0, \qquad (21)$$

indicate that if runway use is at capacity the lagrange multiplier takes a positive value, otherwise it equals zero. The same interpretation holds for the peak traffic period passenger terminal capacity constraint,

$$X_2 - F_p^m \geq 0 \qquad (22)$$

$$\mu_2 \geq 0 \qquad (23)$$

$$\mu_2 \cdot (X_2 - F_p^m) = 0, \qquad (24)$$

and for the off-peak traffic period passenger terminal capacity constraint,

$$X_2 - F_o^m \geq 0 \tag{25}$$

$$\delta_2 \geq 0 \tag{26}$$

$$\delta_2 \cdot (X_2 - F_o^m) = 0. \tag{27}$$

However, the conditions for the passenger terminal exclude terms related to general aviation use of the airport. Maximization of the model with respect to λ returns the societal budget constraint.

Having derived these first-order conditions, it is possible to identify what conditions must hold for efficient pricing of airport services and investment in capital improvements. Specifically, the next section investigates to what extent economies of scale and economies of scope must exist for full user financing to be feasible. The next section also discusses conditions under which the non-user population can be justifiably taxed for a portion of the costs associated with airport operation and when non-users should be compensated for adverse impacts associated with airport use.

Airport financing analysis

By definition, full user financing of airport operation, maintenance and capital investment requires the following condition to hold,

$$M \cdot v_p^m \cdot t_p^m + M \cdot v_o^m \cdot t_o^m + N \cdot v_p^n \cdot t_p^n + N \cdot v_o^n \cdot t_o^n = C_1(F_p^m, F_o^m, F_p^n, F_o^n, X_1) + C_2(F_p^m, F_o^m, X_2), \tag{28}$$

where t^i_j equals $(\partial U^i/\partial v^i_j)/(\partial U^i/\partial y^i)$, $i=m,n$ and $j=p,o$. This condition states that by pricing airport use in such a manner that fees equal each user's period specific rate of substitution between an airport visit and the composite private good revenues will be adequate to cover all airport costs. However, this is only a sufficient condition for full user financing. This condition does not address the issue of whether such a fee structure is efficient. In fact, given the existence of externalities that generally accompany the existence and operation of airports, full user financing will not result in the efficient provision or use of airport facilities and services.

To obtain a fuller understanding of the conditions that must exist for efficient airport pricing requires an analysis of the implications of the simultaneous optimization of the airport model with respect to its use and provision variables. Beginning with the four toll conditions, equations (12) - (15), the substitution of their RHSs for the t^i_j terms in equation (28) yields the following condition,
This condition states that efficient airport pricing requires that non-user externalities, runway congestion, runway operation and maintenance, runway capital investment,

$$- (P-M-N) \cdot \left[\frac{\partial U^l / \partial (F_p^m + h \cdot F_p^n)}{\partial U^l / \partial y^l} \cdot (F_p^m + h \cdot F_p^n) \right]$$

$$- (P-M-N) \cdot \left[\frac{\partial U^l / \partial (F_o^m + h \cdot F_o^n)}{\partial U^l / \partial y^l} \cdot (F_o^m + h \cdot F_o^n) \right]$$

$$- \left[M \cdot \frac{\partial U^m / \partial c_1}{\partial U^m / \partial y^m} + N \cdot \frac{\partial U^n / \partial c_1}{\partial U^n / \partial y^n} \right] \cdot \left[\frac{\partial c_1}{\partial F_p^m} \cdot F_p^m + \frac{\partial c_1}{\partial F_o^m} \cdot F_o^m + \frac{\partial c_1}{\partial F_p^n} \cdot F_p^n + \frac{\partial c_1}{\partial F_o^n} \cdot F_o^n \right]$$

$$+ \left[\frac{\partial C_1(\cdot)}{\partial F_p^m} \cdot F_p^m + \frac{\partial C_1(\cdot)}{\partial F_o^m} \cdot F_o^m + \frac{\partial C_1(\cdot)}{\partial F_p^n} \cdot F_p^n + \frac{\partial C_1(\cdot)}{\partial F_o^n} \cdot F_o^n \right]$$

$$+ \left[\frac{\mu_1}{\lambda} \cdot F_p^m + \frac{\delta_1}{\lambda} \cdot F_o^m + \frac{\mu_1}{\lambda} \cdot k \cdot F_p^n + \frac{\delta_1}{\lambda} \cdot k \cdot F_o^n \right]$$

$$- M \cdot \frac{\partial U^m / \partial c_2}{\partial U^m / \partial y^m} \cdot \left[\frac{\partial c_2}{\partial F_p^m} \cdot F_p^m + \frac{\partial c_2}{\partial F_o^m} \cdot F_o^m \right]$$

$$+ \left[\frac{\partial C_2(\cdot)}{\partial F_p^m} \cdot F_p^m + \frac{\partial C_2(\cdot)}{\partial F_o^m} \cdot F_o^m \right]$$

$$+ \left[\frac{\mu_2}{\lambda} \cdot F_p^m + \frac{\delta_2}{\lambda} \cdot F_o^m \right] \qquad (29)$$

$$= C_1(F_p^m, F_o^m, F_p^n, F_o^n, X_1) + C_2(F_p^m, F_o^m, X_2).$$

passenger terminal congestion, passenger terminal operation and maintenance, and passenger terminal capital investment costs all be taken into consideration.

Next, recalling the discussion in Chapter Three, the design of transportation infrastructure is generally based on the relationship between the forecasted demand for service at some future date and the capability of different size facilities to handle the anticipated traffic demand at some predetermined level of service standard. Furthermore, level of service standards, which reflect different degrees of service delay, or facility congestion, are often measured in terms of the ratio between forecasted traffic demand and the traffic carrying capacity of the transportation facility. Consequently, the congestion functions incorporated in the airport model can be represented as being homogeneous of degree zero. Therefore, by Euler's Theorem, the following condition is derived from the runway congestion function:

$$\frac{\partial c_1}{\partial F_p^m} \cdot F_p^m + \frac{\partial c_1}{\partial F_o^m} \cdot F_o^m + \frac{\partial c_1}{\partial F_p^n} \cdot F_p^n + \frac{\partial c_1}{\partial F_o^n} \cdot F_o^n = - \frac{\partial c_1}{\partial X_1} \cdot X_1. \tag{30}$$

Similarly, the following condition is derived from the airport passenger terminal congestion function:

$$\frac{\partial c_2}{\partial F_p^m} \cdot F_p^m + \frac{\partial c_2}{\partial F_o^m} \cdot F_o^m = - \frac{\partial c_2}{\partial X_2} \cdot X_2. \tag{31}$$

Substitution of the RHSs of equations (30) and (31) into the third and sixth terms of equation (29) yields,

$$
\begin{aligned}
&- (P-M-N) \cdot \left[\frac{\partial U^l / \partial (F_p^m + h \cdot F_p^n)}{\partial U^l / \partial y^l} \cdot (F_p^m + h \cdot F_p^n) \right] \\
&- (P-M-N) \cdot \left[\frac{\partial U^l / \partial (F_o^m + h \cdot F_o^n)}{\partial U^l / \partial y^l} \cdot (F_o^m + h \cdot F_o^n) \right] \\
&+ \left[M \cdot \frac{\partial U^m / \partial c_1}{\partial U^m / \partial y^m} + N \cdot \frac{\partial U^n / \partial c_1}{\partial U^n / \partial y^n} \right] \cdot \left[\frac{\partial c_1}{\partial X_1} \cdot X_1 \right] \\
&+ \left[\frac{\partial C_1(\cdot)}{\partial F_p^m} \cdot F_p^m + \frac{\partial C_1(\cdot)}{\partial F_o^m} \cdot F_o^m + \frac{\partial C_1(\cdot)}{\partial F_p^n} \cdot F_p^n + \frac{\partial C_1(\cdot)}{\partial F_o^n} \cdot F_o^n \right] \qquad (32) \\
&+ \left[\frac{\mu_1}{\lambda} \cdot F_p^m + \frac{\delta_1}{\lambda} \cdot F_o^m + \frac{\mu_1}{\lambda} \cdot k \cdot F_p^n + \frac{\delta_1}{\lambda} \cdot k \cdot F_o^n \right] \\
&+ M \cdot \frac{\partial U^m / \partial c_2}{\partial U^m / \partial y^m} \cdot \left[\frac{\partial c_2}{\partial X_2} \cdot X_2 \right] \\
&+ \left[\frac{\partial C_2(\cdot)}{\partial F_p^m} \cdot F_p^m + \frac{\partial C_2(\cdot)}{\partial F_o^m} \cdot F_o^m \right] \\
&+ \left[\frac{\mu_2}{\lambda} \cdot F_p^m + \frac{\delta_2}{\lambda} \cdot F_o^m \right] = C_1(F_p^m, F_o^m, F_p^n, F_o^n, X_1) + C_2(F_p^m, F_o^m, X_2) .
\end{aligned}
$$

This substitution transforms the relationships between runway and passenger terminal congestion and the volume of different types of flight activity into relationships between runway and passenger terminal congestion and the size, or traffic carrying capacity, of those facilities.

Now, substituting into the revised third and sixth LHS terms of equation (32) from the runway and passenger terminal provision conditions, equations (10) and (11), respectively, and regrouping terms, one derives equation (33),

$$
\begin{aligned}
&- (P-M-N) \cdot \left[\frac{\partial U^{l} / \partial (F_p^m + h \cdot F_p^n)}{\partial U^{l} / \partial y^{l}} \cdot (F_p^m + h \cdot F_p^n) \right] \\
&- (P-M-N) \cdot \left[\frac{\partial U^{l} / \partial (F_o^m + h \cdot F_o^n)}{\partial U^{l} / \partial y^{l}} \cdot (F_o^m + h \cdot F_o^n) \right] \\
&- (P-M-N) \cdot \left[\frac{\partial U^{l} / \partial X_1}{\partial U^{l} / \partial y^{l}} \cdot X_1 \right] \\
&+ \left[\frac{\partial C_1(.)}{\partial F_p^m} \cdot F_p^m + \frac{\partial C_1(.)}{\partial F_o^m} \cdot F_o^m + \frac{\partial C_1(.)}{\partial F_p^n} \cdot F_p^n + \frac{\partial C_1(.)}{\partial F_o^n} \cdot F_o^n + \frac{\partial C_1(.)}{\partial X_1} \cdot X_1 \right] \\
&+ \left[\frac{\partial C_2(.)}{\partial F_p^m} \cdot F_p^m + \frac{\partial C_2(.)}{\partial F_o^m} \cdot F_o^m + \frac{\partial C_2(.)}{\partial X_2} \cdot X_2 \right] \\
&= C_1(F_p^m, F_o^m, F_p^n, F_o^n, X_1) + C_2(F_p^m, F_o^m, X_2)
\end{aligned} \tag{33}
$$

This condition shows that efficient pricing of airport services requires that negative and positive non-user externalities, as well as operating, maintenance and capital costs associated with airport use, be taken into consideration.

More precisely, the first two LHS terms in equation (33) pertain to the adverse environmental costs airport use during peak and off-peak traffic periods imposes on residents of the airport service area. The most common type of such adverse cost is the noise generated by aircraft take-offs and landings. And in fact, most major airports have noise impact abatement programs under which a variety of measures are taken to compensate those most adversely impacted by aircraft noise. Among the most common forms of compensation provided to residents adversely affected by airport generated noise are property buyouts or the purchase of noise easements.

Alternatively, the third LHS term represents the benefits residents of the airport service area derive from the airport's existence. These benefits may include an increase in economic opportunity associated with a community's increased access to national and international markets, or an increased resident's sense of well-being associated with an enhanced ability of one's family and friends to visit. The value of the benefits associated with the existence of an airport often are capitalized in the form of increased property values, and airport authorities can capture some of the added value throughout the establishment of special taxing districts.

The fourth through seventh LHS terms represent the changes in runway operating and maintenance costs associated with both types of airport use during peak and off-peak traffic periods. While the eighth LHS term represents the increase in runway capital cost that would be required to increase runway capacity. Similarly, the ninth and tenth LHS terms represent the change in passenger terminal peak period and off-peak period operating and maintenance costs that would accompany changes in the use of scheduled commercial air carrier service. And the final LHS term represents the increase in capital cost that would be required to expand the airport's passenger terminal to accommodate more use of scheduled commercial air carrier services.

Overall, equation (33) shows that if non-user externalities equal zero, then full user financing of the airport would be feasible when both runways and the passenger terminal exhibit constant ray economies of scale. However, if non-user externalities have a net value which is negative, then the airport would exhibit decreasing ray economies of scale. In this case user fees set equal to the marginal rates of substitution between an airport visit and the private good would generate revenues in excess of what is required to fund airport operations, maintenance and capital improvements. Thus, full use financing of the airport would again be possible, and in addition, at least some funds would be available to compensate non-users for the adverse impacts they suffer due to the airport's use. Furthermore, unless the cost associated with the adverse environmental impacts generated by airport use on non-users are internalized in the airport fee structure, there will be a tendency to over build the airport from an overall societal perspective.

Alternatively, if non-user externalities have a net value which is positive, then the airport would exhibit increasing ray economies of scale. In this case setting airport fees equal only to the benefits derived by airport users would not generate adequate revenues to cover all airport operating, maintenance and capital costs. In this case a contribution from non-users would be required, and requiring non-users to make such a contribution would be justified by the economic, social or personal benefits they derive from the airport's existence. Otherwise, the airport would likely be underbuilt and the benefits to society that would result from the existence of the airport would not be maximized.

Thus, because airports often generate externalities, the fees charged users of the airport will often not equal the marginal benefits they derive from airport use. However, externalities experienced by that portion of the population that does not use the airport is not the only source of inefficiency in airport service pricing. The fact that airports are generally designed to accommodate a very high share of peak level demand typically generates a substantial amount of excess capacity. To take advantage of this excess capacity, commercial airports often offer service to more than just commercial carriers. These other users include military aircraft, all freight carriers, air taxi operators and private aircraft.

As stated above, charging airport users fees equal to the benefits they derive from each airport visit, i.e., landing and take-off, adjusting for whether these visits occur during peak or off-peak traffic periods, will generate adequate revenues to cover all airport operating, maintenance and capital costs in the absence of externalities. However, as was shown in the general two user group two-period model presented in Chapter Three, this type of marginal cost pricing will not necessarily result in a fee structure that is economically efficient. Whether marginal cost pricing of airport services represents an optimal pricing system depends on to what extent there exists economies of scope associated with airport use.

To identify what other conditions must hold for fees based on marginal visitation costs to represent an efficient pricing system, one needs to investigate the relationship between the marginal and average incremental costs associated with serving each of the two user groups during both peak and off-peak traffic periods. For fees charged members of each user group to be efficient, they must equal both the marginal cost and the average incremental cost associated with each type of flight activity, i.e., scheduled commercial service or general aviation service, by time period during which the service is provided, i.e., peak period versus off-peak period.

Letting $t^i_j(*)$ denote the optimal fee for trips made during period j by members of group i, the conditions for optimal pricing of the airport runways and passenger terminal are presented in equations (34) through (37). For peak period trips taken on scheduled commercial air carriers, the optimal per trip fee, or toll, condition is,

$$t_p^m(*) = \frac{C_1(F_p^m, F_o^m, F_p^n, F_o^n, X_1) - C_1(0, F_o^m, F_p^n, F_o^n, X_1')}{F_p^m \cdot A} + \frac{C_2(F_p^m, F_o^m, X_2) - C_2(0, F_o^m, X_2')}{F_p^m \cdot A}$$

$$= -(P-M-N) \cdot \frac{\partial U^l / \partial (F_p^m + h \cdot F_p^n)}{\partial U^l / \partial y^l} \cdot \frac{1}{A} - M \cdot \frac{\partial U^m / \partial c_1}{\partial U^m / \partial y^m} \cdot \frac{\partial c_1}{\partial F_p^m} \cdot \frac{1}{A} - M \cdot \frac{\partial U^m / \partial c_2}{\partial U^m / \partial y^m} \cdot \frac{\partial c_2}{\partial F_p^m} \cdot \frac{1}{A} \quad (34)$$

$$- N \cdot \frac{\partial U^n / \partial c_1}{\partial U^n / \partial y^n} \cdot \frac{\partial c_1}{\partial F_p^m} \cdot \frac{1}{A} + \frac{\partial C_1(\cdot)}{\partial F_p^m} \cdot \frac{1}{A} + \frac{\partial C_2(\cdot)}{\partial F_p^m} \cdot \frac{1}{A} + \frac{\mu_1}{\lambda} \cdot \frac{1}{A} + \frac{\mu_2}{\lambda} \cdot \frac{1}{A},$$

where $X_1' \leq X_1$ represents the runway capacity required to serve all airport users except peak period users of scheduled commercial air carrier service and where $X_2' \leq X_2$ represents the terminal capacity required to serve off-peak period users of scheduled commercial air carrier service. For the off-peak period the optimal toll condition is,

$$t_o^m(*) = \frac{C_1(F_p^m, F_o^m, F_p^n, F_o^n, X_1) - C_1(F_p^m, 0, F_p^n, F_o^n, X_1'')}{F_o^m \cdot A}$$

$$+ \frac{C_2(F_p^m, F_o^m, X_2) - C_2(F_p^m, 0, X_2'')}{F_o^m \cdot A}$$

$$= -(P-M-N) \cdot \frac{\partial U^l / \partial(F_o^m + h \cdot F_o^n)}{\partial U^l / \partial y^l} \cdot \frac{1}{A}$$

$$- M \cdot \frac{\partial U^m / \partial c_1}{\partial U^m / \partial y^m} \cdot \frac{\partial c_1}{\partial F_o^m} \cdot \frac{1}{A} - M \cdot \frac{\partial U^m / \partial c_2}{\partial U_m / \partial y_m} \cdot \frac{\partial c_2}{\partial F_o^m} \cdot \frac{1}{A} \quad (35)$$

$$- N \cdot \frac{\partial U^n / \partial c_1}{\partial U^n / \partial y^n} \cdot \frac{\partial c_1}{\partial F_o^m} \cdot \frac{1}{A} + \frac{\partial C_1(\cdot)}{\partial F_o^m} \cdot \frac{1}{A}$$

$$+ \frac{\partial C_2(\cdot)}{\partial F_o^m} \cdot \frac{1}{A} + \frac{\mu_1}{\lambda} \cdot \frac{1}{A} + \frac{\mu_2}{\lambda} \cdot \frac{1}{A},$$

where $X_1'' \leq X_1$ represents the runway capacity required to serve all airport users except off-peak period users of scheduled commercial air carrier service and where $X_2'' \leq X_2$ represents the terminal capacity required to serve peak period users of scheduled commercial air carrier service.

Similarly, for users of general aviation services, the optimal peak period toll condition is,

$$t_p^n(*) = \frac{C_1(F_p^m, F_o^m, F_p^n, F_o^n, X_1) - C_1(F_p^m, F_o^m, 0, F_o^n, X_1''')}{F_p^n \cdot B}$$

$$= -(P-M-N) \cdot \frac{\partial U^l / \partial (F_p^m + h \cdot F_p^n)}{\partial U^l / \partial y^l} \cdot h \cdot \frac{1}{B}$$

$$- M \cdot \frac{\partial U^m / \partial c_1}{\partial U^m / \partial y^m} \cdot \frac{\partial c_1}{\partial F_p^n} \cdot \frac{1}{B} - N \cdot \frac{\partial U^n / \partial c_1}{\partial U^n / \partial y^n} \cdot \frac{\partial c_1}{\partial F_p^n} \cdot \frac{1}{B} \quad (36)$$

$$+ \frac{\partial C_1(.)}{\partial F_p^n} \cdot \frac{1}{B} + \frac{\mu_1}{\lambda} \cdot k \cdot \frac{1}{B},$$

where $X_1''' \leq X_1$ represents the runway capacity required to serve all airport users except peak period users of general aviation services, and for the off-peak period the optimal toll condition is,

$$t_o^n(*) = \frac{C_1(F_p^m, F_o^m, F_p^n, F_o^n, X_1) - C_1(F_p^m, F_o^m, F_p^n, 0, X_1'''')}{F_o^n \cdot B}$$

$$= -(P-M-N) \cdot \frac{\partial U^l / \partial (F_o^m + h \cdot F_o^n)}{\partial U^l / \partial y^l} \cdot h \cdot \frac{1}{B}$$

$$- M \cdot \frac{\partial U^m / \partial c_1}{\partial U^m / \partial y^m} \cdot \frac{\partial c_1}{\partial F_o^n} \cdot \frac{1}{B} - N \cdot \frac{\partial U^n / \partial c_1}{\partial U^n / \partial y^n} \cdot \frac{\partial c_1}{\partial F_o^n} \cdot \frac{1}{B} \quad (37)$$

$$+ \frac{\partial C_1(.)}{\partial F_o^n} \cdot \frac{1}{B} + \frac{\mu_1}{\lambda} \cdot k \cdot \frac{1}{B},$$

where $X_1'''' \leq X_1$ represents the runway capacity required to serve all airport users except off-peak users of general aviation services.

