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A passenger demand model for air transportation in a hub-and-spoke network

Chieh-Yu Hsiao [a,b,*], Mark Hansen [a]

[a] Department of Civil and Environmental Engineering, Institute of Transportation Studies, National Center of Excellence of Aviation Operations Research (NEXTOR), University of California at Berkeley, Berkeley, CA 94720, USA
[b] Department of Transportation Technology and Management, National Chiao-Tung University, 1001 University Road, Hsinchu 300, Taiwan, ROC

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ABSTRACT

This paper develops an air passenger model that deals with city-pair demand generation and demand assignment in a single framework. Using publicly available and regularly collected panel data, the model captures both time series and cross-sectional variation of air travel demand. The empirical analysis finds that pattern of correlations among alternatives can be described by a three-level nested logit model. Fare, frequency, flight time, direct routing, on-time performance, income, and market distance have significantly effects on air demand. Correcting for the problem of endogenous air fares using instrumental variables yields more plausible estimates of price sensitivity and value of time.

1. Introduction

This paper presents a route-level air travel demand model for the US domestic airline network. Given supply characteristics on routes and regional demand-side variables, the model predicts passenger traffic for individual routes between specific airport pairs. It is based on random utility theory, in which route demand is generated from choices of whether or not to travel, what airports to fly from and to, what kind of route—direct or connecting—to use, and—if the route is connecting—what hub to fly through.

The model incorporates several advances from earlier work in this area. By incorporating the choice of whether or not to travel by air, it incorporates demand generation as well demand allocation, the traditional focus of random utility models. The model is based on publicly available and regularly updated data. Through use of an instrumental variable technique, it overcomes the problem of fare endogeneity that has bedeviled previous efforts to use these data for demand modeling. It includes on-time performance metrics as well as more traditional variables such as fare, frequency, and travel time.

Applications of the model are legion. It can be used with existing forecasts of future flight schedules, used for planning and investment analysis by FAA and NASA, to produce compatible forecasts of air passenger flows, which are currently lacking. Impacts of fare changes resulting from fuel price escalation or changes in aviation tax structures can be assessed. The model can be used to assess the effect of airport congestion on air traveler behavior and the resulting impact of traveler economic welfare. Finally, because the model is estimated on data streams that extend back many years, and are expected to continue into the future, it allows retrospective assessment of structural changes over time, and can be easily updated.

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[*] Corresponding author at: Department of Transportation Technology and Management, National Chiao-Tung University, 1001 University Road, Hsinchu 300, Taiwan, ROC. Tel.: +886 3 513 1576; fax: +886 3 572 0844.
E-mail address: cyhsiao@nctu.edu.tw (C.-Y. Hsiao).

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Our main purpose in this paper is to present the basic model, the data and methodology for estimating it, and key estimation results. More detailed treatment of the various applications appears in forthcoming articles. After a brief literature review in Section 2, Section 3 presents the theoretical model. Data and estimation procedures are discussed in Section 4, while Section 5 discusses estimation results and their implications. Section 6 offers conclusions and discusses prospects for future model enhancements.

2. Literature review

While air travel demand modeling have been the subject of considerable research, virtually all of the models are concerned with either the quantity of air traffic or the assignment of traffic, but not both. This limits model validity, applicability, and utility.

2.1. Demand generation model

We will refer to models of air travel quantity as demand generation models. The literature contains many such models. Units of observation include regions, airports, airlines, flight segments, city-pairs, airport-pairs, county-pairs, and country-pairs. Price, travel time, and flight frequency or schedule delay are typical supply-side variables in these models, while population, income, distance, and various measures of attraction (e.g. dummy variables for tourist destinations) are used to characterize the demand-side.

None of the demand generation models adequately deals with the availability of alternate routes for air travel between a given origin and destination. Models of segment traffic, such as Abrahams (1983), Anderson and Kraus (1981), and Wei and Hansen (2006), overlook network effects, such as availability of alternative routes and characteristics of complementary segments. In some cases (Ippolito, 1981), the data set is intentionally restricted to routes that are (in Ippolito's words), "more or less insulated." This may increase model validity, but at the expense of wide applicability.

The availability of multiple routes is also a problem for city-pair models, including those of Kanafani and Fan (1974), De Vany and Garges (1972), and Bhadra (2003). These models predict total traffic in city-pair markets. Although this traffic is normally divided among several routes, these models require a single set of representative supply-side variables. For example, the first two of the above works use for the travel time the lowest value among the alternatives, while Bhadra employs the average fare across all travelers in the city-pair as the price variable. It is easy to see circumstances in which these use of such variables can lead to misleading results—for example if the lowest travel time alterative also featured a very high fare or low frequency.

2.2. Demand assignment models

Demand assignment models explain the distribution of traffic—or the choice of individual travelers—among alternative modes, airports, routes, airlines, or other dimensions. Literature on such models has burgeoned in recent years, with development paralleling that of random utility models generally. Multinomial logit (MNL), nested logit (NL), mixed multinomial logit (MMNL) models, and specialized variants of these have all been applied.

Airport choice is one of the most widely studied topics in this literature. Harvey (1987), Hansen (1995), and Windle and Dresner (1995) all employ MNL models to analyze traveler choice of airport in multi-airport regions. NL models of airport-airline and airport-access mode choice have been developed by Pels et al. (2001, 2003). Hess and Polak (2005a,b) and Pathomsiri and Haghani (2005) have estimated MMNL models of airport choice. These models are based on airport passenger surveys, with access time, flight frequency, and fare the mainstay explanatory variables. Of these, fare has proven the most problematic, because of the multiplicity of fares available and the difficulty of determining the fares faced by individual choice makers. This has led to the omission of fares in some studies, and the use of average fares in others. Pathomsiri and Haghani (2005) note that the use of average fare often results in an insignificant or counterintuitive coefficient estimate. This may be the result of endogeneity bias. Since airline pricing and yield management systems often result in higher average fares on more popular routes, demand estimations that ignore simultaneity of supply and demand systems may give erroneous results. The estimated fare coefficient may also be affected by omitted service attributes that passengers value. Therefore, both simultaneity and omitted variables may lead the estimated coefficients that are biased upward (i.e., toward 0).

Route demand assignment models explain the market shares of routes serving the same O–D airport-pair or O–D city-pair. Route demand assignment model for city-pairs combine the airport demand assignment for multiple airport regions and the route demand assignment for airport-pairs. Earlier models of this type, such as Kanafani and Fan (1974) and Kanafani et al. (1977), considered settings in which non-stop routes are the dominant alternatives, such San Francisco–Los Angeles. These are essentially airport-pair choice models.

Many airport-pair route assignment models have been developed, often as part of a supply–demand model that also predicts supply side behavior. Examples of MNL route assignment models include Kanafani and Ghobrial (1985), Hansen (1990, 1995), Hansen and Kanafani (1990), Ghobrial and Kanafani (1995) and Adler (2001, 2005). The NL model is also sometimes applied (e.g. Weidner (1996), and Hsiao and Hansen (2005)), with elemental alternatives nested according to routing type (direct/connecting). Other NL models, such as Coldren and Koppelman (2005), consider choice of both route and carrier, with