These conditions provide the basis for determining to what extent the existence of economies of scope with respect to runway and airport terminal use will influence the optimal pricing of airport services. First, by summing tolls by user group for each time period, one obtains the aggregate incremental costs associated with each type of use and time period. For users of scheduled commercial air carrier services during the peak traffic period total fees must equal,

$$\begin{aligned} t_p^m(*) \cdot F_p^m \cdot A = {} & C_1(F_p^m, F_o^m, F_p^n, F_o^n, X_1) - C_1(0, F_o^m, F_p^n, F_o^n, X_1') \\ & + C_2(F_p^m, F_o^m, X_2) - C_2(0, F_o^m, X_2') \\ = {} & -(P-M-N) \cdot \frac{\partial U^l / \partial (F_p^m + h \cdot F_p^n)}{\partial U^l / \partial y^l} \cdot F_p^m \qquad (38) \\ & - M \cdot \frac{\partial U^m / \partial c_1}{\partial U^m / \partial y^m} \cdot \frac{\partial c_1}{\partial F_p^m} \cdot F_p^m - M \cdot \frac{\partial U^m / \partial c_2}{\partial U^m / \partial y^m} \cdot \frac{\partial c_2}{\partial F_p^m} \cdot F_p^m \\ & - N \cdot \frac{\partial U^n / \partial c_1}{\partial U^n / \partial y^n} \cdot \frac{\partial c_1}{\partial F_p^m} \cdot F_p^m + \frac{\partial C_1(\cdot)}{\partial F_p^m} \cdot F_p^m \\ & + \frac{\partial C_2(\cdot)}{\partial F_p^m} \cdot F_p^m + \frac{\mu_1}{\lambda} \cdot F_p^m + \frac{\mu_2}{\lambda} \cdot F_p^m, \end{aligned}$$

and for the off-peak period the aggregate optimal toll condition equals,

$$t_o^m(*)\cdot F_o^m\cdot A = C_1(F_p^m, F_o^m, F_p^n, F_o^n, X_1) - C_1(F_p^m, 0, F_p^n, F_o^n, X_1^{//})$$

$$+ C_2(F_p^m, F_o^m, X_2) - C_2(F_p^m, 0, X_2^{//})$$

$$= -(P-M-N)\cdot \frac{\partial U^l/\partial(F_o^m + h\cdot F_o^n)}{\partial U^l/\partial y^l}\cdot F_o^m$$

$$- M\cdot \frac{\partial U^m/\partial c_1}{\partial U^m/\partial y^m}\cdot \frac{\partial c_1}{\partial F_o^m}\cdot F_o^m - M\cdot \frac{\partial U^m/\partial c_2}{\partial U^m/\partial y^m}\cdot \frac{\partial c_2}{\partial F_o^m}\cdot F_o^m \qquad (39)$$

$$- N\cdot \frac{\partial U^n/\partial c_1}{\partial U^n/\partial y^n}\cdot \frac{\partial c_1}{\partial F_o^m}\cdot F_o^m + \frac{\partial C_1(.)}{\partial F_o^m}\cdot F_o^m$$

$$+ \frac{\partial C_2(.)}{\partial F_o^m}\cdot F_o^m + \frac{\mu_1}{\lambda}\cdot F_o^m + \frac{\mu_2}{\lambda}\cdot F_o^m.$$

Similarly, the peak period aggregate optimal toll condition for users of general aviation services equals,

$$t_p^n(*)\cdot F_p^n\cdot B = C_1(F_p^m, F_o^m, F_p^n, F_o^n, X_1) - C_1(F_p^m, F_o^m, 0, F_o^n, X_1^{///})$$

$$= -(P-M-N)\cdot \frac{\partial U^l/\partial(F_p^m + h\cdot F_p^n)}{\partial U^l/\partial y^l}\cdot h\cdot F_p^n$$

$$- M\cdot \frac{\partial U^m/\partial c_1}{\partial U^m/\partial y^m}\cdot \frac{\partial c_1}{\partial F_p^n}\cdot F_p^n - N\cdot \frac{\partial U^n/\partial c_1}{\partial U^n/\partial y^n}\cdot \frac{\partial c_1}{\partial F_p^n}\cdot F_p^n \qquad (40)$$

$$+ \frac{\partial C_1(.)}{\partial F_p^n}\cdot F_p^n + \frac{\mu_1}{\lambda}\cdot k\cdot F_p^n,$$

and for the off-peak period aggregate tolls must equal,

$$t_o^n(*) \cdot F_o^n \cdot B = C_1(F_p^m, F_o^m, F_p^n, F_o^n, X_1) - C_1(F_p^m, F_o^m, F_p^n, 0, X_1^{''''}) \tag{41}$$

$$= -(P-M-N) \cdot \frac{\partial U^l / \partial (F_o^m + h \cdot F_o^n)}{\partial U^l / \partial y^l} \cdot h \cdot F_o^n$$

$$- M \cdot \frac{\partial U^m / \partial c_1}{\partial U^m / \partial y^m} \cdot \frac{\partial c_1}{\partial F_o^n} \cdot F_o^n - N \cdot \frac{\partial U^n / \partial c_1}{\partial U^n / \partial y^n} \cdot \frac{\partial c_1}{\partial F_o^n} \cdot F_o^n$$

$$+ \frac{\partial C_1(\cdot)}{\partial F_o^n} \cdot F_o^n + \frac{\mu_1}{\lambda} \cdot k \cdot F_o^n.$$

Now, by summing tolls over the two time periods for each group of users, optimality conditions are obtained for the amount of fees each of the two user groups should be expected to pay toward the provision and operation of the airport's infrastructure, i.e., runways and passenger terminal.

Focusing on the incremental cost portions of equations (38) and (39), the total fees users of scheduled commercial air carrier services should be required to pay equals,

$$t_p^m \cdot F_p^m \cdot A + t_o^m \cdot F_o^m \cdot A =$$

$$[C_1(F_p^m, F_o^m, F_p^n, F_o^n, X_1) - C_1(0, F_o^m, F_p^n, F_o^n, X_1')$$

$$+ C_2(F_p^m, F_o^m, X_2) - C_2(0, F_o^m, X_2')] \tag{42}$$

$$+ [C_1(F_p^m, F_o^m, F_p^n, F_o^n, X_1) - C_1(F_p^m, 0, F_p^n, F_o^n, X_1'')$$

$$+ C_2(F_p^m, F_o^m, X_2) - C_2(F_p^m, 0, X_2'')].$$

Similarly, the sum of the incremental cost portions of equations (40) and (41),

$$t_p^n \cdot F_p^n \cdot B + t_o^n \cdot F_o^n \cdot B =$$

$$[C_1(F_p^m, F_o^m, F_p^n, F_o^n, X_1) - C_1(F_p^m, F_o^m, 0, F_o^n, X_1^{\prime\prime\prime}) \qquad (43)$$

$$+ [C_1(F_p^m, F_o^m, F_p^n, F_o^n, X_1) - C_1(F_p^m, F_o^m, F_p^n, 0, X_1^{\prime\prime\prime\prime}),$$

yields the total fees users of general aviation services should be required to pay.

Equations (42) and (43) provide the basis for evaluating the relationship between the degree of scope economies exhibited in the use of the airport runways and passenger terminal and whether user fees set equal to the marginal cost arising from use of these facilities will provide an efficient and adequate means of financing for the airport. Focusing first on equation (42), one can determine under what conditions economies and diseconomies of scope would result from the shared use of the passenger terminal over the peak and off-peak traffic periods. As stated previously, the airport terminal cost function is assumed to be monotonically increasing with respect to each of its arguments. Therefore, if the sum of the incremental costs associated with use of the terminal during the two time periods is less than the joint cost associated with the provision and use of the terminal, i.e.,

$$
\begin{aligned}
& [C_2(F_p^m, F_o^m, X_2) - C_2(0, F_o^m, X_2')] \\
& + [C_2(F_p^m, F_o^m, X_2) - C_2(F_p^m, 0, X_2'')] \qquad (44) \\
& < C_2(F_p^m, F_o^m, X_2),
\end{aligned}
$$

then the airport terminal exhibits inter-period economies of scope. This condition holds because the subadditivity of the period specific incremental costs relative to the overall two-period terminal joint cost results in the joint cost being less than the sum of the costs required to provide peak period and off-peak period terminal space on a stand alone basis, i.e.,

$$
C_2(F_p^m, F_o^m, X_2) < C_2(F_p^m, 0, X_2'') + C_2(0, F_o^m, X_2'), \qquad (45)
$$

which is the condition for economies of scope. On the other hand, if the peak period and off-peak period incremental terminal costs are superadditive relative to the two-period joint terminal costs, then the airport terminal exhibits inter-period diseconomies of scope.

What determines whether the period specific incremental costs are subadditive or superadditive with respect to the two-period joint costs is the relationship between the sum of the stand alone terminal space requirements for the two periods, i.e., $X_2'+X_2''$, and the overall joint two-period terminal space requirement, i.e., X_2. If the sum of the two period specific space requirements is greater than the joint two-period space requirement, then the incremental costs are subadditive because this means at least some of the same terminal space must be used during the two time periods. Alternatively, if $X_2' + X_2'' < X_2$, then the incremental time period specific costs are superadditive relative to the joint two-period terminal cost, which means use of the terminal over the two periods requires more space than if separate terminals were used to provide service for each period on an exclusive basis. The first of these situations is more likely to occur at most airports. However, the superadditivity case could arise at extremely busy airports if peak period traffic so congests the terminal that there is a spillover effect on travelers trying to use the terminal during the off-peak traffic period.

The airport financing implications of the existence of economies or diseconomies of scope relative to passenger terminal use are twofold. First, in the more common situation, when economies of scope exist, the subadditivity of the period specific incremental costs implies user fees set equal to marginal costs will be inadequate to fully fund provision and operation of the terminal. Alternatively, the existence of inter-period terminal diseconomies of scope implies that marginal cost pricing would provide more than adequate funds to cover passenger terminal provision and operating costs. Second, expressed in the context of club theory, airports that have terminals which exhibit inter-period economies of scope have a financial incentive to increase the use of their passenger terminals, or the membership of their user groups, particularly during the off-peak period. While, airports with terminals exhibiting diseconomies of scope have a financial inventive to reduce use of the passenger terminal, particularly during the peak traffic period.

The determination of what conditions give rise to economies or diseconomies of scope relative to runway use is somewhat more complicated than for the passenger terminal. The added complexity arises from the use of the airport's runways by two types of aircraft, which correspond to the different user groups, as well as use of the airport over two time periods. As a result, both within period and between period scope economies must be investigated.

First, the within period analysis focuses on under what conditions the simultaneous sharing of the airport's runways by two different user groups results in economies of scope or diseconomies of scope. This analysis can be conducted for either the peak traffic period or for the off-peak traffic period. But since it is generally assumed excess runway capacity exists during the off-peak traffic period, and since the existence of the possibility of runway congestion is required to illustrate the full range of scope economy issues, the analysis is only presented for the peak traffic period.

As with the analysis for the airport passenger terminal, the investigation of what conditions give rise to runway economies of scope or diseconomies of scope begins with consideration of the relationship between the incremental costs associated with each user group's peak period runway use and the overall joint cost associated with the simultaneous use of the runways by both groups.

Holding off-peak period traffic constant, the degree of runway scope economies depends on the relationship between the sum of stand alone runway capacity requirements for the two user groups and runway capacity requirements under joint operation. If the sum of stand alone runway capacity requirements, $X_1'' + X_1''''$, is greater than the joint operation runway capacity requirements, then the sum of group specific peak traffic period incremental costs is less than the joint cost associated with providing peak period service to both user groups simultaneously, i.e.,

$$\begin{aligned} &[C_1(F_p^m, F_o^m, F_p^n, F_o^n, X_1) - C_1(0, F_o^m, F_p^n, F_o^n, X_1')] \\ &+ [C_1(F_p^m, F_o^m, F_p^n, F_o^n, X_1) - C_1(F_p^m, F_o^m, 0, F_o^n, X_1''')] \qquad (46) \\ &< C_1(F_p^m, F_o^m, F_p^n, F_o^n, X_1). \end{aligned}$$

This implies the different types of aircraft used by the two user groups share at least some portion of the airport's peak period runway capacity. This sharing of runway capacity in turn results in the airport exhibiting peak traffic period economies of scope with respect to runway use, i.e.,

$$C_1(F_p^m, F_o^m, F_p^n, F_o^n, X_1) < C_1(F_p^m, F_o^m, 0, F_o^n, X_1^{'''}) + C_1(0, F_o^m, F_p^n, F_o^n, X_1^{'}), \quad (47)$$

because the joint cost associated with the sharing of runway capacity is less than the sum of the costs that would be incurred if the airport operated separate runways to serve peak period scheduled commercial air carrier and general aviation traffic. Since at most airports commercial carrier aircraft and general aviation aircraft use the same runways during both peak and off-peak traffic periods, this implies the existence of economies of scope with respect to runway use is the prevailing condition for most United States commercial airports. This further implies that landing fees set equal to the marginal costs associated with runway use do not provide adequate funds to fully finance the provision and operation of airport runways and other airside facilities. In fact, as presented in the second part of this chapter, the financing of airport airside facilities is often subsidized from other airport revenues, the federal government, and local special district assessments or general taxes. Thus, airport management generally has an incentive to accommodate users of general aviation services as well as users of scheduled commercial air carriers during both peak and off-peak traffic periods.

However, at a few of the nation's busiest airports, commercial carrier operations are so great during peak traffic periods that accommodation of general aviation activity during these time periods requires runway capacity that exceeds the runway capacity that would be required if the two types of aircraft traffic were segregated on their own separate runways. This situation occurs because greater spacing of aircraft during take-offs and landings is required for a traffic stream consisting of a mix of large and small aircraft than if all aircraft in the traffic stream are of the same size. Also, allowing general aviation aircraft to use runways constructed to accommodate larger commercial carrier aircraft results in the inefficient use of these runways during peak traffic periods. Consequently, in this situation diseconomies of scope arise with respect to runway use. But also in this situation landing fees set equal to marginal costs provide more than adequate funds to finance the expansion of runway capacity.

This analysis of conditions that result in economies of scope or diseconomies of scope relative to runway use by the two user groups during a single time period suggests diseconomies of scope may exist during the peak traffic period while economies of scope exist during the off-peak period. If this situation occurs, then logically airport management has an incentive to attempt to divert some of the peak period demand for runway capacity to the off-peak period. However, to determine whether such traffic shifting is feasible, it is first necessary to identify what conditions must hold for runway use over the two time periods to exhibit economies of scope relative to use by the two user groups.

This analysis first requires a comparison of the sum of runway capacities needed to provide scheduled commercial air carrier service, X_1^m, and general aviation service, X_1^n, each on a stand alone basis with the runway capacity required to provide these services jointly, disregarding the distinction between time periods. Again in this case one finds that if the sum of the stand alone runway capacities is more than the runway capacity required to provide the service jointly, i.e., $X_1^m + X_1^n > X_1$, then the necessary and sufficient conditions for the airport to exhibit economies of scope with respect to runway use by the two user groups are established. To prove this one notes first that the superadditivity of the stand alone runway capacities implies the different types of aircraft used to provide service to the two user groups share at least some runway capacity under joint operation. This in turn implies the subadditivity of user group incremental costs relative to the cost associated with providing both types of service jointly, i.e.,

$$
\begin{aligned}
&[C_1(F_p^m, F_o^m, F_p^n, F_o^n, X_1) - C_1(0, 0, F_p^n, F_o^n, X_1^n)] \\
&+ [C_1(F_p^m, F_o^m, F_p^n, F_o^n, X_1) - C_1(F_p^m, F_o^m, 0, 0, X_1^m)] \qquad (48) \\
&< C_1(F_p^m, F_o^m, F_p^n, F_o^n, X_1).
\end{aligned}
$$

As a result, the existence of between group economies of scope is established, i.e.,

$$
C_1(F_p^m, F^{o^m}, F_p^n, F_o^n, X_1) < C_1(F_p^m, F_o^m, 0, 0, X_1^m) + C_1(0, 0, F_p^n, F_o^n, X_1^n). \qquad (49)
$$

However, in addition, if for each user group separately economies of scope exist with respect to runway use over the two time periods, then the airport exhibits overall economies of scope with respect to runway use, i.e.,

$$
\begin{aligned}
C_1(F_p^m, F_o^m, F_p^n, F_o^n, X_1) &< C_1(F_p^m, 0, 0, 0, X_1^{mp}) + C_1(0, F_o^m, 0, 0, X_1^{mo}) \\
&\quad + C_1(0, 0, F_p^n, 0, X_1^{np}) + C_1(0, 0, 0, F_o^n, X_1^{no}), \qquad (50)
\end{aligned}
$$

where X_1^{mp}, X_1^{mo}, X_1^{np} and X_1^{no} represent the stand alone runway capacities required to serve peak period scheduled commercial air traffic, off-peak period scheduled commercial air traffic, peak period general aviation traffic and off-peak period general aviation traffic, respectively. The necessary and sufficient conditions required for overall economies of scope to exist are that the sums of between time period stand alone runway capacity requirements be greater than the joint runway capacity requirements for each user group separately, i.e., for scheduled commercial air carrier service $X_1^{mp} + X_1^{mo} > X_1^{m}$ and for general aviation service $X_1^{np} + X_1^{no} > X_1^{n}$. Thus, for overall economies of scope relative to runway use to exist there must be at least some sharing of runway capacity within each period by commercial carrier aircraft and general aviation aircraft and some sharing of runway capacity between periods by each type of aircraft.

However, under these conditions, setting landing fees or other airside facility users fees equal to the marginal costs which arise from each type of runway use over the two time periods will yield inadequate revenues to finance the provision and operation of the required runway capacity. On the other hand, when diseconomies of scope exist during the peak traffic period relative to the shared use of the airport's runways by scheduled commercial air carriers and general aviation aircraft, and economies of scope exist both during the off-peak traffic period and between periods for at least one of the types of airport users, then marginal cost pricing of runway use may provide the means for shifting traffic from the peak period to the off-peak period. Such a shift of runway service demand would result in the more efficient use of airport facilities and reduce or delay the need for future runway expansion.

Policy Implications

This theoretical analysis of the conditions which must exist for full user financing of airport airside services to be feasible, suggests marginal cost pricing has the potential for improving the efficiency with which airport infrastructure is used. However, the benefits of marginal cost pricing will vary among airports depending on traffic volume, traffic mix and the available capacity of runways and passenger terminals. Thus, the degree to which the efficiency with which airport infrastructure may be improved through marginal cost pricing is an empirical issue which depends on each airport's cost structure. An analysis of this type is presented in the next chapter.

CHAPTER 5: EMPIRICAL ANALYSIS

Empirical Research Issues and Approach

The model presented in Chapter 4 provides the theoretical framework for addressing a variety of policy issues related to the pricing of and investment in airport infrastructure. Principal among these issues is the level of fees, or tolls, required for runway and passenger terminal facility use and investment to be optimized. A related pricing issue addressed by the airport model is to what extent should side payments be made to or be received from individuals who do not themselves use the airport facilities to insure that infrastructure investment is optimized. The answers to these questions were shown in the previous chapter to depend on the cost characteristics of the airport facilities being analyzed. For example, in the absence of non-user externalities or if the net impact of non-user externalities approaches zero, the model implies full user financing of the airport through fees set equal to marginal cost requires cost functions that exhibit constant economies of scale and the absence of scope economies. On the other hand, the existence of externalities that result in a net negative impact on individuals who do not use the airport requires an airport cost structure characterized by decreasing economies of scale and diseconomies of scope in order for user fees set equal to marginal cost to internalize all costs arising from airport use.

Consequently, the following empirical analysis focuses on the nature of airport costs. Specifically, the empirical research presented in this chapter attempts to identify under what conditions airports are characterized by increasing or decreasing economies of scale and by the existence of economies or diseconomies of scope.

Statement of Hypotheses

Observation of the pattern of airport use in the United States suggests that whether individual airports are characterized by increasing, constant or decreasing economies of scale depends on the size of the airport and the volume of flights served by the airport. Alternatively, scope economies appear to depend on the degree to which airport facilities are shared by different types of users and the degree to which airport use is distributed over different time periods. These observations suggest the following testable hypotheses.

First, regarding the issue of economies of scale, it is hypothesized that most of the nation's commercial airports operate within the range where their cost functions are characterized by constant economies of scale. However, there are a small number of airports that are so large as to exhibit decreasing economies of scale. Alternatively, the nation's smallest commercial airports, as well as most of its general aviation airports, exhibit increasing economies of scale.

Second, regarding the issue of scope economies, it is hypothesized that most of the nation's commercial airports, as well as almost all of its general aviation airports, exhibit economies of scope. However, the nation's busiest commercial airports exhibit cost structures characterized by diseconomies of scope.

The rationale behind the first hypothesis is that once an airport has two runways the addition of more runways only results in a proportional increase in the amount of traffic the airport can serve. Also, once airports get beyond a certain size, airspace rather than airport infrastructure becomes the critical factor which limits airport traffic. Small airports, on the other hand, exhibit increasing economies of scale due to the large minimum investment required to initiate operation. Also, since a large share of operating and maintenance cost for small airports is environmental or time related, the average cost of airport use decreases as the volume of flight activity increases.

For the hypothesis regarding airport economies of scope, the demand for air transportation service tends to be temporally peaked rather than uniformly spread throughout the day. Also, most airports are designed to serve fortieth highest hour traffic demands (Walters, 1978). Therefore, for much of each day a substantial amount of excess capacity is available.

Consequently, the attraction of general aviation, military and all freight carrier activity to off-peak periods is generally desired by the management of most commercial airports. However, a few of the nation's large hub airports have become so busy serving commercial passenger carriers they have very high levels of traffic during much of the day. Also, many large hub airports are surrounded by other land uses which limit the space available for expansion and this often results in limitations on daily hours of operation due to noise impact considerations. As a result, in these cases operations of other than scheduled commercial passenger carriers are discouraged.

Empirical Research Approach

Empirical testing for the existence of economies of scale and economies of scope in airport operations has been conducted by analyzing the relationship between airport costs and measures of flight activity and airport size, or capacity, for a sample of FAA tower controlled airports. The model used for this analysis is an adaptation of the quadratic form cost function recommended by Baumol, Panzar and Willig (1988),

$$C = \beta_0 + \Sigma_i \beta_i F_i + \Sigma_i \Sigma_j \beta_{ij} F_i F_j + \Sigma_k \beta_k X_k + \Sigma_i \Sigma_k \beta_{ik} F_i X_k + \Sigma_k \Sigma_l \beta_{kl} X_k X_l,$$

where C denotes total annual airport operating cost including depreciation, F_i denotes the annual number of operations for different types of flight activity (i.e., commercial carrier, air taxi, general aviation and military), and X_k denotes the size, or capacity, of airport runways and passenger terminals measured in terms of VFR (visual flight rule) capacity and number of passenger loading gates, respectively.

According to Baumol, Panzar and Willig this functional form possesses three desirable qualities which support its use in the empirical analysis of the cost structure for multi-product industries. First, it does not prejudge the presence or absence of scale or scope economies. Second, it accommodates data observations in which one or more of the possible firm outputs take a value of zero, which is not the case for the more commonly used standard translog cost function. Third, this functional form possesses "substantive flexibility", which means it is consistent with both economies and diseconomies of scope, with both cost subadditivity and superadditivity, and it does not prejudge the shapes of ray average cost curves, the shapes of average incremental cost curves or the properties of the trans-ray cross sections (Baumol, Panzar and Willig, 1988: 448- 450, 453-454).

Baumol, Panzar and Willig indicate this form of cost function may be subject to criticism because it does not explicitly incorporate variables for input prices. However, they argue that input prices can be assumed to be implicitly taken into consideration by the model's parameters. In fact, the omission of input price variables in the quadratic form cost function makes it particularly attractive for the analysis of airport costs because of the difficulty associated with obtaining meaningful measures for these prices. Given the complexity of airport operations, the variety of financial resources used to fund airport capital improvements, and the practice of contracting out and franchising many airport services, imputing valid input prices for the cost of labor, capital and utilities is not feasible.

The regression results are used to test for the degree of ray economies of scale and the existence of economies of scope by using mean independent variable values for the airport data to estimate the following measures of scale and scope economies presented in Bailey and Friedlaender (1982: 1031). The measure used to assess the degree of ray economies of scale is,

$$S_l = \frac{C(Y_1, Y_2, \ldots, Y_i)}{Y_1 \cdot \frac{\partial C}{\partial Y_1} + Y_2 \cdot \frac{\partial C}{\partial Y_2} + \ldots + Y_i \cdot \frac{\partial C}{\partial Y_i}},$$

where values greater than one indicate increasing ray economies of scale, a value equal to 1 represents constant ray economies of scale, and values less than one represent decreasing ray economies of scale. The measure used to determine the degree of economies of scope is,

$$SC = \frac{C(Y_1,0,\ldots,0) + C(0,Y_2,0,\ldots,0) + \ldots + C(0,\ldots,0,Y_i)}{C(Y_1,Y_2,\ldots,Y_i)},$$

where values greater than one indicate the existence of economies of scope and values less than one represent the existence of diseconomies of scope.

Data and Data Sources

Since most airports are publicly owned and since many raise funds required for capital investment through the nation's bond markets, financial information for the nation's airports is generally available to the public. However, this type of information is not available through a single source. Therefore, letters were sent to the 100 busiest airports as identified using 1989 aircraft operation statistics published by the Federal Aviation Administration. Each letter requested financial statements, i.e, balance sheets, income statements, statements of change in financial position and accompanying notes, for the years 1989 through 1992. Also requested was information on the number and dimensions of airport runways, number of terminal gates, and VFR (visual flight rule) and IFR (instrument flight rule) saturation capacities.

Fifty-five airports provided either some or all of the requested information. Table 5.1 lists these airports along with their 3-character identification codes, state locations

Table 5.1: Sample of United States Airports

Airport Name	State	Air-port ID	Hub Class[1]	Type of Opera-tion[2]	Fiscal Year Ending Date	Sam-ple[3]
Albuquerque International	NM	ABQ	Medium	C/GA	Jun 30	3
Baltimore/Washington Intl	MD	BWI	Medium	C/GA	Sep 30	0
Boise Air Terminal	ID	BOI	Small	C/GA	Sep 30	3
Charleston International	SC	CHS	Small	C/GA	Jun 30	3
Greater Cincinnati Intl	KY	CVG	Medium	C/GA	Dec 31	3
Cleveland Hopkins Intl	OH	CLE	Large	C/GA	Dec 31	3
Columbus International	OH	CMH	Medium	C/GA	Dec 31	2
Dallas Love Field	TX	DAL	Large	C/GA	Sep 30	3
Dallas/Ft. Worth Intl	TX	DFW	Large	C/GA	Sep 30	0
Denver Stapleton Intl	CO	DEN	Large	C/GA	Dec 31	3
Denver Centennial	CO	APA	Large	GA	Dec 31	2
Des Moines International	IA	DSM	Small	C/GA	Jun 30	0
Detroit Metro/Wayne Co	MI	DTW	Large	C/GA	Nov 30	3
Fort Lauderdale Intl	FL	FLL	Large	C/GA	Sep 30	1
Grand Fork International	ND	GFK	Nonhub	C/GA	Dec 31	3
Grand Rapids	MI	GRR	Small	C/GA	Sep 30	2
Hilo International	HI	ITO	Medium	C/GA	Jun 30	0
Honolulu International	HI	HNL	Large	C/GA	Jun 30	0
Houston Intercontinental	TX	IAH	Large	C/GA	Jun 30	3
Indianapolis International	IN	IND	Medium	C/GA	Dec 31	2
John F. Kennedy Intl	NY	JFK	Large	C/GA	Dec 31	3
Kansas City International	MO	MCI	Large	C/GA	Apr 30	3
La Guardia	NY	LGA	Large	C/GA	Dec 31	3
Las Vegas McCarran Intl	NV	LAS	Large	C/GA	Jun 30	3
Little Rock Regional	AR	LIT	Small	C/GA	Dec 31	1
Los Angeles International	CA	LAX	Large	C/GA	Jun 30	3
Louisville Regional	KY	SDF	Medium	C/GA	Jun 30	3
Memphis-Shelby Co Airport	TN	MEM	Medium	C/GA	Jun 30	3
Miami International	FL	MIA	Large	C/GA	Sep 30	0
Milwaukee Mitchell Intl	WI	MKE	Medium	C/GA	Dec 31	3
Minneapolis/St. Paul Intl	MN	MSP	Large	C/GA	Dec 31	0
Nashville International	TN	BNA	Medium	C/GA	Jun 30	2
Newark International	NJ	EWR	Large	C/GA	Dec 31	3
Norfolk International	VA	ORF	Medium	C/GA	Jun 30	3
Oklahoma City Will Rogers	OK	OKC	Medium	C/GA	Jun 30	3
Omaha Eppley Field	NE	OMA	Medium	C/GA	Dec 31	3
Ontario International	CA	ONT	Small	C/GA	Jun 30	3
Orlando International	FL	MCO	Large	C/GA	Sep 30	2
Philadelphia International	PA	PHL	Large	C/GA	Jun 30	3
Phoenix/Sky Harbor Intl	AZ	PHX	Large	C/GA	Jun 30	2

Table 5.1: (continued)

Airport Name	State	Air-port ID	Hub Class	Type of Opera-tion	Fiscal Year Ending Date	Sam-ple
Portland International	OR	PDX	Medium	C/GA	Jun 30	2
Raleigh-Durham Airport	NC	RDU	Medium	C/GA	Mar 31	3
Reno Cannon International	NV	RNO	Medium	C/GA	Jun 30	3
Richmond Byrd Intl	VA	RIC	Small	C/GA	Jun 30	0
Salt Lake City Intl	UT	SLC	Medium	C/GA	Jun 30	3
San Francisco Intl	CA	SFO	Large	C/GA	Jun 30	3
San Jose International	CA	SJC	Small	C/GA	Jun 30	2
Sarasota Bradenton Airport	FL	SRQ	Small	C/GA	Sep 30	3
St. Louis/Lambert Intl	MO	STL	Large	C/GA	Jun 30	3
Tampa International	FL	TPA	Large	C/GA	Sep 30	0
Tulsa International	OK	TUL	Medium	C/GA	Jun 30	3
Washington Dulles Intl	VA	IAD	Large	C/GA	Sep 30	1
Washington National	DC	DCA	Large	C/GA	Sep 30	2
Wichita Mid Continent	KS	ICT	Small	C/GA	Jun 30	3
Santa Ana/Orange County	CA	SNA	Large	C/GA	Jun 30	1

Notes:

1. The Federal Aviation Administration designates hub classifications for airports based on the percentage of the total enplaned revenue passengers of U.S. certificated route carriers served by an air traffic control (ATC) area, which may include one or more airports. Under this classification system large hubs serve 1.000 percent or more of annual enplanements, medium hubs serve 0.250 to 0.999 percent, small hubs serve 0.050 to 0.249 percent, and nonhubs serve under 0.050 percent of annual enplanements.

2. For the purposes of this analysis airport operations have been divided into two groups, commercial carrier (C) or general aviation (GA), which consists of all other types of air traffic including air taxi, private and military.

3. Of the 55 airports that responded to the request for information, nine did not provide adequate information to be included in any of the statistical analysis (sample code 0), four provided neither VFR capacity nor gate information (sample code 1), and ten did not provide VFR capacity information (sample code 2). However, 33 airports (sample code 3) provided adequate financial and airport infrastructure information to be included in all statistical analyses.

hub area classifications, whether they serve commercial traffic, general aviation traffic or both, fiscal year ending dates, and the types of data provided. A complete listing of the financial data for these airports is provided in Appendix B. Information regarding each responding airport's number of runways, length of longest runway, VFR capacity, IFR capacity, and number of terminal gates is provided in Appendix C.

Information on airport use is available from the Federal Aviation Administration (FAA) on a federal fiscal year basis for tower controlled airports. This airport use information, which is classified by six types of aircraft operations (i.e., commercial carrier, air taxi, itinerant general aviation, local general aviation, itinerant military and local military), was obtained from issues of the FAA Air Traffic Activity report for fiscal years 1989 through 1992. The flight operation data for the 55 airports included in this analysis is provided in Appendix D.

To facilitate and simplify the analysis the financial and aircraft operations data had to be modified in two ways. First, as indicated in Table 5.1, airport fiscal years end on a variety of different dates while aircraft operation data were only available on a consistent basis for federal fiscal years which run from October 1 through September 30. Therefore, the airport financial data were converted to a federal fiscal year basis. This was accomplished by apportioning airport financial statistics between the federal fiscal years to which they correspond. For example, for an airport with a fiscal year ending date of June 30, three quarters of that year's financial amounts were assigned to the current federal fiscal year with the remaining quarter of financial data taken from the next airport fiscal year. One consequence of this transformation of airport financial data was a reduction in the number of years of observations available for making model estimates. Second, airport operation statistics of similar type flight activity were grouped to reduce the number of independent variables, reduce the problem with data collinearity and better replicate the structure of the theoretical model presented in Chapter Four. Specifically, commercial carrier and air taxi flight activity were combined into one group, referred to as commercial traffic, and general aviation and military flight activity were combined into a second group, referred to as non-commercial traffic. Flight activity was grouped in this manner because both commercial carrier and air taxi flight activity are positively correlated with the total annual airport operating expenses, while general aviation and military flight activity are negatively correlated with total annual airport operating expenses. These relationships are illustrated in Figures 5.1 and 5.2.

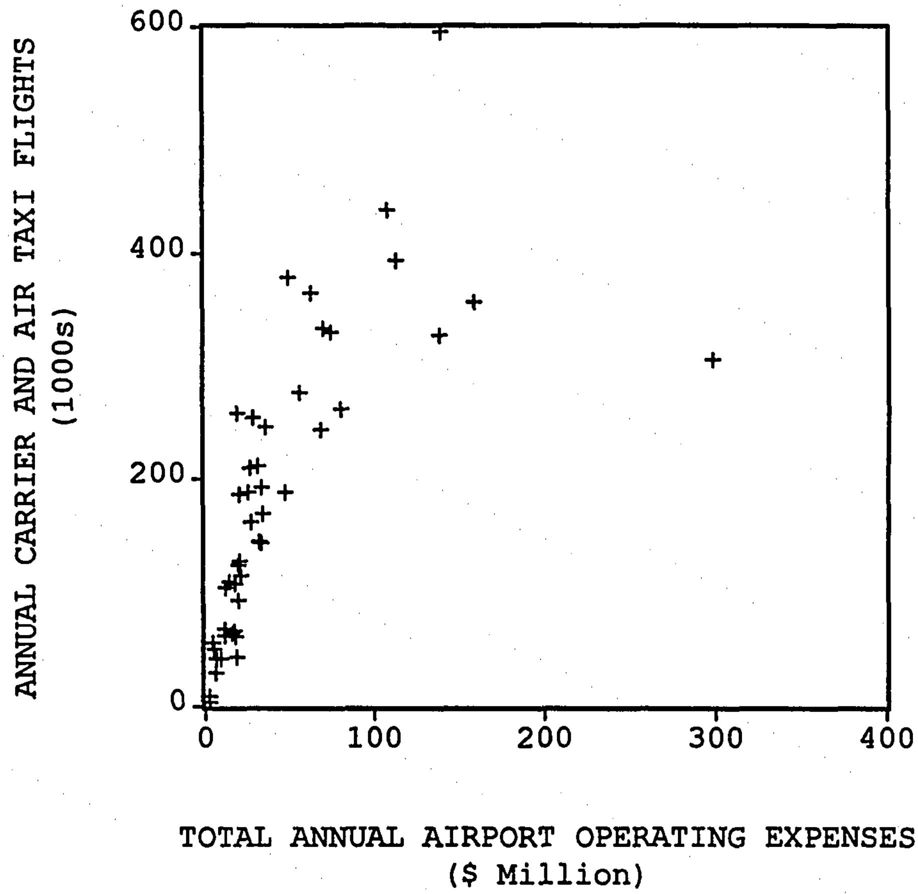

Figure 5.1: Annual Commercial Aircraft Operations vs Annual Airport Operating Expenses

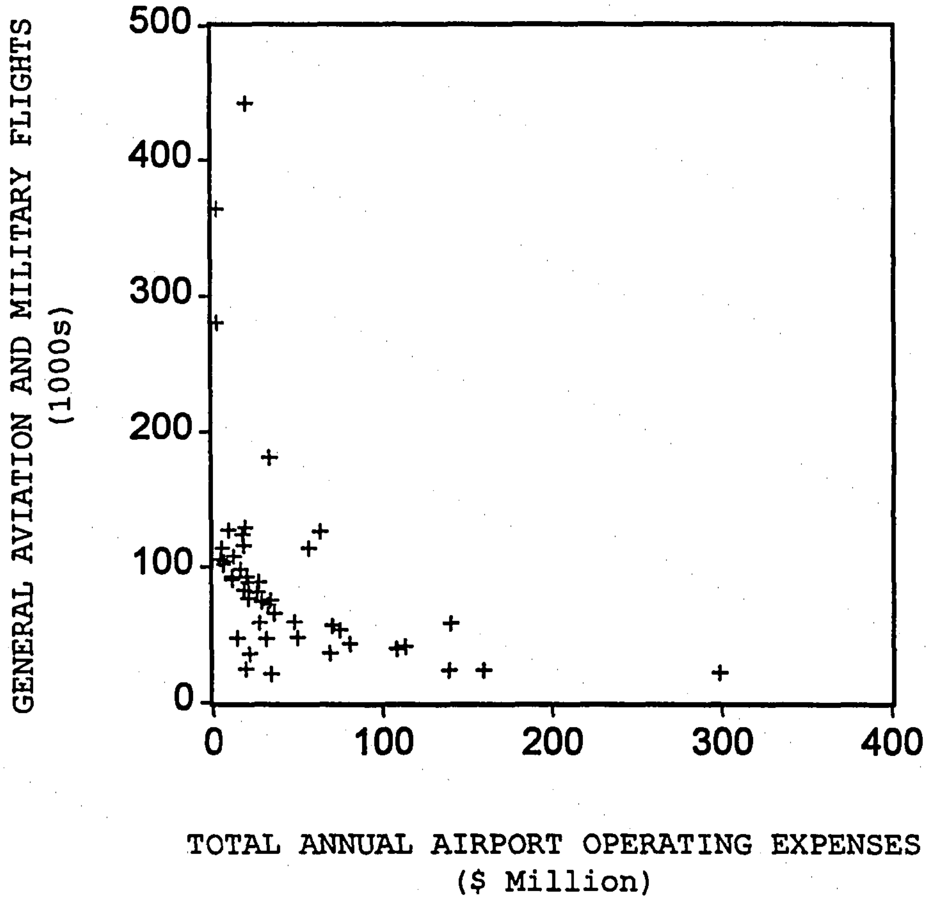

Figure 5.2: Annual Non-commercial Aircraft Operations vs Annual Airport Operating Expenses

Model Estimation

Three sets of models using three years of data for each of 45 airports were estimated. The three sets of models reflect the inclusion of different explanatory variables. The first model (MODEL 1) includes only flight activity explanatory variables. The second model (MODEL 2) includes flight activity plus a measure of airport terminal capacity as explanatory variables. And the third model (MODEL 3) includes flight activity plus measures for both airport terminal and runway capacity as explanatory variables. The dependent variable for all three models is total airport operating expenses including depreciation. A list of variables for all of the models is presented in Table 5.2.

For each of the models separate regressions were carried out on data for federal fiscal years 1989, 1990 and 1991, as well as for mean values of the data for the three years. Each year of observations includes aircraft operation and financial statistics for 46 airports. This number is less than the 55 airports from which information was received due either to the providing of less that three years of usable financial data or because information on depreciation expenses was missing. Furthermore, due to missing terminal gate and VFR capacity information, the number of airports providing usable observations for MODEL 2 and MODEL 3 estimates was reduced to 42 and 32, respectively.

Table 5.2: List of Regression Variables

DEPENDENT VARIABLE:		
TOTOPEXP	=	Total operating expenses, operating expenses including depreciation
INDEPENDENT VARIABLES:		
COMM	=	Annual commercial carrier and air taxi flight operations
NONCOMM	=	Annual general aviation and military flight operations
VFRCAP	=	Hourly airport take-off and landing capacity when operating under visual flight rules (VFR)
GATES	=	Number of airport passenger terminal loading gates
COMMSQ	=	Number of commercial flights squared
NONCOMSQ	=	Number of non-commercial flights squared
VFRCAPSQ	=	Hourly VFR runway capacity squared
GATESSQ	=	Number of terminal gates squared
COMM_NON	=	Product of the number of annual commercial and non-commercial flights
COMM_VFR	=	Product of the number of annual commercial flights and hourly VFR runway capacity
COMM_GAT	=	Product of the number of annual commercial flights and number of passenger terminal gates
NON_VFR	=	Product of the number of annual non-commercial flights and hourly VFR runway capacity
NON_GAT	=	Product of the number of annual non-commercial flights and number of passenger terminal gates
VFR_GAT	=	Product of hourly VFR runway capacity and the number of passenger terminal gates

Since the data exhibits increased variance as the amount of total operating expense increases each model was estimated using a weighted least squares procedure to correct for heteroscedasticity. The number of annual commercial flights was used as the weight in each case. Also, since the data observations used in the analysis consist of both cross-sectional and time series data, initial model regressions were estimated using a pooled error-components generalized least squares (GLS) procedure. However, due to the fact that runway capacities and the number of passenger terminal gates remained stable over the study period for most of the airports included in the sample, use of this technique was not possible for MODEL 2 or MODEL 3 because the second stage of the procedure resulted in the matrices of explanatory variables being singular or nearly singular.

Regression Results

In MODEL 1, total annual airport operating expense (TOTOPEXP) was regressed on the number of commercial flights (COMM), the number of non-commercial flights (NONCOMM), the number of commercial flights squared (COMMSQ), the number of non-commercial flights squared (NONCOMSQ) and the product of the numbers of commercial and non-commercial flights (COMM_ NON). The results of these regressions are summarized in Table 5.3.

Table 5.3: Regression of Total Operating Expenditures on Commercial and Non-commercial Aircraft Operations

MODEL 1
DEPENDENT VARIABLE: TOTOPEXP

INDEPENDENT VARIABLES	1989 WLS MODEL	1990 WLS MODEL	1991 WLS MODEL	MEANS WLS MODEL
COMM	297.66974 * (5.385)	367.67924 * (6.323)	395.99273 * (6.024)	357.61042 * (6.098)
NONCOMM	-102.44780 (-0.421)	-202.23112 (-0.734)	-341.83132 (-1.043)	-219.18208 (-0.791)
COMMSQ	0.0000551 (0.485)	-0.0000551 (-0.482)	-0.0001184 (-0.804)	-0.0000435 (-0.355)
NONCOMSQ	0.0005898 (1.045)	0.0008820 (1.316)	0.0010405 (1.515)	0.0008510 (1.354)
COMM_NON	-0.0015495 ** (-2.042)	-0.0015592 ** (-1.913)	-0.0009483 (-1.018)	-0.0013705 (-1.664)
N	46	46	46	46
ADJ R-SQ	0.907	0.896	0.884	0.898
F	107.802	96.032	84.764	98.326
WEIGHT	COMM	COMM	COMM	COMM

NOTES:

1. (*) denotes regression coefficient estimate is significant at at the 0.01 level of siginificance,(**) denotes regression coefficient estimate is significant at the 0.05 level of significance, and (***) denotes regression coefficient estimate is significant at the 0.10 level of significance.

For each year of data, as well as for the data means, the model explained approximated 90 percent of the variation in total annual operating expenses as reflected in the adjusted R-square statistic. Also, the F-statistic indicates the regression model as a whole is highly significant. However, the T-statistics, provided in parentheses below each coefficient estimate, indicate that only the number of commercial flights variable is individually significant at the 0.01 level of significance. Focusing on the means regression, since only the COMM coefficient estimate is significant, each additional commercial flight is estimated to add approximately $358 to annual airport operating costs.

MODEL 2 includes the same explanatory variables as MODEL 1 plus the addition of the GATESSQ variable to account for the impact of passenger terminal capacity on annual airport operating expenses. In addition to the version of the model for which results are reported in Table 5.4, alternative versions of this model including the GATES, COMM_GAT, and NON_GAT variables were also estimated. However, none of these versions of the model performed as well as the one including only the GATESSQ form of the terminal capacity variable. The deficiencies encountered with the other versions of MODEL 2 can generally be attributed to a high degree of collinearity among the various forms of the measures of terminal capacity and between the COMM and GATES variables.

Table 5.4: Regression of Total Operating Expenditures on Commercial and Non-commercial Aircraft Operations Plus Measure of Terminal Capacity

MODEL 2
DEPENDENT VARIABLE: TOTOPEXP

INDEPENDENT VARIABLES	1989 WLS MODEL	1990 WLS MODEL	1991 WLS MODEL	MEANS WLS MODEL
COMM	339.49675 * (4.857)	424.00059 * (5.776)	395.43877 * (5.302)	388.07207 * (5.444)
NONCOMM	-605.57986 (-1.676)	-995.94237 ** (-2.468)	-891.10229 ** (-2.083)	-841.72019 ** (-2.152)
COMMSQ	-0.0002017 ** (-1.752)	-0.0002512 ** (-2.268)	-0.0003203 ** (-2.265)	-0.0002547 ** (-2.122)
NONCOMSQ	0.0055049 ** (2.399)	0.0087363 * (3.160)	0.0066487 ** (2.591)	0.0070542 * (2.805)
COMM_NON	-0.0025511 * (-3.122)	-0.0029017 * (-3.319)	-0.0017535 ** (-1.849)	-0.0024363 * (-2.798)
GATESSQ	6884.5368 * (10.710)	6880.8775 * (9.698)	7466.0012 * (9.265)	7083.9807 * (9.984)
N	42	42	42	42
ADJ R-SQ	0.939	0.938	0.925	0.936
F	127.908	124.457	101.732	120.481
WEIGHT	COMM	COMM	COMM	COMM

NOTES:

1. (*) denotes regression coefficient estimate is significant at at the 0.01 level of siginificance, (**) denotes regression coefficient estimate is significant at the 0.05 level of significance, and (***) denotes regression coefficient estimate is significant at the 0.10 level of significance.

By including the GATESSQ variable the share of variation in total annual operating expenses explained increases to between 92 and 94 percent. The overall significance of the model also increases. More importantly, for each year's data and for the data means, most individual coefficient estimates are significant at the 0.05 level of significance or better. Focusing on the means regression, the COMM coefficient increases to 388.07207 from 357.61042 in MODEL 1. However, now that the coefficients for the COMMSQ and COMM_NON variables are also significant, the change in annual airport operating cost that would result from increasing commercial traffic by one operation per year would be only between $95 and $132 based on traffic mix and activity levels for the least and most busy airports included in the sample, Los Angeles International and Charlestown Municipal, respectively. This decrease in the marginal cost associated with increased commercial aircraft operations is likely attributable to the inclusion of the GATESSQ variable. Again focusing on the means regression version of MODEL 2, the addition of one more passenger terminal gate would increase annual airport operating costs by approximately $338,000 for an average size airport with 48 existing gates.

MODEL 3 builds on MODEL 2 by including the VFRCAPSQ variable to provide a measure of runway capacity. The results of this model are summarized in Table 5.5. With the addition

Table 5.5: Regression of Total Operating Expenditures on Commercial and Non-commercial Aircraft Operations Plus Measures of Both Runway and Terminal Capacity

MODEL 3
DEPENDENT VARIABLE: TOTOPEXP

INDEPENDENT VARIABLES	1989 WLS MODEL	1990 WLS MODEL	1991 WLS MODEL	MEANS WLS MODEL
COMM	455.22922 *	519.91181 *	486.97216 *	490.52082 *
	(5.121)	(5.920)	(4.638)	(5.333)
NONCOMM	-917.47384	-1136.3250	-1357.7121	-1176.6922
	(-1.297)	(-1.561)	(-1.493)	(-1.521)
COMMSQ	-0.0000967	-0.0001530	-0.0002898	-0.0001588
	(-0.601)	(-0.973)	(-1.279)	(-0.887)
NONCOMSQ	0.0128505 **	0.0143719 *	0.0140459 **	0.0143490 **
	(2.488)	(2.781)	(2.090)	(2.552)
COMM_NON	-0.0048089 *	-0.0049810 *	-0.0028757	-0.0044042 *
	(-3.205)	(-3.262)	(-1.674)	(-2.777)
GATESSQ	6883.7821 *	6973.9718 *	7690.667 *	7128.1866 *
	(10.275)	(9.378)	(8.459)	(9.379)
VFRCAPSQ	-1974.5753 **	-1890.5369 **	-1446.9175	-1781.6456 **
	(-2.089)	(-1.849)	(-1.183)	(-1.700)
N	32	32	32	32
ADJ R-SQ	0.951	0.951	0.928	0.945
F	100.412	100.580	67.925	90.280
WEIGHT	COMM	COMM	COMM	COMM

NOTES:

1. (*) denotes regression coefficient estimate is significant at at the 0.01 level of siginificance, (**) denotes regression coefficient estimate is significant at the 0.05 level of significance, and (***) denotes regression coefficient estimate is significant at the 0.10 level of significance.

of the VFRCAPSQ variable the overall explanatory power of the model increases to from 92 to 95 percent as reflected by the adjusted R-square statistic. On the other hand, the overall significance of the regression reflected by the F-statistic decreases below the levels for all four of the data sets for MODEL 2 and below all except the 1990 data set for MODEL 1. Furthermore, in evaluating the significance of the individual coefficient estimates for the VFRCAPSQ variable, the regression on the 1991 data set results in an estimate with below a 0.10 level of significance, the regressions on the 1990 and means data sets yield estimates with only between 0.05 and 0.10 levels of significance, and the regression on the 1989 data set yields a estimate with only a 0.05 level of significance. Thus, addition of this measure of runway capacity does not improve on the results of MODEL 2. Other forms of the runway capacity measure were also tested and the results of those regressions were inferior to the results reported in Table 5.5.

Focusing again on the coefficient for the COMM variable, there is a substantial increase in magnitude for all four MODEL 3 regressions compared to the corresponding estimates for MODEL 2. Correspondingly, there is a substantial increase in the difference between the estimates for the marginal cost associated with an additional commercial flight for Charleston Municipal Airport and Los Angeles International Airport.

Using the means data set, for Charleston Municipal Airport the marginal cost of an additional commercial flight decreases from $132 for MODEL 2 to $42, and for Los Angeles International Airport the marginal cost increases from $95 to $235. On the other hand, the estimated cost of adding another passenger gate at an average size terminal increases only by about $4,000 to $342,000.

Further comparison of the three models shows in all cases the sign on the coefficient estimates for the COMM variable is positive. While except in one case, for the COMMSQ variable the sign of the coefficient estimate is negative. These signs imply that airport operating costs increase as the number of commercial flights increases, but at a decreasing rate. The opposite situation holds for the signs of the coefficient estimates for the NONCOMM and NONCOMSQ variables. The negative signs on the NONCOMM coefficient estimates imply that the cost of airport operations decreases as the number of non-commercial flights increases, while the positive signs on the coefficient estimates for the NONCOMSQ variable imply a reduction in the rate of decrease. These signs on the non-commercial flight variables' coefficient estimates are opposite what would normally be expected. Airport operating costs would not be expected to decrease as airport use increases regardless of the type of aircraft. More likely, the signs on the NONCOMM and the NONCOMSQ variable coefficient estimates imply that as the number of non-commercial flights increases, the number of commercial flights decreases. And since most airport operating costs arise from serving commercial aircraft traffic, the crowding out of commercial traffic by non-commercial traffic results in a decrease in airport operating costs.

The negative signs on the coefficient estimates for the COMM_NON variable imply a decrease in airport operating costs when both commercial and non-commercial traffic are served. Furthermore, for a given overall amount of aircraft traffic, the magnitude of the cost reduction is maximized when the volume of the two types of traffic are equal. Generally, the negative coefficient estimates on the COMM_NON variable may be interpreted as an indication of the existence of economies of scope with respect to serving multiple types of airport users. However, in this case, because the amounts of commercial and non-commercial flight activity are negatively correlated, one cannot conclude there exist economies of scope.

Finally, the positive signs on the coefficient estimates for the GATESSQ variable indicate that airport operating costs rise at an increasing rate as the capacity of the airport terminal increases. In addition, the regression results imply that terminal capacity more than any other factor explains the magnitude of annual airport operating costs. Evidence of this is provided in Figure 5.3 which shows the relationship between

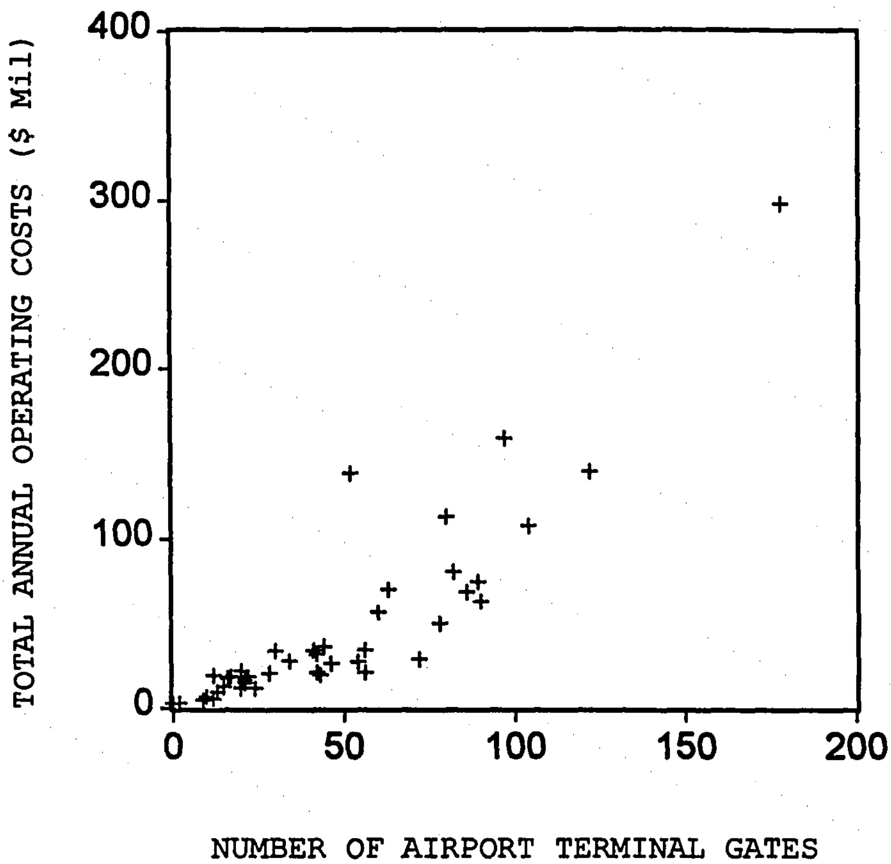

Figure 5.3: Annual Airport Operating Costs vs Number of Airport Terminal Gates

airport terminal capacity and total annual airport operating costs.

Now, having described the results of the regression analysis, the final part of the empirical analysis focuses on to what extent economies of scale and economies of scope characterize the cost structures of different size airports.

Economies of Scale and Scope Analysis

Based on regression results presented above, the means version of MODEL 2 is used to evaluate the extent to which different size airports exhibit economies of scale and economies of scope. However, in both cases the negative relationship between the TOTOPEXP and NONCOMM variables prevents the direct application of the measures of ray economies of scale (S_l) and economies of scope (SC). These complications arise because for most of the airports in the sample both the marginal cost of additional non-commercial flights and the stand alone cost of providing airport services to non-commercial flights are negative.

Focusing first on economies of scale, columns 7 through 9 of Table 5.6, labelled unconstrained marginal costs, show the computed values for the marginal costs associated with an additional commercial flight, an additional non-commercial flight and an additional passenger terminal gate, respectively. These values, which were computed using the

Table 5.6: Measures of Economies of Scale Based on Regression Model 2

AIR-PORT ID	HUB CLS (2)	OBSERVATION VALUES TOTOPEXP (3)	COMM (4)	NONCOMM (5)	GATES (6)	UNCONSTRAINED MARGINAL COSTS COMM (7)	NONCOMM (8)	GATES (9)
EWR	L	159,333,333	357,629	23,267	97	240.30	-1548.88	687146.13
JFK	L	298,750,000	306,335	21,438	178	257.82	-1436.82	1260948.56
LGA	L	138,916,667	327,842	23,313	52	247.77	-1475.99	368367.00
DEN	L	108,094,345	438,929	39,300	104	180.53	-1633.85	736733.99
CVG	M	19,387,436	258,293	24,101	43	263.57	-1300.99	304611.17
LAX	L	140,077,917	595,889	58,022	122	94.94	-1884.18	864245.65
SFO	L	113,102,996	394,513	41,008	80	187.68	-1513.59	566718.46
MCI	L	34,165,273	169,351	20,399	56	295.24	-1110.41	396702.92
STL	L	49,847,976	379,306	47,506	78	175.72	-1430.71	552550.49
MCO	L	68,620,667	243,722	35,809	86	238.75	-1182.89	609222.34
DTW	L	74,784,113	330,558	53,084	89	174.55	-1272.59	630474.28
IAH	L	80,542,167	262,225	42,739	82	217.16	-1179.09	580886.42
PHL	L	70,317,725	334,020	56,318	63	165.79	-1258.21	446290.78
CLE	L	31,781,847	211,629	46,452	42	221.00	-1029.63	297527.19
DCA	L	36,244,925	245,919	65,435	44	166.02	-979.26	311695.15
MEM	M	28,890,397	254,463	74,274	72	142.31	-937.72	510046.61
ONT	S	21,645,417	114,602	35,419	20	272.59	-871.07	141679.61
PHX	L	63,060,083	365,537	126,467	90	-13.14	-840.15	637558.26
IND	M	27,463,036	161,821	58,773	34	203.67	-821.37	240855.34
PDX	M	33,837,917	192,683	75,463	41	155.15	-778.83	290443.21
LAS	L	56,446,007	276,778	113,767	60	40.41	-713.50	425038.84
SLC	M	27,214,311	210,032	88,966	54	117.83	-725.83	382534.96
SDF	M	14,822,760	109,427	46,927	21	245.87	-777.29	148763.59
BNA	M	26,027,554	188,318	81,369	46	141.87	-726.53	325863.11
RDU	M	20,966,351	186,714	88,783	56	124.21	-670.32	396702.92
MKE	M	21,008,625	127,375	76,752	42	168.64	-610.62	297527.19
CMH	M	20,070,965	124,476	92,268	28	131.58	-494.11	198351.46
DAL	L	12,535,667	104,387	107,675	15	99.16	-336.48	106259.71
ABQ	M	18,420,124	107,435	115,575	22	79.13	-288.17	155847.58
SJC	S	33,409,902	143,924	180,837	30	-89.16	83.29	212519.42
OMA	M	11,724,578	67,713	90,755	20	149.72	-366.49	141679.61
OKC	M	18,265,408	61,151	82,591	17	171.28	-408.09	120427.67
ORF	M	11,660,666	61,399	92,620	24	146.78	-337.94	170015.54
RNO	M	16,519,959	63,889	98,239	21	132.46	-304.38	148763.59
TUL	M	17,443,481	65,681	124,177	16	68.81	-125.77	113343.69
BOI	S	4,815,153	55,056	105,304	9	117.50	-233.02	63755.83
GRR	S	5,349,624	50,021	113,710	12	98.30	-161.45	85007.77
ICT	S	19,084,347	43,015	129,065	12	62.67	-36.07	85007.77
SRQ	S	9,431,091	41,399	127,247	13	67.52	-44.95	92091.75
CHS	S	6,575,643	29,339	101,860	10	132.44	-194.66	70839.81
GFK	N	2,835,481	8,347	280,669	2	-297.85	1117.84	14167.96
APA	L	2,741,050	3,823	364,356	0	-500.58	1719.20	0.00
MEAN		47,053,166	192,261	87,431	48	126.10	-693.37	337838.41
TOP 3RD		99,123,033	329,303	38,054	84	211.49	-1375.56	593030.38
MIDDLE 3RD		29,302,430	190,181	80,881	45	142.58	-734.50	315237.14
BOTTOM 3RD		12,734,036	57,299	143,357	15	24.22	29.95	105247.71

Table 5.6: (continued)

AIR-PORT ID	HUB CLS (2)	CONSTRAINED MARGINAL COSTS COMM (10)	NONCOMM (11)	GATES (12)	UNCON-STRAINED ECONOMIES OF SCALE (13)	CON-STRAINED ECONOMIES OF SCALE (14)	TOTAL FLIGHTS (15)	COMM FLIGHT SHARE (16)
EWR	L	240.30	0.00	687146.13	1.3671	1.0442	380,896	0.9389
JFK	L	257.82	0.00	1260948.56	1.0958	0.9846	327,773	0.9346
LGA	L	247.77	0.00	368367.00	2.1055	1.3838	351,154	0.9336
DEN	L	180.53	0.00	736733.99	1.1794	0.6935	478,229	0.9178
CVG	M	263.57	0.00	304611.17	0.3891	0.2388	282,394	0.9147
LAX	L	94.94	0.00	864245.65	2.6587	0.8646	653,911	0.9113
SFO	L	187.68	0.00	566718.46	1.9735	0.9474	435,521	0.9058
MCI	L	295.24	0.00	396702.92	0.6893	0.4731	189,750	0.8925
STL	L	175.72	0.00	552550.49	1.1930	0.4542	426,813	0.8887
MCO	L	238.75	0.00	609222.34	1.0058	0.6205	279,531	0.8719
DTW	L	174.55	0.00	630474.28	1.6167	0.6571	383,642	0.8616
IAH	L	217.16	0.00	580886.42	1.4864	0.7702	304,964	0.8599
PHL	L	165.79	0.00	446290.78	5.5661	0.8422	390,338	0.8557
CLE	L	221.00	0.00	297527.19	2.7788	0.5363	258,081	0.8200
DCA	L	166.02	0.00	311695.15	-3.8006	0.6645	311,354	0.7898
MEM	M	142.31	0.00	510046.61	8.7914	0.3961	328,737	0.7741
ONT	S	272.59	0.00	141679.61	6.7210	0.6353	150,021	0.7639
PHX	L	0.00	0.00	637558.26	-1.1748	1.0990	492,004	0.7430
IND	M	203.67	0.00	240855.34	-3.8531	0.6674	220,594	0.7336
PDX	M	155.15	0.00	290443.21	-1.9940	0.8095	268,146	0.7186
LAS	L	40.41	0.00	425038.84	-1.2688	1.5386	390,546	0.7087
SLC	M	117.83	0.00	382534.96	-1.4196	0.5994	298,998	0.7025
SDF	M	245.87	0.00	148763.59	-2.2994	0.4936	156,354	0.6999
BNA	M	141.87	0.00	325863.11	-1.4949	0.6241	269,687	0.6983
RDU	M	124.21	0.00	396702.92	-1.4864	0.4617	275,497	0.6777
MKE	M	168.64	0.00	297527.19	-1.6299	0.6183	204,127	0.6240
CMH	M	131.58	0.00	198351.46	-0.8484	0.9151	216,743	0.5743
DAL	L	99.16	0.00	106259.71	-0.5162	1.0495	212,063	0.4922
ABQ	M	79.13	0.00	155847.58	-0.8617	1.5440	223,010	0.4817
SJC	S	0.00	83.29	212519.42	3.8820	1.5584	324,761	0.4432
OMA	M	149.72	0.00	141679.61	-0.5779	0.9039	158,468	0.4273
OKC	M	171.28	0.00	120427.67	-0.8623	1.4587	143,742	0.4254
ORF	M	146.78	0.00	170015.54	-0.6404	0.8906	154,019	0.3986
RNO	M	132.46	0.00	148763.59	-0.9020	1.4258	162,128	0.3941
TUL	M	68.81	0.00	113343.69	-1.8788	2.7544	189,859	0.3459
BOI	S	117.50	0.00	63755.83	-0.2752	0.6837	160,359	0.3433
GRR	S	98.30	0.00	85007.77	-0.4307	0.9010	163,731	0.3055
ICT	S	62.67	0.00	85007.77	-20.3285	5.1357	172,081	0.2500
SRQ	S	67.52	0.00	92091.75	-5.4578	2.3623	168,646	0.2455
CHS	S	132.44	0.00	70839.81	-0.4316	1.4314	131,199	0.2236
GFK	N	0.00	1117.84	14167.96	0.0091	0.0090	289,015	0.0289
APA	L	0.00	1719.20	0.00	0.0044	0.0044	368,178	0.0104
MEAN		126.10	0.00	337838.41	-2.3216	1.1660	279,692	0.6874
TOP 3RD		211.49	0.00	593030.38	1.4807	0.8310	367,357	0.8964
MIDDLE 3RD		142.58	0.00	315237.14	-1.6044	0.7122	271,062	0.7016
BOTTOM 3RD		24.22	29.95	105247.71	1.7576	1.7576	187,771	0.3052

results of the means version of MODEL 2, show that the marginal costs associated with an additional non-commercial flight are negative for 39 of the 42 airports in the sample, and their use in evaluating the degree of airport economies of scale yield 23 negative S_l values, which are meaningless. These negative values reflect the crowding out of commercial flight activity rather than a true reduction in airport operating costs when non-commercial flight activity increases. Therefore, to obtain a more meaningful test for airport economies of scale the S_l values were recomputed by setting any negative commercial or non-commercial flight activity marginal cost values equal to zero. These constrained marginal costs computations are presented in columns 10 through 12 and the adjusted S_l values are presented in column 14, labelled constrained economies of scale.

Although constraining all marginal cost values to be equal to or greater than zero likely results in the overstating of the degree of airport economies of scale, these adjusted S_l values provide reasonable approximations of true S_l values. These approximations are reasonable because most commercial airport operating costs are associated with passenger terminal activities, which to a great extent are not affected by users of non-commercial aircraft, and costs associated with runway use are primarily a function of aircraft size and weight meaning most runway costs are attributable to commercial flight activity.

Thus, for the overall sample, the constrained S_l value of 1.166 implies the airports included in the study exhibit slightly increasing economies of scale. However, as shown in Figure 5.4, disaggregation of the sample of airports according to the share of total flight activity accounted for by commercial flights tells a different story. This more detailed look at the sample of airports reveals that the 14 airports with the highest concentration of commercial flights, those with commercial flight shares greater than or equal to 82 percent, exhibit decreasing economies of scale as reflected by an average S_l value of 0.8310. Similarly, the middle 14 airports, with commercial flight shares between 82 and 49 percent, also exhibit decreasing returns to scale with an average S_l of 0.7122. On the other hand, the 14 airports with commercial flights accounting for less than 49 percent of total aircraft operations exhibit increasing returns to scale with an average S_l of 1.7576. These results tend to confirm the theoretical findings of Chapter Four that larger airports will exhibit decreasing returns to scale, while smaller airports will exhibit increasing returns to scale. The theoretical analysis presented in Chapter Four also implies very large airports will likely exhibit diseconomies of scope, while small airports will exhibit economies of scope. An attempt was made to again use the results of MODEL 2 to test

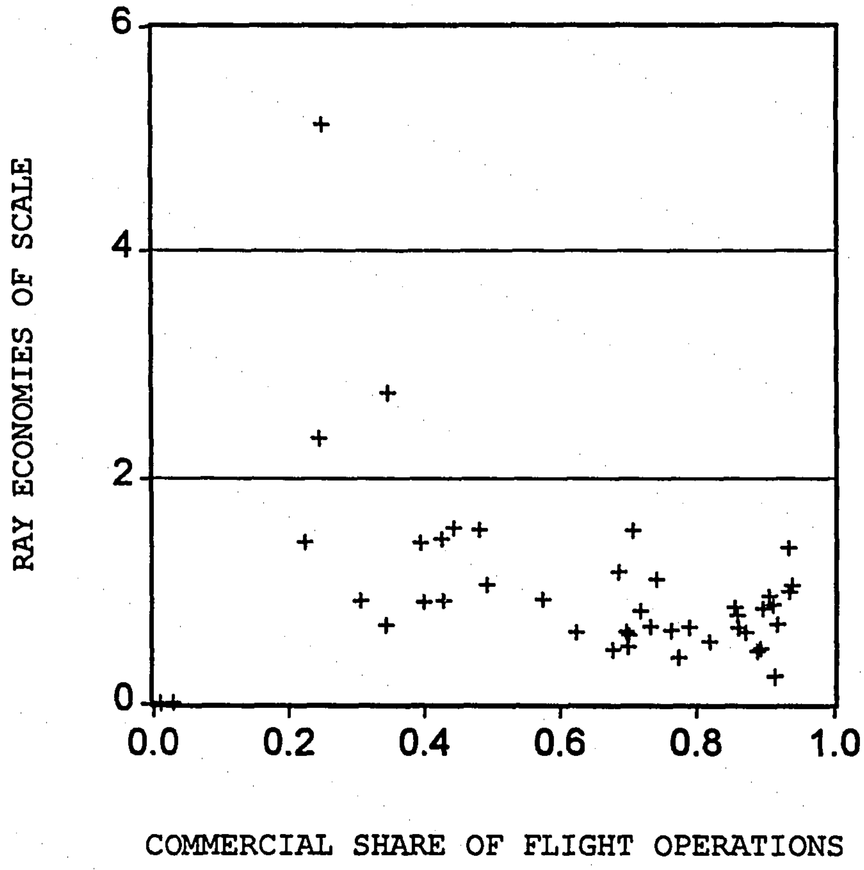

Figure 5.4: Ray Economies of Scale Index vs Commercial Flight Share of Airport Operations

Table 5.7: Measures of Economies of Scope Based on Regression Model 2

AIRPORT MEANS DATASET 1989-91

AIR-PORT ID (1)	TOTOPEXP (2)	STAND ALONE COSTS COMM (3)	NONCOMM (4)	ECONOMIES OF SCOPE (5)	TOTAL FLIGHTS (6)	COMM FLIGHT SHARE (7)
EWR	159,333,333	172,863,184	(15,765,660)	0.9860	380,896	0.9389
JFK	298,750,000	319,427,566	(14,802,773)	1.0197	327,773	0.9346
LGA	138,916,667	119,006,082	(15,788,923)	0.7430	351,154	0.9336
DEN	108,094,345	197,886,258	(22,184,462)	1.6254	478,229	0.9178
CVG	19,387,436	96,342,114	(16,188,808)	4.1343	282,394	0.9147
LAX	140,077,917	246,246,000	(25,089,962)	1.5788	653,911	0.9113
SFO	113,102,996	158,795,253	(22,654,523)	1.2037	435,521	0.9058
MCI	34,165,273	80,630,921	(14,235,047)	1.9434	189,750	0.8925
STL	49,847,976	153,652,604	(24,066,757)	2.5996	426,813	0.8887
MCO	68,620,667	131,845,449	(21,095,779)	1.6139	279,531	0.8719
DTW	74,784,113	156,561,755	(24,803,766)	1.7618	383,642	0.8616
IAH	80,542,167	131,881,301	(23,088,842)	1.3508	304,964	0.8599
PHL	70,317,725	129,323,436	(25,030,071)	1.4832	390,338	0.8557
CLE	31,781,847	83,216,240	(23,878,178)	1.8670	258,081	0.8200
DCA	36,244,925	93,745,693	(24,873,716)	1.9002	311,354	0.7898
MEM	28,890,397	118,981,153	(23,602,466)	3.3014	328,737	0.7741
ONT	21,645,417	43,962,185	(20,963,354)	1.0625	150,021	0.7639
PHX	63,060,083	165,202,551	6,374,671	2.7209	492,004	0.7430
IND	27,463,036	64,317,811	(25,103,341)	1.4279	220,594	0.7336
PDX	33,837,917	77,226,979	(23,347,504)	1.5923	268,146	0.7186
LAS	56,446,007	113,400,660	(4,457,708)	1.9300	390,546	0.7087
SLC	27,214,311	90,928,654	(19,050,706)	2.6412	298,998	0.7025
SDF	14,822,760	42,539,863	(23,965,044)	1.2531	156,354	0.6999
BNA	26,027,554	79,038,160	(21,784,780)	2.1997	269,687	0.6983
RDU	20,966,351	85,794,373	(19,126,132)	3.1798	275,497	0.6777
MKE	21,008,625	57,794,577	(23,048,336)	1.6539	204,127	0.6240
CMH	20,070,965	49,913,000	(17,608,880)	1.6095	216,743	0.5743
DAL	12,535,667	39,328,311	(8,846,267)	2.4316	212,063	0.4922
ABQ	18,420,124	42,181,240	(3,054,503)	2.1241	223,010	0.4817
SJC	33,409,902	56,952,686	78,471,870	4.0534	324,761	0.4432
OMA	11,724,578	27,943,422	(18,288,755)	0.8235	158,468	0.4273
OKC	18,265,408	24,825,948	(21,399,886)	0.1876	143,742	0.4254
ORF	11,660,666	26,947,432	(17,445,765)	0.8148	154,019	0.3986
RNO	16,519,959	26,878,055	(14,610,544)	0.7426	162,128	0.3941
TUL	17,443,481	26,203,805	4,253,267	1.7460	189,859	0.3459
BOI	4,815,153	21,167,341	(10,413,170)	2.2334	160,359	0.3433
GRR	5,349,624	19,794,561	(4,501,196)	2.8588	163,731	0.3055
ICT	19,084,347	17,241,866	8,870,981	1.3683	172,081	0.2500
SRQ	9,431,091	16,826,342	7,113,820	2.5384	168,646	0.2455
CHS	6,575,643	11,874,805	(12,547,051)	-0.1022	131,199	0.2236
GFK	2,835,481	3,249,700	319,449,419	113.8076	289,015	0.0289
APA	2,741,050	1,479,748	629,795,166	230.3040	368,178	0.0104
MEAN	9,948,541	81,308,010	(19,668,874)	1.3100	160,001	0.0000

this hypothesis. However, as shown in Table 5.7, and for the reasons explained previously, this could not be accomplished either on an individual airport basis or for sub-samples of airports.

Several other approaches were also attempted to obtain a meaningful tests for economies of scope, but these attempts also failed. These alternative approaches included estimating separate regressions for commercial and non-commercial variables, matching airports with approximately the same volumes of total flights but with opposite shares of commercial and non-commercial operations, and a two-stage regression to filter out the impact of terminal size on total annual operating cost.

However, failure to find statistical evidence of the existence of either economies of scope or diseconomies of scope does not invalidate this aspect of the theoretical analysis in Chapter Four. Rather the theoretical analysis suggests the issue of economies of scope should be addressed on a time period basis instead of in aggregate. Specifically, the analysis in Chapter Four suggested inter-period economies of scope may exist with respect to use of the passenger terminal, while intra-period economies of scope may exist during the off-peak traffic period and intra-period diseconomies of space may exist during the peak traffic period relative to runway use. To test for these conditions would require aircraft operations data disaggregated by time period. This data has not been obtained but may be pursued for future follow-up studies.

Finally, none of the empirical analysis presented here addresses issues related to non-user externalities. However, to provide a basis for using the models developed in this dissertation to help establish airport user fees and non-user taxes such research is needed. Types of data required to facilitate the estimation of the value of beneficial and adverse non-user externalities include airport expenditures on noise abatement programs, tax collections from special airport taxing districts or airport budget contributions from general tax revenues, and home value information.

CHAPTER 6: CONCLUSION

Although not a new subject, the pricing of and investment in publicly provided transportation infrastructure has received increased attention in recent years. One explanation for this heightened level of interest in transportation investment and finance is the current debate among politicians and economists over to what extent public capital investment influences a nation's competitiveness in the "new global" economy. A second explanation for the revived interest in transportation infrastructure pricing is that because of the explosion of the national debt over the past decade and the poor financial condition of many states public resources available for capital investment have become extremely limited. Third, new technology makes the imposition of congestion tolls feasible at a reasonable cost, while at the same time improvements in fuel efficiency for the nation's fleet of transportation vehicles makes one major traditional source of funding for transportation infrastructure (i.e., fuel taxes) less reliable for funding needed system improvements in future years.

In spite of the increased interest in this subject very little has been done to expand the theoretical treatment of transportation infrastructure pricing beyond the work completed in the 1960s and 1970s. In particular, advances in the public finance field related to the theory of club goods and in the industrial organization field related to the theory of multi-product industries have not been incorporated to any great extent into the theory of transportation infrastructure pricing and investment. This dissertation employs the methods of analysis and findings from research in these two relatively new areas of economic theory to expand the theoretical foundation for the empirical analysis of transportation financing issues.

Summary of Results and Findings

Taking the work of Mohring and Harwitz (1962) as a point of departure, this dissertation develops a set of three general transportation club models. The first model focuses on a single, capacity constrained transportation facility used by a single group of homogeneous individuals during a single time period. This model replicates the findings of Mohring and Harwitz that efficient transportation infrastructure investment requires that fees imposed on users of such facilities incorporate the cost associated with the increase in congestion each individual's use of the facility imposes on all other users. Furthermore, this model determines that for user fees set equal to marginal cost to be adequate to fully fund the provision, operation and maintenance of the transportation facility, the facility's cost structure must be characterized by constant economies of scale.

The second model extends the treatment of the single transportation facility model by taking into consideration the impact of externalities on individuals who do not directly use the transportation facility. This model shows that if the existence and use of the transportation facility results in a net adverse impact on non-users, then efficient user fees should increase from the level found in the first model to an amount adequate to compensate non-users. In addition this model shows that unless the costs associated with adverse external impacts are internalized in user fees the transportation facility will tend to be overbuilt. Alternatively, if the net external impact of the transportation facility is beneficial, then non-users of the facility should be expected to contribute part of its funding. Otherwise, investment in the facility will be below the socially optimal level.

The third model introduces consideration of the pricing and investment implications of having use of the transportation facility shared by two groups of users. This model also incorporates the influence of variation in the level of usage of the transportation facilities over time by distinguishing between peak and off-peak traffic periods. These extensions of the model introduce the concepts of ray economies of scale and economies of scope to the analysis. Through the introduction of these concepts, the model provides a theoretical basis for using market pricing mechanisms to facilitate the more efficient use of the transportation facility by shifting traffic from the peak to the off-peak traffic period. The third model all provides a rationale for sharing high cost public infrastructure and for using marginal cost pricing as a meaning for determining the optimal level of use by members of the different user groups.

Overall, the three general transportation models developed in Chapter Three illustrate the flexibility of the club theory approach for incorporating a wide variety of policy considerations in a single model. The flexibility of this approach, as well as its adaptability to special applications, is further illustrated in Chapter Four through the customization of an two-period, two user group airport pricing and investment model. This special application not only incorporates the consideration of the impact of non-user externalities, multiple user groups, and multiple time periods, but in addition, it explicitly translates differences in service preferences of members of different user groups through the introduction of transportation vehicles (i.e., commercial carrier aircraft and general aviation aircraft) and multiple transportation facilities (i.e., runways and a passenger terminal).

Regarding the pricing of airport services, this model found the requirement that, in the absence of externalities, constant economies of scale is a necessary condition for full user financing to be feasible extends to the multiple user case. Although in this multiple user group context the full user financing condition becomes constant ray economies of scale. The airport club model further shows that the degree to which a transportation facility's cost structure is characterized by economies or diseconomies of scope may vary by time period. For example, the model suggests that an airport that experiences a high level of use during the peak traffic period may exhibit diseconomies of scope during that period, while during the off-peak traffic period it may exhibit economies of scope. In such cases, the model implies marginal cost pricing of the use of airside facilities may provide an efficient mechanism for shifting airport use from the peak to the off-peak traffic period.

To test the financing implications of the airport club model an econometric analysis of the cost structures of a sample of domestic airports was conducted. The focus of this empirical analysis was the degree of economies of scale and economies of scope exhibited by different size airports. The primary focus of this analysis was to determine how the cost characteristics of airports vary by size measured in terms of VFR (visual flight rule) runway capacity and the number of passenger terminal boarding gates. The results of this analysis were somewhat confounded by the discovery of a "crowding out" effect between commercial and general aviation aircraft. However, the sample of airports was found to exhibit substantial variation in the degree of economies of scale by size of airport. As was expected large airports tended to exhibit cost structures characterized by decreasing economies of scale, while small airports exhibited costs structures characterized by increasing economies of scale. On the other hand, results pertaining to the issue of economies of scope were indeterminant. This may be attributed both to the dominant influence of terminal related costs, which prevented the detection of any possible economies of scope related to runway use, and the lack of time period specific aircraft traffic data, which would be needed to test for economies of scope relative to use of the passenger terminal.

Policy Implications

As discussed in Chapter Four the pricing of airport airside services is generally not reflective of the costs different classes of users impose on those facilities. Although, aircraft landing fees are generally based on aircraft gross weight for commercial carriers this method of pricing represents only a minimal attempt to relate user fees to runway "wear and tear."

Almost no attempt is made by managers of United States airports to make user fees demand sensitive by incorporating the congestion related costs users impose on each other through their travel time choices. The costs and benefits associated with externalities arising from the existence and use of airports are also generally excluded from consideration in setting landing fees and aviation fuel taxes.

The airport club model provides the theoretical justification for moving to a cost based pricing system in establishing fees for the use of airport infrastructure. Not only does this model provide justification for the incorporation of charges related to congestion and non-user externalities, it also provides a basis for assigning costs based on which elements of the airport's infrastructure different classes of consumers use. As a result, the model establishes a framework for allocating capital and operating costs among different classes of users. Furthermore, it provides a legal foundation for differential pricing of services among different classes of users and by time period.

Both the airport model and the general transportation facility models suggest a number of additional policy issues that could be addressed using club theory and the theory of multi-product enterprises. Most significantly, the existence of non-user externalities provides only one justification for side payments to and from specific airports. Throughout the domestic transportation system there exists substantial cross-subsidization among different system elements. The models presented here provide a foundation for extending the analysis to complete networks of facilities. This extension of the theory would incorporate issues related to network externalities, multi-jurisdictional cost sharing and a hierarchy of clubs. These possible extensions of the theoretical models developed in this dissertation provide part of an agenda for future research.

Future Research

As stated above, the combination of club theory and the theory of multi-product enterprises provides substantial opportunities for additional extension of the theoretical analysis of transportation infrastructure pricing and investment issues. Through extension of the models from the "closed" system of single facilities to the context of entire "open" networks the influence of location and the issues of optimal siting and size distribution of facilities are introduced.

Also, although the current models represent the providers of the transportation facilities (i.e., airports, highways, etc.) and the providers of transportation services (i.e., airlines, motor carriers, etc.) as passive players in the infrastructure investment process, the incorporation of strategic decision-making by these groups would add another significant dimension to the theory of transportation infrastructure pricing and investment.

Another avenue which merits additional research is the further empirical analysis of the implications of the airport model. Although the current research failed to determine the extent to which different size airports exhibit economies of scope, the theory suggests that disaggregation of aircraft flight information by time period may provide more revealing results. It may also be possible to develop an econometric procedure that will filter out the effects of terminal costs so that tests for economies of scope with respect to runway use may be conducted.

Finally, the model also suggests approaches for measuring the implication of airport externalities on surrounding land uses and on regional economic activity. In particular, both the model and the empirical analysis could be expanded to take into consideration multiple groups of non-users. Through this sort of disaggregation of the non-user population, estimates of side payment which should be made to and collected from residents of an airport's service area may be obtained. This sort of refinement of the model and accompanying empirical analysis would provide the framework for operationalizing the pricing of airport generated externalities. Similarly, further disaggregation of the elements of airport infrastructure would provide a basis for the allocation of airport airside costs among different classes of users. Thus, the models developed in this dissertation provide a strong and very flexible foundation for future research.

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APPENDIX A

Part 1: Alternative Objective Function for Two-period, Two User Group, Capacity Constrained Single Transportation Facility Club Model without Non-user Externalities

In Chapter 3, those service area residents who did not use the transportation facility were represented by a single group of P-M-N individuals. Since in the context of this model society rather than individuals decides who is and is not a user of the transportation facility, a technically more correct representation of the non-user population would be to have two non-user groups, one each paired with the two user groups. This change in the setup of the model would result in the following alternative objective function,

$$W = (M' - M)\cdot U^m(y^{m'},0,0,0) + (N' - N)\cdot U^n(y^{n'},0,0,0)$$
$$+ M\cdot U^m[y^m, v_p^m, v_o^m, c(F_p^m, F_o^m, F_p^n, F_o^n, X)]$$
$$+ N\cdot U^n[y^n, v_p^n, v_o^n, c(F_p^m, F_o^m, F_p^n, F_o^n, X)],$$

where M′ represents the total population of individuals with type-M preferences and N′ represents the total population of individuals with type N-preferences. All other variables are defined the same as in Chapter 3.

This modification of the objective function and a corresponding change of the budget constraint, will results in a slight change in notation for the LHS of the user group membership conditions and the RHS income adjustment terms, but these changes have no material impact on the interpretation of these first-order conditions. None of the other first-order conditions are affected by this change. More inportantly, this change has no impact on the financing conditions.

Therefore, to simplify the development of the model non-users of the transportation facility have been combined into a single group.

Part 2: Proof that Subadditivity of Incremental Costs Implies Economies of Scope

Prove:

If Σ IC < JC, Then JC < Σ SAC, where IC denotes incremental cost, JC denotes joint costs, and SAC denotes stand alone cost.

Proof:

(1) Given,

$$[C(X,Y,Z) - C(0,Y,Z)] + [C(X,Y,Z) - C(X,0,Z)] + [C(X,Y,Z) - C(X,Y,0)] < C(X,Y,Z)$$

(2) Begin with the two output case.

$$[C(A,B) - C(0,B)] + [C(A,B) - C(A,0)] < C(A,B)$$

(3) Then,

$$2 \cdot C(A,B) < C(A,B) + C(A,0) + C(0,B)$$
$$\Rightarrow C(A,B) < C(A,0) + C(0,B)$$

(4) Next, if all three outputs make use of some common resource,

$$C(X,Y,Z) - C(0,Y,Z) > C(X,Y,Z) - C(0,Y,0) - C(0,0,Z)$$

and

$$C(X,Y,Z) - C(X,0,Z) > C(X,Y,Z) - C(X,0,0) - C(0,0,Z)$$

and

$$C(X,Y,Z) - C(X,Y,0) > C(X,Y,Z) - C(X,0,0) - C(0,Y,0)$$

(5) So now,

$$\begin{aligned} & [C(X,Y,Z) - C(0,Y,0) - C(0,0,Z)] \\ + & [C(X,Y,Z) - C(X,0,0) - C(0,0,Z)] \\ + & [C(X,Y,Z) - C(X,0,0) - C(0,Y,0)] \\ < & \; C(X,Y,Z) \end{aligned}$$

(6) Therefore,

$$\begin{aligned} & 2 \cdot C(X,Y,Z) \\ < & \; 2 \cdot C(X,0,0) + 2 \cdot C(0,Y,Z) + 2 \cdot C(0,0,Z) \\ \Rightarrow & \; C(X,Y,Z) < C(X,0,0) + C(0,Y,0) + C(0,0,Z) \end{aligned}$$

APPENDIX B

FISCAL YEAR FINANCIAL STATISTICS

UNITED STATES AIRPORT SAMPLE, FY 1989 - 1992

FISCAL YEAR FINANCIAL STATISTICS

AIR-PORT ID	FISCAL YEAR	OPERATING REVENUES	OPERATING EXPENSES EXCLUDING DEPRECTION	OPERATING INCOME BEFORE DEPRECTION	DEPRECTION	TOTAL OPERATING EXPENSES & DEPRECTION	NET OPERATING INCOME
ABQ	1989	18,463,826	(8,198,964	10,264,862	(5,372,623	(13,571,586)	4,892,239
ABQ	1990	23,970,770	(10,180,582	13,790,189	(10,032,417	(20,212,998)	3,757,772
ABQ	1991	27,000,285	(11,066,640	15,933,646	(10,409,148	(21,475,787)	5,524,498
ABQ	1992						
BWI	1989	43,795,613	(27,783,167	16,012,446			
BWI	1990	43,949,613	(29,573,319	14,376,294			
BWI	1991	48,534,333	(30,721,636	17,812,697			
BWI	1992	50,916,975	(30,586,612	20,330,363			
BOI	1989	4,452,178	(2,921,458	1,530,720	(1,123,013	(4,044,471)	407,707
BOI	1990	4,868,433	(4,571,602	296,831	(1,168,260	(5,739,862)	(871,429
BOI	1991	4,674,668	(3,376,973	1,297,695	(1,284,152	(4,661,125)	13,543
BOI	1992	4,853,795	(3,692,941	1,160,854	(1,410,889	(5,103,830)	(250,035
CHS	1989	8,566,859	(3,590,306	4,976,553	(2,403,036	(5,993,342)	2,573,518
CHS	1990	8,990,174	(3,895,903	5,094,272	(2,744,067	(6,639,970)	2,350,204
CHS	1991	9,360,612	(4,204,649	5,155,962	(2,888,967	(7,093,616)	2,266,995
CHS	1992						
CVG	1989	24,792,778	(12,543,630	12,249,148	(4,628,432	(17,172,062)	7,620,716
CVG	1990	31,384,422	(13,847,051	17,537,371	(4,905,694	(18,752,745)	12,631,678
CVG	1991	36,285,000	(16,230,500	20,054,500	(6,007,000	(22,237,500)	14,047,500
CVG	1992	39,783,750	(19,264,000	20,519,750	(9,141,750	(28,405,750)	11,378,000
CLE	1989	32,875,308	(21,767,580	11,107,728	(7,628,352	(29,395,931)	3,479,377
CLE	1990	36,139,352	(23,051,193	13,088,159	(7,978,139	(31,029,332)	5,110,020
CLE	1991	36,067,938	(25,896,650	10,171,288	(9,023,627	(34,920,278)	1,147,661
CLE	1992	41,131,705	(27,110,000	14,021,704	(10,116,064	(37,226,065)	3,905,640

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CMH	1989	18,967,798	(15,606,325	3,361,472	(2,693,488	(18,299,814)	667,984
CMH	1990	22,063,753	(17,002,376	5,061,377	(2,793,187	(19,795,563)	2,268,190
CMH	1991	22,914,756	(19,130,301	3,784,456	(2,987,219	(22,117,520)	797,237
CMH	1992	27,033,868	(16,629,542	10,404,326	(1,650,137	(18,279,679)	8,754,189
DAL	1989	15,633,000	(8,102,000	7,531,000	(3,477,000	(11,579,000)	4,054,000
DAL	1990	15,353,000	(8,502,000	6,851,000	(2,968,000	(11,470,000)	3,883,000
DAL	1991	14,761,000	(8,704,000	6,057,000	(5,854,000	(14,558,000)	203,000
DAL	1992	15,644,000	(8,503,000	7,141,000	(5,065,000	(13,568,000)	2,076,000
DFW	1989	171,737,000	(75,715,000	96,022,000			
DFW	1990	187,900,000	(81,302,000	106,598,000	(28,695,000	(109,997,000)	77,903,000
DFW	1991	188,479,000	(85,222,000	103,257,000	(29,085,000	(114,307,000)	74,172,000
DFW	1992						
DEN	1989	114,828,518	(59,516,176	55,312,343	(37,350,292	(96,866,467)	17,962,051
DEN	1990	134,212,310	(67,003,662	67,208,647	(44,183,583	(111,187,246)	23,025,064
DEN	1991	148,696,265	(69,285,689	79,410,576	(46,943,634	(116,229,323)	32,466,942
DEN	1992	152,592,105	(65,039,887	87,552,219	(47,515,534	(112,555,421)	40,036,685
APA	1989	2,041,282	(944,510	1,096,772	(1,971,911	(2,916,421)	(875,139
APA	1990	2,138,991	(831,948	1,307,043	(1,857,843	(2,689,791)	(550,800
APA	1991	1,971,422	(982,712	988,710	(1,634,228	(2,616,940)	(645,518
APA	1992	1,921,677	(926,415	995,262	(1,605,188	(2,531,602)	(609,926
DSM	1989	7,901,548	(7,170,296	731,252			
DSM	1990	8,557,878	(8,033,385	524,493			
DSM	1991	8,375,679	(7,623,283	752,396			
DSM	1992						

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FISCAL YEAR FINANCIAL STATISTICS

AIR-PORT ID	FISCAL YEAR	OPERATING REVENUES	OPERATING EXPENSES EXCLUDING DEPRECTION	OPERATING INCOME BEFORE DEPRECTION	DEPRECTION	TOTAL OPERATING EXPENSES & DEPRECTION	NET OPERATING INCOME
DTW	1989	68,607,154	(51,600,240	17,006,914	(15,993,206	(67,593,445)	1,013,709
DTW	1990	75,681,405	(55,530,287	20,151,118	(17,169,883	(72,700,170)	2,981,235
DTW	1991	82,244,984	(64,500,976	17,744,008	(19,557,748	(84,058,723)	(1,813,740
DTW	1992						
FLL	1989	51,279,000	(23,510,000	27,769,000	(6,323,000	(29,833,000)	21,446,000
FLL	1990	54,534,000	(24,807,000	29,727,000	(7,217,000	(32,024,000)	22,510,000
FLL	1991	56,997,000	(28,474,000	28,523,000	(6,951,000	(35,425,000)	21,572,000
FLL	1992	50,822,000	(27,243,000	23,579,000	(6,981,000	(34,224,000)	16,598,000
GFK	1989	1,616,836	(1,637,456	(20,620	(732,502	(2,369,958)	(753,122
GFK	1990	2,105,371	(2,153,094	(47,723	(864,109	(3,017,203)	(911,832
GFK	1991	2,027,224	(2,123,022	(95,798	(996,260	(3,119,282)	(1,092,058
GFK	1992	2,157,784	(2,278,897	(121,113	(1,107,536	(3,386,432)	(1,228,649
GRR	1989	6,493,596	(3,989,585	2,504,011	(1,063,458	(5,053,044)	1,440,552
GRR	1990	6,860,228	(4,246,080	2,614,148	(1,101,262	(5,347,342)	1,512,887
GRR	1991	6,926,685	(4,548,855	2,377,830	(1,099,630	(5,648,486)	1,278,199
GRR	1992	8,468,674	(4,866,178	3,602,496	(1,179,793	(6,045,971)	2,422,703
ITO	1989						
ITO	1990						
ITO	1991	4,581,275	(7,119,776	(2,538,501			
ITO	1992						
HNL	1989						
HNL	1990						
HNL	1991	318,348,261	(64,687,633	253,660,628			
HNL	1992						

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AIR-PORT ID	FISCAL YEAR	OPERATING REVENUES	OPERATING EXPENSES EXCLUDING DEPRECTION	OPERATING INCOME BEFORE DEPRECTION	DEPRECTION	TOTAL OPERATING EXPENSES & DEPRECTION	NET OPERATING INCOME
IAH	1989	99,522,750	(53,576,000	45,946,750	(11,448,750	(65,024,750)	34,498,000
IAH	1990	107,439,250	(61,478,750	45,960,500	(16,055,250	(77,534,000)	29,905,250
IAH	1991	119,905,250	(70,024,250	49,881,000	(29,043,500	(99,067,750)	20,837,500
IAH	1992						
IND	1989	34,375,955	(12,482,717	21,893,238	(11,574,655	(24,057,372)	10,318,583
IND	1990	36,408,982	(13,815,874	22,593,108	(13,342,293	(27,158,167)	9,250,815
IND	1991	39,258,123	(15,190,906	24,067,217	(15,982,663	(31,173,569)	8,084,554
IND	1992						
JFK	1989	321,500,000	(245,000,000	76,500,000	(36,500,000	(281,500,000)	40,000,000
JFK	1990	351,000,000	(264,500,000	86,500,000	(40,000,000	(304,500,000)	46,500,000
JFK	1991	373,250,000	(265,500,000	107,750,000	(44,750,000	(310,250,000)	63,000,000
JFK	1992						
MCI	1989	34,459,718	(22,549,556	11,910,162	(9,292,039	(31,841,595)	2,618,123
MCI	1990	35,154,646	(25,329,137	9,825,509	(10,012,030	(35,341,167)	(186,521
MCI	1991	35,674,606	(24,723,530	10,951,076	(10,589,527	(35,313,057)	361,549
MCI	1992						
LGA	1989	140,750,000	(110,250,000	30,500,000	(14,750,000	(125,000,000)	15,750,000
LGA	1990	158,500,000	(127,500,000	31,000,000	(14,250,000	(141,750,000)	16,750,000
LGA	1991	168,500,000	(133,750,000	34,750,000	(16,250,000	(150,000,000)	18,500,000
LGA	1992						
LAS	1989	91,575,677	(33,608,531	57,967,146	(17,761,233	(51,369,763)	40,205,914
LAS	1990	102,275,785	(37,250,284	65,025,502	(19,326,693	(56,576,977)	45,698,809
LAS	1991	110,124,810	(41,419,435	68,705,375	(19,971,845	(61,391,280)	48,733,530
LAS	1992						

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LIT	1989	6,816,026	(4,354,373	2,461,653	(2,148,024	(6,502,396)	313,629
LIT	1990	7,105,842	(4,528,615	2,577,227	(2,173,505	(6,702,120)	403,722
LIT	1991	7,531,420	(4,796,277	2,735,142	(2,729,519	(7,525,796)	5,623
LIT	1992	8,302,682	(4,962,753	3,339,929	(3,454,212	(8,416,965)	(114,283
LAX	1989	175,753,750	(111,012,250	64,741,500	(28,494,250	(139,506,500)	36,247,250
LAX	1990	185,726,750	(120,366,750	65,360,000	(21,555,750	(141,922,500)	43,804,250
LAX	1991	196,749,250	(131,604,750	65,144,500	(7,200,000	(138,804,750)	57,944,500
LAX	1992						
SDF	1989	14,231,845	(7,755,300	6,476,545	(5,977,853	(13,733,153)	498,692
SDF	1990	16,405,167	(7,905,012	8,500,156	(7,103,393	(15,008,405)	1,396,763
SDF	1991	17,270,596	(8,478,791	8,791,805	(7,247,932	(15,726,722)	1,543,874
SDF	1992						
MEM	1989	35,072,586	(18,072,212	17,000,374	(8,411,478	(26,483,690)	8,588,896
MEM	1990	43,293,500	(19,877,500	23,416,000	(9,668,250	(29,545,750)	13,747,750
MEM	1991	45,189,750	(19,982,000	25,207,750	(10,659,750	(30,641,750)	14,548,000
MEM	1992						
MIA	1989	267,699,000	(194,016,000	73,683,000	(36,434,000	(230,450,000)	37,249,000
MIA	1990	293,325,000	(195,310,000	98,015,000	(40,098,000	(235,408,000)	57,917,000
MIA	1991						
MIA	1992						
MKE	1989	19,901,401	(13,386,494	6,514,907	(5,941,187	(19,327,681)	573,721
MKE	1990	21,353,238	(14,216,979	7,136,259	(6,397,786	(20,614,764)	738,474
MKE	1991	25,384,151	(15,544,808	9,839,343	(7,538,622	(23,083,430)	2,300,721
MKE	1992	27,925,240	(16,143,303	11,781,936	(8,193,448	(24,336,751)	3,588,489

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		FISCAL YEAR FINANCIAL STATISTICS					
AIR-PORT ID	FISCAL YEAR	OPERATING REVENUES	OPERATING EXPENSES EXCLUDING DEPRECTION	OPERATING INCOME BEFORE DEPRECTION	DEPRECTION	TOTAL OPERATING EXPENSES & DEPRECTION	NET OPERATING INCOME
MSP	1989						
MSP	1990						
MSP	1991						
MSP	1992						
BNA	1989	24,816,622	(15,727,817	9,088,805	(7,637,643	(23,365,459)	1,451,163
BNA	1990	28,831,231	(17,294,853	11,536,377	(9,025,461	(26,320,315)	2,510,916
BNA	1991	31,880,134	(18,602,927	13,277,208	(9,793,963	(28,396,889)	3,483,245
BNA	1992						
EWR	1989	177,250,000	(120,250,000	57,000,000	(27,750,000	(148,000,000)	29,250,000
EWR	1990	207,500,000	(125,250,000	82,250,000	(33,750,000	(159,000,000)	48,500,000
EWR	1991	234,250,000	(135,250,000	99,000,000	(35,750,000	(171,000,000)	63,250,000
EWR	1992	243,750,000	(137,250,000	106,500,000	(36,750,000	(174,000,000)	69,750,000
ORF	1989	12,007,967	(8,380,322	3,627,645	(2,922,182	(11,302,504)	705,463
ORF	1990	12,580,269	(8,268,348	4,311,921	(3,298,825	(11,567,173)	1,013,096
ORF	1991	12,986,788	(8,614,448	4,372,340	(3,497,874	(12,112,322)	874,466
ORF	1992						
OKC	1989	18,680,397	(9,368,482	9,311,915	(8,233,667	(17,602,149)	1,078,248
OKC	1990	20,293,444	(9,492,994	10,800,450	(8,779,122	(18,272,116)	2,021,328
OKC	1991	22,115,819	(9,408,365	12,707,454	(9,513,596	(18,921,960)	3,193,858
OKC	1992						
OMA	1989	13,932,877	(5,873,609	8,059,269	(5,329,573	(11,203,181)	2,729,696
OMA	1990	14,136,149	(6,155,240	7,980,909	(5,568,341	(11,723,581)	2,412,568
OMA	1991	14,719,266	(6,468,331	8,250,935	(5,778,641	(12,246,972)	2,472,294
OMA	1992	14,458,316	(6,605,027	7,853,289	(6,182,602	(12,787,629)	1,670,688

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FISCAL YEAR FINANCIAL STATISTICS

AIR-PORT ID	FISCAL YEAR	OPERATING REVENUES	OPERATING EXPENSES EXCLUDING DEPRECTION	OPERATING INCOME BEFORE DEPRECTION	DEPRECTION	TOTAL OPERATING EXPENSES & DEPRECTION	NET OPERATING INCOME
ONT	1989	19,256,250	(16,536,500	2,719,750	(2,608,750	(19,145,250)	111,000
ONT	1990	22,545,000	(19,207,000	3,338,000	(2,356,250	(21,563,250)	981,750
ONT	1991	25,422,000	(21,639,500	3,782,500	(2,588,250	(24,227,750)	1,194,250
ONT	1992						
MCO	1989	74,136,000	(33,473,000	40,663,000	(13,542,000	(47,015,000)	27,121,000
MCO	1990	104,186,000	(48,712,000	55,474,000	(19,397,000	(68,109,000)	36,077,000
MCO	1991	143,314,000	(58,083,000	85,231,000	(32,655,000	(90,738,000)	52,576,000
MCO	1992	150,295,000	(61,971,000	88,324,000	(35,119,000	(97,090,000)	53,205,000
PHL	1989	70,964,473	(49,774,385	21,190,088	(13,036,361	(62,810,745)	8,153,728
PHL	1990	78,596,456	(54,953,601	23,642,854	(13,814,265	(68,767,866)	9,828,590
PHL	1991	93,407,488	(63,384,194	30,023,294	(15,990,368	(79,374,563)	14,032,926
PHL	1992						
PHX	1989	73,562,750	(41,220,750	32,342,000	(11,508,250	(52,729,000)	20,833,750
PHX	1990	85,237,250	(45,996,250	39,241,000	(14,661,500	(60,657,750)	24,579,500
PHX	1991	101,531,000	(53,318,250	48,212,750	(22,475,250	(75,793,500)	25,737,500
PHX	1992						
PDX	1989	35,494,750	(21,523,500	13,971,250	(8,718,500	(30,242,000)	5,252,750
PDX	1990	40,749,500	(23,044,250	17,705,250	(10,917,500	(33,961,750)	6,787,750
PDX	1991	42,958,750	(25,260,500	17,698,250	(12,049,500	(37,310,000)	5,648,750
PDX	1992						
RDU	1989	30,157,508	(7,047,875	23,109,634	(12,524,079	(19,571,954)	10,585,555
RDU	1990	31,107,847	(7,524,816	23,583,031	(13,747,332	(21,272,148)	9,835,699
RDU	1991	31,613,612	(7,848,715	23,764,898	(14,206,237	(22,054,952)	9,558,661
RDU	1992						

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FISCAL YEAR FINANCIAL STATISTICS

AIRPORT ID	FISCAL YEAR	OPERATING REVENUES	OPERATING EXPENSES EXCLUDING DEPRECTION	OPERATING INCOME BEFORE DEPRECTION	DEPRECTION	TOTAL OPERATING EXPENSES & DEPRECTION	NET OPERATING INCOME
RNO	1989	19,606,723	(10,459,644	9,147,079	(5,065,069	(15,524,713)	4,082,010
RNO	1990	20,231,648	(11,395,246	8,836,402	(5,446,319	(16,841,565)	3,390,083
RNO	1991	21,479,710	(11,372,729	10,106,981	(5,820,871	(17,193,600)	4,286,110
RNO	1992						
RIC	1989						
RIC	1990	12,630,054	(6,888,709	5,741,345	(4,383,133	(11,271,842)	1,358,212
RIC	1991	12,643,873	(7,067,643	5,576,230	(4,521,656	(11,589,299)	1,054,574
RIC	1992						
SLC	1989	36,948,910	(14,984,137	21,964,774	(9,063,213	(24,047,350)	12,901,561
SLC	1990	40,419,681	(16,636,711	23,782,970	(10,278,007	(26,914,718)	13,504,963
SLC	1991	43,376,339	(18,949,444	24,426,895	(11,731,423	(30,680,866)	12,695,473
SLC	1992						
SFO	1989	131,555,419	(80,162,352	51,393,066	(23,526,644	(103,688,997)	27,866,422
SFO	1990	143,727,674	(88,815,743	54,911,931	(24,922,050	(113,737,793)	29,989,881
SFO	1991	158,648,348	(93,728,665	64,919,683	(28,153,535	(121,882,200)	36,766,148
SFO	1992						
SJC	1989	29,717,194	(23,807,553	5,909,641	(2,240,459	(26,048,012)	3,669,182
SJC	1990	38,421,872	(30,477,983	7,943,889	(3,257,934	(33,735,916)	4,685,956
SJC	1991	47,447,761	(34,838,343	12,609,418	(5,607,435	(40,445,778)	7,001,983
SJC	1992						
SRQ	1989	5,406,572	(4,379,439	1,027,133	(1,241,069	(5,620,508)	(213,936
SRQ	1990	8,277,300	(6,185,279	2,092,021	(3,537,440	(9,722,719)	(1,445,419
SRQ	1991	14,631,055	(8,380,018	6,251,037	(4,570,028	(12,950,046)	1,681,009
SRQ	1992	13,811,305	(8,787,092	5,024,213	(4,768,719	(13,555,811)	255,494

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FISCAL YEAR FINANCIAL STATISTICS

AIR-PORT ID	FISCAL YEAR	OPERATING REVENUES	OPERATING EXPENSES EXCLUDING DEPRECTION	OPERATING INCOME BEFORE DEPRECTION	DEPRECTION	TOTAL OPERATING EXPENSES & DEPRECTION	NET OPERATING INCOME
STL	1989	58,586,866	(31,558,542	27,028,324	(15,012,192	(46,570,734)	12,016,133
STL	1990	60,468,784	(33,132,518	27,336,266	(15,664,126	(48,796,644)	11,672,140
STL	1991	65,771,836	(37,734,302	28,037,535	(16,442,250	(54,176,551)	11,595,285
STL	1992						
TPA	1989	47,880,229	(24,119,354	23,760,875			
TPA	1990	55,984,573	(27,294,128	28,690,445			
TPA	1991	58,032,991	(29,257,928	28,775,063	(14,463,618	(43,721,546)	14,311,445
TPA	1992	66,074,585	(32,184,312	33,890,273	(18,095,319	(50,279,631)	15,794,954
TUL	1989	14,184,467	(8,984,952	5,199,515	(8,002,054	(16,987,005)	(2,802,539
TUL	1990	16,434,190	(9,457,298	6,976,893	(8,204,629	(17,661,926)	(1,227,736
TUL	1991	17,203,045	(9,667,492	7,535,553	(8,014,020	(17,681,512)	(478,467
TUL	1992						
IAD	1989	49,267,765	(36,776,642	12,491,123	(5,044,418	(41,821,060)	7,446,705
IAD	1990	70,375,671	(41,858,349	28,517,322	(6,400,307	(48,258,656)	22,117,015
IAD	1991	77,350,009	(47,658,478	29,691,531	(6,356,988	(54,015,466)	23,334,543
IAD	1992	83,190,899	(52,788,234	30,402,665	(6,645,336	(59,433,570)	23,757,329
DCA	1989	44,702,875	(30,032,527	14,670,348	(864,948	(30,897,475)	13,805,400
DCA	1990	60,274,689	(35,033,821	25,240,868	(1,379,905	(36,413,726)	23,860,963
DCA	1991	52,952,291	(39,786,635	13,165,656	(1,636,938	(41,423,573)	11,528,718
DCA	1992	67,745,576	(42,633,380	25,112,196	(1,790,574	(44,423,954)	23,321,622
ICT	1989	26,020,797	(22,038,302	3,982,495	(3,766,151	(25,804,452)	216,345
ICT	1990	16,000,736	(12,358,342	3,642,395	(4,705,050	(17,063,391)	(1,062,655
ICT	1991	11,562,211	(7,960,899	3,601,312	(6,424,299	(14,385,198)	(2,822,987
ICT	1992						

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FISCAL YEAR FINANCIAL STATISTICS

AIR-PORT ID	FISCAL YEAR	OPERATING REVENUES	OPERATING EXPENSES EXCLUDING DEPRECTION	OPERATING INCOME BEFORE DEPRECTION	DEPRECTION	TOTAL OPERATING EXPENSES & DEPRECTION	NET OPERATING INCOME
SNA	1989	23,349,750	(11,488,000	11,861,750	(1,475,250	(12,963,250)	10,386,500
SNA	1990	29,383,500	(14,906,250	14,477,250	(3,196,250	(18,102,500)	11,281,000
SNA	1991	46,732,750	(21,519,500	25,213,250	(8,075,000	(29,594,500)	17,138,250
SNA	1992						

APPENDIX C

AIRPORT INFRASTRUCTURE AND CAPACITY STATISTICS

UNITED STATES AIRPORT SAMPLE, FY 1989 - 1992

AIRPORT INFRASTRUCTURE AND CAPACITY STATISTICS

AIR-PORT ID	FISCAL YEAR	ST	HUB CLS	NUMBER OF RUNWAYS	LONGEST RUNWAY	VFR CAPACITY	IFR CAPACITY	NUMBER OF GATES	FAA IFR ARRIVAL CAPACITY
ABQ	1989	NM	M	4	8500	120	45	22	26
ABQ	1990	NM	M	4	8500	120	45	22	26
ABQ	1991	NM	M	4	8500	120	45	22	26
ABQ	1992	NM	M						
BWI	1989	MD	M	4	9519	99	99	47	26
BWI	1990	MD	M	4	9519	99	99	47	26
BWI	1991	MD	M	4	9519	99	99	47	26
BWI	1992	MD	M	4	9519	99	99	47	26
BOI	1989	ID	S	2	9763	118	54	9	26
BOI	1990	ID	S	2	9763	118	54	9	26
BOI	1991	ID	S	2	9763	118	54	9	26
BOI	1992	ID	S	2	9763	118	54	9	26
CHS	1989	SC	S	2	9000	79	54	10	26
CHS	1990	SC	S	2	9000	79	54	10	26
CHS	1991	SC	S	2	9000	79	54	10	26
CHS	1992	SC	S						
CVG	1989	KY	M	3	10000	115	105	43	
CVG	1990	KY	M	3	10000	115	105	43	
CVG	1991	KY	M	3	10000	115	105	43	
CVG	1992	KY	M	3	10000	115	105	43	
CLE	1989	OH	L	6	8999	65	60	42	26
CLE	1990	OH	L	6	8999	65	60	42	26
CLE	1991	OH	L	6	8999	65	60	42	26
CLE	1992	OH	L	6	8999	65	60	51	26

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AIRPORT INFRASTRUCTURE AND CAPACITY STATISTICS

AIR-PORT ID	FISCAL YEAR	ST	HUB CLS	NUMBER OF RUNWAYS	LONGEST RUNWAY	VFR CAPACITY	IFR CAPACITY	NUMBER OF GATES	FAA IFR ARRIVAL CAPACITY
CMH	1989	OH	M	3	10250			28	36
CMH	1990	OH	M	3	10250			28	36
CMH	1991	OH	M	3	10250			28	36
CMH	1992	OH	M	3	10250			28	36
DAL	1989	TX	L	3	8800	72		15	36
DAL	1990	TX	L	3	8800	72		15	36
DAL	1991	TX	L	3	8800	72		15	36
DAL	1992	TX	L	3	8800	72		15	36
DFW	1989	TX	L	6	11400	252	124	113	52
DFW	1990	TX	L	6	11400	252	124	113	52
DFW	1991	TX	L	6	11400	252	124	113	52
DFW	1992	TX	L						
DEN	1989	CO	L	4	12000	122	32	104	
DEN	1990	CO	L	4	12000	122	32	104	
DEN	1991	CO	L	4	12000	122	32	104	
DEN	1992	CO	L	4	12000	122	32	104	
APA	1989	CO	L	3	10000			0	
APA	1990	CO	L	3	10000			0	
APA	1991	CO	L	3	10000			0	
APA	1992	CO	L	3	10000			0	
DSM	1989	IA	S	3	9000			13	26
DSM	1990	IA	S	3	9000			13	26
DSM	1991	IA	S	3	9000			13	26
DSM	1992	IA	S						

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AIRPORT INFRASTRUCTURE AND CAPACITY STATISTICS

AIR-PORT ID	FISCAL YEAR	ST	HUB CLS	NUMBER OF RUNWAYS	LONGEST RUNWAY	VFR CAPACITY	IFR CAPACITY	NUMBER OF GATES	FAA IFR ARRIVAL CAPACITY
DTW	1989	MI	L	4	12000	70	30	89	52
DTW	1990	MI	L	4	12000	70	30	89	52
DTW	1991	MI	L	4	12000	70	30	89	52
DTW	1992	MI	L						
FLL	1989	FL	L						26
FLL	1990	FL	L						26
FLL	1991	FL	L						26
FLL	1992	FL	L						26
GFK	1989	ND	N	3	7350	225	35	2	
GFK	1990	ND	N	3	7350	225	35	2	
GFK	1991	ND	N	3	7350	225	35	2	
GFK	1992	ND	N	3	7350	225	35	2	
GRR	1989	MI	S	3	10000			12	26
GRR	1990	MI	S	3	10000			12	26
GRR	1991	MI	S	3	10000			12	26
GRR	1992	MI	S	3	10000			12	26
ITO	1989	HI	M						26
ITO	1990	HI	M						26
ITO	1991	HI	M						26
ITO	1992	HI	M						26
HNL	1989	HI	L						52
HNL	1990	HI	L						52
HNL	1991	HI	L						52
HNL	1992	HI	L						52

UNITED STATES AIRPORT SAMPLE, FY 1989 - 1992

AIRPORT INFRASTRUCTURE AND CAPACITY STATISTICS

AIRPORT ID	FISCAL YEAR	ST	HUB CLS	NUMBER OF RUNWAYS	LONGEST RUNWAY	VFR CAPACITY	IFR CAPACITY	NUMBER OF GATES	FAA IFR ARRIVAL CAPACITY
IAH	1989	TX	L	4	12000	144	144	82	52
IAH	1990	TX	L	4	12000	144	144	82	52
IAH	1991	TX	L	4	12000	144	144	82	52
IAH	1992	TX	L						
IND	1989	IN	M	3	10000			34	36
IND	1990	IN	M	3	10000			34	36
IND	1991	IN	M	3	10000			34	36
IND	1992	IN	M						
JFK	1989	NY	L	4	14600	104	80	178	36
JFK	1990	NY	L	4	14600	104	80	178	36
JFK	1991	NY	L	4	14600	104	80	178	36
JFK	1992	NY	L						
MCI	1989	MO	L	3	10800	109	105	56	26
MCI	1990	MO	L	3	10800	109	105	56	26
MCI	1991	MO	L	3	10800	109	105	56	26
MCI	1992	MO	L						
LGA	1989	NY	L	2	7000	76	73	52	26
LGA	1990	NY	L	2	7000	76	73	52	26
LGA	1991	NY	L	2	7000	76	73	52	26
LGA	1992	NY	L						
LAS	1989	NV	L	4	12636	96	82	60	26
LAS	1990	NV	L	4	12636	96	82	60	26
LAS	1991	NV	L	4	12636	96	82	60	26
LAS	1992	NV	L						

UNITED STATES AIRPORT SAMPLE, FY 1989 - 1992

AIRPORT INFRASTRUCTURE AND CAPACITY STATISTICS

AIR-PORT ID	FISCAL YEAR	ST	HUB CLS	NUMBER OF RUNWAYS	LONGEST RUNWAY	VFR CAPACITY	IFR CAPACITY	NUMBER OF GATES	FAA IFR ARRIVAL CAPACITY
LIT	1989	AR	S	2	7200				52
LIT	1990	AR	S	2	7200				52
LIT	1991	AR	S	3	7200				52
LIT	1992	AR	S	3	7200				52
LAX	1989	CA	L	8	12090	140		122	52
LAX	1990	CA	L	8	12090	140		122	52
LAX	1991	CA	L	8	12090	140		122	52
LAX	1992	CA	L						
SDF	1989	KY	M	2	10000	69	57	21	26
SDF	1990	KY	M	2	10000	69	57	21	26
SDF	1991	KY	M	2	10000	69	57	21	26
SDF	1992	KY	M						
MEM	1989	TN	M	3	9319	145	120	72	36
MEM	1990	TN	M	3	9319	145	120	72	36
MEM	1991	TN	M	3	9319	145	120	72	36
MEM	1992	TN	M						
MIA	1989	FL	L	3	13500	120		113	49
MIA	1990	FL	L	3	13500	120		113	49
MIA	1991	FL	L						
MIA	1992	FL	L						
MKE	1989	WI	M	5	9690	109	57	42	26
MKE	1990	WI	M	5	9690	109	57	42	26
MKE	1991	WI	M	5	9690	109	57	42	26
MKE	1992	WI	M	5	9690	109	57	42	26

UNITED STATES AIRPORT SAMPLE, FY 1989 - 1992

AIRPORT INFRASTRUCTURE AND CAPACITY STATISTICS

AIR-PORT ID	FISCAL YEAR	ST	HUB CLS	NUMBER OF RUNWAYS	LONGEST RUNWAY	VFR CAPACITY	IFR CAPACITY	NUMBER OF GATES	FAA IFR ARRIVAL CAPACITY
MSP	1989	MN	L	3	10000				36
MSP	1990	MN	L						36
MSP	1991	MN	L						36
MSP	1992	MN	L						36
BNA	1989	TN	M	4	9200		100	46	52
BNA	1990	TN	M	4	9200		100	46	52
BNA	1991	TN	M	4	9200		100	46	52
BNA	1992	TN	M						
EWR	1989	NJ	L	3	9300	116	116	97	26
EWR	1990	NJ	L	3	9300	116	116	97	26
EWR	1991	NJ	L	3	9300	116	116	97	26
EWR	1992	NJ	L	3	9300	116	116	97	26
ORF	1989	VA	M	2	9000	103	57	24	26
ORF	1990	VA	M	2	9000	103	57	24	26
ORF	1991	VA	M	2	9000	103	57	24	26
ORF	1992	VA	M						
OKC	1989	OK	M	4	9800	125	102	17	52
OKC	1990	OK	M	4	9800	125	102	17	52
OKC	1991	OK	M	4	9800	125	102	17	52
OKC	1992	OK	M						
OMA	1989	NE	M	3	8500	146	51	20	26
OMA	1990	NE	M	3	8500	146	51	20	26
OMA	1991	NE	M	3	8500	146	51	20	26
OMA	1992	NE	M	3	8500	146	51	20	26

UNITED STATES AIRPORT SAMPLE, FY 1989 - 1992

AIRPORT INFRASTRUCTURE AND CAPACITY STATISTICS

AIR-PORT ID	FISCAL YEAR	ST	HUB CLS	NUMBER OF RUNWAYS	LONGEST RUNWAY	VFR CAPACITY	IFR CAPACITY	NUMBER OF GATES	FAA IFR ARRIVAL CAPACITY
ONT	1989	CA	S	2	12200	121	56	20	26
ONT	1990	CA	S	2	12200	121	56	20	26
ONT	1991	CA	S	2	12200	121	56	20	26
ONT	1992	CA	S						
MCO	1989	FL	L	3	12000			60	52
MCO	1990	FL	L	3	12000			99	52
MCO	1991	FL	L	3	12000			99	52
MCO	1992	FL	L	3	12000			99	52
PHL	1989	PA	L	3	10500	88	74	63	52
PHL	1990	PA	L	3	10500	88	74	63	52
PHL	1991	PA	L	3	10500	88	74	63	52
PHL	1992	PA	L						
PHX	1989	AZ	L	2	11001			90	26
PHX	1990	AZ	L	2	11001			90	26
PHX	1991	AZ	L	2	11001			90	26
PHX	1992	AZ	L						
PDX	1989	OR	M	3	11000			41	36
PDX	1990	OR	M	3	11000			41	36
PDX	1991	OR	M	3	11000			41	36
PDX	1992	OR	M						
RDU	1989	NC	M	2	10000	100	75	56	36
RDU	1990	NC	M	2	10000	100	75	56	36
RDU	1991	NC	M	2	10000	100	75	56	36
RDU	1992	NC	M						

UNITED STATES AIRPORT SAMPLE, FY 1989 - 1992

AIRPORT INFRASTRUCTURE AND CAPACITY STATISTICS

AIR-PORT ID	FISCAL YEAR	ST	HUB CLS	NUMBER OF RUNWAYS	LONGEST RUNWAY	VFR CAPACITY	IFR CAPACITY	NUMBER OF GATES	FAA IFR ARRIVAL CAPACITY
RNO	1989	NV	M	3	10000	130	51	21	26
RNO	1990	NV	M	3	10000	130	51	21	26
RNO	1991	NV	M	3	10000	130	51	21	26
RNO	1992	NV	M						
RIC	1989	VA	S						
RIC	1990	VA	S	3	9003	100	60	19	26
RIC	1991	VA	S	3	9003	100	60	19	26
RIC	1992	VA	S						
SLC	1989	UT	M	3	12003	110	48	54	36
SLC	1990	UT	M	3	12003	110	48	54	36
SLC	1991	UT	M	3	12003	110	48	54	36
SLC	1992	UT	M						
SFO	1989	CA	L	4	11870	102	51	80	26
SFO	1990	CA	L	4	11870	102	51	80	26
SFO	1991	CA	L	4	11870	102	51	80	26
SFO	1992	CA	L						
SJC	1989	CA	S	3	8900			30	26
SJC	1990	CA	S	3	8900			30	26
SJC	1991	CA	S	3	8900			30	26
SJC	1992	CA	S						
SRQ	1989	FL	S	2	7003	90	60	13	26
SRQ	1990	FL	S	2	7003	90	60	13	26
SRQ	1991	FL	S	2	7003	90	60	13	26
SRQ	1992	FL	S	2	7003	90	60	13	26

UNITED STATES AIRPORT SAMPLE, FY 1989 - 1992

AIRPORT INFRASTRUCTURE AND CAPACITY STATISTICS

AIR-PORT ID	FISCAL YEAR	ST	HUB CLS	NUMBER OF RUNWAYS	LONGEST RUNWAY	VFR CAPACITY	IFR CAPACITY	NUMBER OF GATES	FAA IFR ARRIVAL CAPACITY
STL	1989	MO	L	5	11019	112	87	78	26
STL	1990	MO	L	5	11019	112	87	78	26
STL	1991	MO	L	5	11019	112	87	78	26
STL	1992	MO	L						
TPA	1989	FL	L	3	11000	140	50	45	52
TPA	1990	FL	L	3	11000	140	50	45	52
TPA	1991	FL	L	3	11000	140	50	45	52
TPA	1992	FL	L	3	11000	140	50	45	52
TUL	1989	OK	M	3	10000	117	73	16	52
TUL	1990	OK	M	3	10000	117	73	16	52
TUL	1991	OK	M	3	10000	117	73	16	52
TUL	1992	OK	M						
IAD	1989	VA	L						52
IAD	1990	VA	L						52
IAD	1991	VA	L						52
IAD	1992	VA	L						52
DCA	1989	DC	L	3	6869		60	44	26
DCA	1990	DC	L	3	6869		60	44	26
DCA	1991	DC	L	3	6869		60	44	26
DCA	1992	DC	L	3	6869		60	44	26
ICT	1989	KS	S	3	10300	151	116	12	52
ICT	1990	KS	S	3	10300	151	116	12	52
ICT	1991	KS	S	3	10300	151	116	12	52
ICT	1992	KS	S						

UNITED STATES AIRPORT SAMPLE, FY 1989 - 1992

AIRPORT INFRASTRUCTURE AND CAPACITY STATISTICS

AIR-PORT ID	FISCAL YEAR	ST	HUB CLS	NUMBER OF RUNWAYS	LONGEST RUNWAY	VFR CAPACITY	IFR CAPACITY	NUMBER OF GATES	FAA IFR ARRIVAL CAPACITY
SNA	1989	CA	L						26
SNA	1990	CA	L						26
SNA	1991	CA	L						26
SNA	1992	CA	L						26

APPENDIX D

AIRPORT FLIGHT OPERATIONS STATISTICS

UNITED STATES AIRPORT SAMPLE, FY 1989 - 1992

AIR-PORT ID	FISCAL YEAR	FISCAL YEAR TOTAL OPERATIONS	FISCAL YEAR OPERATIONS: AIR CARRIER	AIR TAXI	ITINERANT GENERAL AVIATION	LOCAL GENERAL AVIATION	ITINERANT MILITARY	LOCAL MILITARY
ABQ	1989	231,316	69,776	41,094	79,279	1,930	33,059	6,178
ABQ	1990	226,153	70,125	39,788	77,396	2,420	31,237	5,187
ABQ	1991	211,561	64,931	36,590	72,838	3,124	27,083	6,995
ABQ	1992	211,601	64,951	38,170	72,068	3,326	26,048	7,038
BWI	1989	306,717	158,792	84,961	60,565	1,010	1,219	170
BWI	1990	303,502	157,850	88,116	54,700	815	1,883	138
BWI	1991	282,320	148,637	84,003	46,628	1,211	1,741	100
BWI	1992	265,844	128,648	85,862	42,986	4,844	2,542	962
BOI	1989	159,882	18,018	35,121	61,926	22,084	16,292	6,441
BOI	1990	168,450	18,761	40,140	63,715	24,425	16,576	4,833
BOI	1991	152,746	18,058	35,069	58,548	22,044	14,836	4,191
BOI	1992	161,434	18,613	36,420	65,252	22,885	12,829	5,435
CHS	1989	130,057	26,572	2,466	37,205	2,443	25,271	36,100
CHS	1990	132,096	28,908	1,939	37,905	2,790	25,679	34,875
CHS	1991	131,444	26,330	1,802	34,788	3,902	31,090	33,532
CHS	1992	135,599	23,264	2,646	34,590	4,096	27,047	43,956
CVG	1989	264,699	128,855	108,502	25,240	561	1,541	0
CVG	1990	284,519	132,568	127,409	22,264	560	1,718	0
CVG	1991	297,963	142,438	135,106	18,676	90	1,649	4
CVG	1992	304,214	151,969	139,412	11,650	0	1,183	0
CLE	1989	256,537	139,252	64,234	47,692	1,647	3,696	16
CLE	1990	273,081	152,337	71,713	45,044	644	3,331	12
CLE	1991	244,626	135,405	71,946	34,355	158	2,668	94
CLE	1992	237,216	122,026	80,467	31,612	48	3,053	10

UNITED STATES AIRPORT SAMPLE, FY 1989 - 1992

AIR-PORT ID	FISCAL YEAR	FISCAL YEAR TOTAL OPERATIONS	FISCAL YEAR OPERATIONS AIR CARRIER	AIR TAXI	ITINERANT GENERAL AVIATION	LOCAL GENERAL AVIATION	ITINERANT MILITARY	LOCAL MILITARY
CMH	1989	233,223	59,292	51,073	74,271	45,005	2,196	1,386
CMH	1990	224,295	57,891	55,936	71,871	34,732	2,414	1,451
CMH	1991	192,712	90,381	58,854	40,394	860	2,203	20
CMH	1992	149,879	54,008	51,676	39,485	2,496	2,168	46
DAL	1989	213,705	77,983	25,502	108,300	342	1,578	0
DAL	1990	214,468	80,894	24,036	107,768	47	1,721	2
DAL	1991	208,015	85,145	19,602	101,871	92	1,305	0
DAL	1992	212,049	89,174	24,110	97,404	4	1,357	0
DFW	1989	693,614	505,822	168,258	18,501	0	1,033	0
DFW	1990	724,786	532,911	174,378	16,541	0	956	0
DFW	1991	731,070	547,144	167,296	15,860	0	770	0
DFW	1992	763,372	571,260	175,338	15,793	0	981	0
DEN	1989	468,490	323,165	104,560	38,707	204	1,854	0
DEN	1990	474,922	303,988	129,911	39,169	199	1,655	0
DEN	1991	491,275	304,134	151,029	33,896	162	2,054	0
DEN	1992	499,001	316,128	149,913	31,479	101	1,380	0
APA	1989	367,700	0	4,001	166,104	189,069	4,103	4,423
APA	1990	370,104	0	4,045	161,437	196,677	2,146	5,799
APA	1991	366,731	0	3,422	157,479	200,210	1,752	3,868
APA	1992	371,478	0	4,876	165,111	193,063	1,998	6,430
DSM	1989	159,598	33,106	21,614	72,622	22,675	6,090	3,491
DSM	1990	146,257	28,528	20,066	70,285	18,584	5,988	2,806
DSM	1991	144,952	27,616	23,073	64,968	20,118	5,775	3,402
DSM	1992	139,135	27,179	21,763	62,436	18,349	6,054	3,354

UNITED STATES AIRPORT SAMPLE, FY 1989 - 1992

AIR-PORT ID	FISCAL YEAR	FISCAL YEAR TOTAL OPERATIONS	FISCAL YEAR OPERATIONS: AIR CARRIER	AIR TAXI	ITINERANT GENERAL AVIATION	LOCAL GENERAL AVIATION	ITINERANT MILITARY	LOCAL MILITARY
DTW	1989	368,897	269,199	47,176	52,312	0	210	0
DTW	1990	391,165	279,148	56,001	55,796	0	220	0
DTW	1991	390,863	271,720	68,429	50,147	0	567	0
DTW	1992	413,544	277,880	83,788	49,804	0	2,072	0
FLL	1989	216,740	89,820	51,097	69,853	4,970	968	32
FLL	1990	224,120	98,777	54,105	64,475	5,229	1,518	16
FLL	1991	209,752	89,666	51,434	60,236	7,223	1,149	44
FLL	1992	204,183	83,157	45,128	68,035	6,439	1,390	34
GFK	1989	284,783	4,222	4,312	91,601	183,921	662	65
GFK	1990	305,274	3,948	4,183	108,970	187,682	491	0
GFK	1991	276,989	3,780	4,595	103,556	164,423	583	52
GFK	1992	240,251	3,580	6,935	91,716	137,102	588	330
GRR	1989	151,124	23,884	21,093	63,317	40,618	1,286	926
GRR	1990	168,645	25,429	24,772	65,213	51,377	1,332	522
GRR	1991	171,425	25,093	29,792	62,762	51,722	1,312	744
GRR	1992	152,260	24,069	25,344	57,705	43,220	1,074	848
ITO	1989	92,862	17,251	24,431	15,846	18,345	7,782	9,207
ITO	1990	100,080	18,878	39,293	13,070	14,116	6,885	7,838
ITO	1991	89,252	20,037	39,432	9,249	11,298	4,404	4,832
ITO	1992	89,284	20,591	36,524	10,180	10,456	4,709	6,824
HNL	1989	406,110	195,981	67,022	78,118	21,523	40,145	3,321
HNL	1990	406,825	194,000	56,909	80,414	37,504	34,780	3,218
HNL	1991	393,709	194,293	63,608	74,636	37,319	20,899	2,954
HNL	1992	413,725	201,999	59,984	81,786	38,110	27,831	4,015

UNITED STATES AIRPORT SAMPLE, FY 1989 - 1992

AIR-PORT ID	FISCAL YEAR	FISCAL YEAR TOTAL OPERATIONS	FISCAL YEAR OPERATIONS: AIR CARRIER	AIR TAXI	ITINERANT GENERAL AVIATION	LOCAL GENERAL AVIATION	ITINERANT MILITARY	LOCAL MILITARY
IAH	1989	294,011	207,163	44,601	41,217	0	1,030	0
IAH	1990	310,477	215,990	51,192	41,840	0	1,455	0
IAH	1991	310,404	208,315	59,415	41,235	0	1,439	0
IAH	1992	320,243	218,906	56,857	42,473	0	2,007	0
IND	1989	202,615	99,530	41,353	57,034	2,074	2,376	248
IND	1990	225,123	111,686	53,753	55,603	1,705	2,263	113
IND	1991	234,045	120,451	58,691	51,811	1,312	1,697	83
IND	1992	247,553	122,249	73,322	49,651	780	1,483	68
JFK	1989	336,731	220,467	91,220	24,339	0	705	0
JFK	1990	342,275	219,497	102,020	20,094	0	664	0
JFK	1991	304,315	202,294	83,508	16,470	0	2,043	0
JFK	1992	328,528	205,689	106,262	16,111	0	466	0
MCI	1989	239,018	150,889	67,199	17,404	1,116	1,170	1,240
MCI	1990	162,039	108,519	33,235	16,845	1,182	1,134	1,124
MCI	1991	168,193	111,569	36,641	16,559	1,410	1,157	857
MCI	1992	176,754	110,356	49,265	14,783	719	1,125	506
LGA	1989	355,568	262,784	65,426	26,904	0	454	0
LGA	1990	364,965	273,682	67,672	23,129	0	482	0
LGA	1991	332,930	255,163	58,798	18,542	0	427	0
LGA	1992	337,279	254,848	65,356	16,754	0	321	0
LAS	1989	378,117	183,362	78,700	88,519	20,503	6,176	857
LAS	1990	394,883	198,083	79,804	91,822	19,900	5,029	245
LAS	1991	398,637	211,973	78,413	85,054	18,217	4,766	214
LAS	1992	407,668	201,688	95,365	86,768	16,745	6,952	150

UNITED STATES AIRPORT SAMPLE, FY 1989 - 1992

AIR-PORT ID	FISCAL YEAR	FISCAL YEAR TOTAL OPERATIONS	FISCAL YEAR OPERATIONS: AIR CARRIER	AIR TAXI	ITINERANT GENERAL AVIATION	LOCAL GENERAL AVIATION	ITINERANT MILITARY	LOCAL MILITARY
LIT	1989	147,676	32,623	8,129	85,174	10,838	4,720	6,192
LIT	1990	149,109	32,861	8,490	85,600	9,747	6,022	6,389
LIT	1991	140,255	32,978	9,939	77,195	10,439	4,282	5,422
LIT	1992	162,439	36,030	12,231	83,136	13,537	6,659	10,846
LAX	1989	632,237	427,419	151,785	42,670	5,311	5,000	52
LAX	1990	668,816	450,418	162,508	42,775	8,526	4,425	164
LAX	1991	660,680	417,086	178,450	47,537	5,834	11,689	84
LAX	1992	678,398	407,152	193,419	50,960	12,915	13,620	332
SDF	1989	151,093	83,916	22,646	36,341	3,585	4,171	434
SDF	1990	159,920	81,988	27,323	41,547	3,912	4,799	351
SDF	1991	158,050	84,350	28,059	38,076	2,712	4,385	468
SDF	1992	156,083	83,553	27,637	36,956	1,549	5,484	904
MEM	1989	334,461	197,470	58,303	70,775	956	6,738	219
MEM	1990	329,937	184,339	69,772	67,763	1,474	6,447	142
MEM	1991	321,814	171,613	81,892	60,548	1,113	6,492	156
MEM	1992	344,655	165,445	114,130	58,805	719	5,425	131
MIA	1989	378,257	247,256	55,208	70,541	0	5,152	0
MIA	1990	463,066	278,754	99,544	77,542	0	7,226	0
MIA	1991	481,709	281,295	121,433	73,200	0	5,781	0
MIA	1992	486,222	274,964	126,034	75,569	0	9,655	0
MKE	1989	197,394	73,655	40,904	58,653	17,563	5,710	909
MKE	1990	209,401	82,054	54,404	50,205	16,647	5,313	778
MKE	1991	205,587	76,429	54,680	49,160	19,539	5,295	484
MKE	1992	202,286	74,545	56,727	46,964	16,936	6,318	796

UNITED STATES AIRPORT SAMPLE, FY 1989 - 1992

AIR-PORT ID	FISCAL YEAR	FISCAL YEAR TOTAL OPERATIONS	FISCAL YEAR OPERATIONS: AIR CARRIER	AIR TAXI	ITINERANT GENERAL AVIATION	LOCAL GENERAL AVIATION	ITINERANT MILITARY	LOCAL MILITARY
MSP	1989	376,239	230,656	76,290	52657	11,642	4,927	67
MSP	1990	382,046	226,821	80,533	67,623	4,210	2,853	6
MSP	1991	382,856	229,251	79,683	68,201	3,315	2,344	62
MSP	1992	404,243	241,984	80,128	75,025	4,114	2,986	6
BNA	1989	275,659	129,448	54,790	83,232	1,473	6,649	67
BNA	1990	259,263	109,435	64,540	77,377	1,675	6,207	29
BNA	1991	274,139	125,335	81,407	60,735	624	6,001	37
BNA	1992	302,030	132,715	102,921	59,616	275	6,481	22
EWR	1989	376,789	269,839	82,197	24,102	0	552	0
EWR	1990	384,148	271,862	88,328	23,275	0	683	0
EWR	1991	381,850	275,009	85,651	20,648	0	542	0
EWR	1992	403,978	283,651	99,125	20,730	0	472	0
ORF	1989	158,105	53,279	6,804	68,744	14,082	14,973	223
ORF	1990	161,211	52,357	10,450	71,385	13,304	13,589	126
ORF	1991	142,742	49,671	11,636	60,606	9,870	10,939	20
ORF	1992	138,084	43,183	15,139	54,724	8,939	15,953	146
OKC	1989	137,173	57,280	6,791	39,885	18,206	3,715	11,296
OKC	1990	145,342	54,738	4,778	51,777	14,620	11,390	8,039
OKC	1991	148,712	56,117	3,750	63,981	3,287	18,061	3,516
OKC	1992	163,336	57,087	8,097	70,125	4,151	20,673	3,203
OMA	1989	158,207	44,780	25,801	51,794	33,464	1,099	1,269
OMA	1990	153,189	42,828	24,098	54,015	29,709	1,161	1,378
OMA	1991	164,008	40,684	24,949	56,624	39,484	1,019	1,248
OMA	1992	155,058	37,061	24,347	56,159	35,854	812	825

UNITED STATES AIRPORT SAMPLE, FY 1989 - 1992

			FISCAL YEAR OPERATIONS					
AIR-PORT ID	FISCAL YEAR	FISCAL YEAR TOTAL OPERATIONS	AIR CARRIER	AIR TAXI	ITINERANT GENERAL AVIATION	LOCAL GENERAL AVIATION	ITINERANT MILITARY	LOCAL MILITARY
ONT	1989	142,680	85,191	25,018	28,864	3,080	525	2
ONT	1990	151,076	88,199	24,420	33,195	4,771	489	2
ONT	1991	156,306	93,716	27,261	29,353	5,676	294	6
ONT	1992	152,935	92,506	29,399	28,023	2,561	442	4
MCO	1989	285,637	190,921	48,726	41,423	135	4,336	96
MCO	1990	277,799	181,345	61,402	31,073	354	3,606	19
MCO	1991	275,157	185,857	62,914	23,712	0	2,674	0
MCO	1992	294,387	201,452	64,918	23,229	0	4,788	0
PHL	1989	383,279	181,342	143,386	57,700	0	851	0
PHL	1990	405,089	221,676	128,002	54,440	0	971	0
PHL	1991	382,646	206,173	121,481	51,914	0	3,078	0
PHL	1992	377,033	204,628	120,609	45,543	0	6,253	0
PHX	1989	479,790	285,493	66,214	115,825	4,152	7,988	118
PHX	1990	497,065	293,670	76,924	112,535	4,640	9,224	72
PHX	1991	499,157	301,957	72,352	110,870	6,987	6,771	220
PHX	1992	487,615	300,352	72,710	96,906	8,025	9,538	84
PDX	1989	267,807	97,051	92,372	59,657	3,580	12,725	2,422
PDX	1990	271,777	99,211	97,147	57,500	3,415	12,991	1,513
PDX	1991	264,854	93,479	98,790	56,692	2,081	12,483	1,329
PDX	1992	269,445	89,014	105,966	58,119	2,509	12,439	1,398
RDU	1989	272,512	129,543	52,360	78,681	3,457	7,832	639
RDU	1990	283,445	125,317	64,370	79,870	5,057	8,276	555
RDU	1991	270,534	118,339	70,212	70,722	4,210	6,401	650
RDU	1992	289,462	119,964	88,995	67,912	3,308	8,261	1,022

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AIR-PORT ID	FISCAL YEAR	FISCAL YEAR TOTAL OPERATIONS	FISCAL YEAR OPERATIONS: AIR CARRIER	AIR TAXI	ITINERANT GENERAL AVIATION	LOCAL GENERAL AVIATION	ITINERANT MILITARY	LOCAL MILITARY
RNO	1989	162,604	45,174	15,411	66,376	27,580	6,374	1,689
RNO	1990	163,673	44,775	18,723	67,554	22,645	7,912	2,064
RNO	1991	160,107	49,457	18,128	60,229	21,844	7,807	2,642
RNO	1992	161,839	49,579	20,124	60,006	21,066	8,744	2,320
RIC	1989	154,193	34,742	25,266	64,803	7,792	12,613	8,977
RIC	1990	160,204	37,655	23,856	64,708	8,766	14,194	11,025
RIC	1991	141,300	35,650	22,829	57,786	7,687	9,449	7,899
RIC	1992	145,079	35,918	26,453	54,404	7,196	11,032	10,076
SLC	1989	293,126	148,492	57,502	77,612	4,125	4,864	531
SLC	1990	302,113	149,325	59,444	84,802	3,201	4,649	692
SLC	1991	301,755	154,545	60,787	79,608	2,247	4,131	437
SLC	1992	316,783	159,920	67,725	82,915	857	5,210	156
SFO	1989	434,298	311,430	85,209	29,878	5,218	2,563	0
SFO	1990	436,955	313,300	77,617	32,204	11,260	2,574	0
SFO	1991	435,309	310,013	85,969	26,195	10,771	2,361	0
SFO	1992	424,829	296,904	92,850	22,870	9,786	2,419	0
SJC	1989	317,764	96,596	31,993	128,718	59,704	709	44
SJC	1990	319,591	96,197	51,079	115,180	56,468	641	26
SJC	1991	336,928	101,040	54,868	115,098	65,292	606	24
SJC	1992	342,918	95,874	55,792	122,382	67,823	1,023	24
SRQ	1989	164,006	24,624	12,378	88,572	35,897	2,325	210
SRQ	1990	168,191	31,275	13,825	84,939	34,776	2,975	401
SRQ	1991	173,740	27,679	14,415	82,754	46,043	2,327	522
SRQ	1992	161,749	24,066	10,660	83,056	41,360	2,384	223

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AIRPORT ID	FISCAL YEAR	FISCAL YEAR TOTAL OPERATIONS	FISCAL YEAR OPERATIONS						
			AIR CARRIER	AIR TAXI	ITINERANT GENERAL AVIATION	LOCAL GENERAL AVIATION	ITINERANT MILITARY	LOCAL MILITARY
STL	1989	425,257	283,436	93,644	39,768	0	8,409	0
STL	1990	442,642	284,995	108,480	39,032	0	10,135	0
STL	1991	412,539	261,528	105,836	35,947	0	9,228	0
STL	1992	429,473	273,790	110,151	36,502	0	9,030	0
TPA	1989	217,119	123,886	38,211	53,248	10	1,747	17
TPA	1990	227,330	132,465	45,804	47,101	132	1,826	2
TPA	1991	233,650	124,832	56,309	50,119	35	2,351	4
TPA	1992	229,470	120,479	58,170	48,291	32	2,468	30
TUL	1989	187,142	55,931	12,869	76,770	23,689	9,735	8,148
TUL	1990	194,604	54,888	10,426	77,048	34,260	10,391	7,591
TUL	1991	187,830	55,239	7,691	76,147	30,218	11,155	7,380
TUL	1992	196,835	57,118	9,582	75,337	37,660	10,830	6,308
IAD	1989	235,213	132,722	46,422	51,050	2,050	2,721	248
IAD	1990	239,818	123,209	52,006	60,447	1,090	2,963	103
IAD	1991	267,007	124,469	85,446	52,420	824	3,635	213
IAD	1992	287,111	108,317	116,066	54,506	462	7,719	41
DCA	1989	316,138	185,580	55,962	74,346	0	250	0
DCA	1990	320,366	196,536	59,112	64,426	2	290	0
DCA	1991	297,559	184,008	56,560	56,464	0	527	0
DCA	1992	312,014	183,722	71,319	56,443	0	530	0
ICT	1989	167,114	30,355	14,552	87,765	32,923	1,208	311
ICT	1990	175,406	30,320	13,312	94,997	35,011	1,183	583
ICT	1991	173,722	29,121	11,386	93,474	37,996	1,145	600
ICT	1992	178,853	27,991	13,680	96,216	39,501	1,076	389

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			FISCAL YEAR OPERATIONS					
AIR-PORT ID	FISCAL YEAR	FISCAL YEAR TOTAL OPERATIONS	AIR CARRIER	AIR TAXI	ITINERANT GENERAL AVIATION	LOCAL GENERAL AVIATION	ITINERANT MILITARY	LOCAL MILITARY
SNA	1989	533,522	62,302	27,727	241,383	196,778	5,086	246
SNA	1990	522,833	60,497	32,596	254,687	173,609	1,442	2
SNA	1991	550,602	65,388	30,886	276,392	177,370	566	0
SNA	1992	557,442	61,887	27,978	276,992	189,990	595	0