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Economic Counsel to the Transportation Industry

ACRP

Project Number 03-36

Using Disaggregated Socioeconomic Data in Air Passenger Demand Studies

Final Report

Appendix A: Survey of Past Analyses of Air Passenger Demand

Draft 6/28/18

TRANSPORTATION RESEARCH BOARD
NAS-NRC

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Appendix A

Survey of Past Analyses of Air Passenger Demand

A.1 Introduction

This appendix to the final report reviews the air travel demand and airport aviation activity forecasting literature to document how prior work has examined the relationship between socioeconomic and other factors and air travel demand. The focus of this literature review is on studies, papers, and reports that have examined the general relationships between socioeconomic factors and air travel demand, rather than those that have developed models and forecasts for specific airports or airport systems. The material contained in this appendix was originally submitted to the ACRP Project Panel as Technical Memorandum #1.

Since the 1960's, there have been numerous studies that have examined factors that influence air travel demand. Although many of the older studies are now dated, some still represent the most comprehensive study of a particular market, the best use of a particular technique or dataset, or provide unique insights into the influence of particular socioeconomic variables on air travel demand. What is striking about many of the more recent studies is how aspects of air passenger demand that were addressed in studies more than 30 years ago remain problematic today. The literature review advances the state of practice by familiarizing researchers and practitioners with important lessons learned in past studies and highlighting issues that need to be considered and addressed in future studies.

At the same time, the objective of the current research project is to assess the place of disaggregated socioeconomic data in air passenger demand studies. Therefore, the primary focus of the literature review is to identify socioeconomic variables that have been considered in prior studies, the relationships between the various socioeconomic factors and air travel demand, and the extent to which disaggregated socioeconomic and other data have been used to study air travel demand.

The next section provides a critical review and discussion of the literature. The literature has been classified into five categories: past Airport Cooperative Research Project (ACRP) studies, past reviews of the air travel demand literature, air travel demand studies, selected intercity travel demand studies, and recent accounts of relevant socioeconomic trends. The air travel demand studies have been further subdivided into academic studies, government studies, and industry studies. Government and industry studies refer to those conducted for or by government agencies and industry organizations, respectively.

The inclusion of a section on intercity travel demand studies deserves some explanation. This was included in the literature review for three reasons. The first is that many of these models generate projections of air travel in addition to travel demand for surface modes. Indeed, although many air travel demand studies (in fact the great majority of such studies) do not consider the effect of competition from other modes, in reality competition from surface modes, particularly personal vehicles, can be significant for trips up to about 1,500 miles (U.S. Bureau

of Transportation Statistics, 2006). Furthermore, past studies have shown that in countries that have made a major investment in high-speed rail systems, many of the users of those services would otherwise have flown to their destination, as evidenced by the drop in air travel between London and Paris or Brussels with the opening of the Channel Tunnel and completion of the high-speed rail link between the two cities (Behrens & Pels, 2012). Therefore intercity travel demand studies that generate projections of air travel are one type of air travel demand study, although they may not be thought of as such, and the models developed in these studies may shed some light on the role of socioeconomic factors on air travel demand.

A second reason for including these studies is that in contrast to the majority of air passenger demand studies described in this review, which have focused on identifying the factors explaining past levels of air travel, many intercity travel demand studies have been undertaken with the explicit purpose of generating data driven projections of future travel demand, including air travel demand. This forward-looking aspect is likely to be of particular interest and relevance for airport practitioners and planners. The third reason is that a number of these studies have made use of disaggregated socioeconomic data. In contrast, almost all the studies of air travel demand identified in the literature review have used aggregated measures of socioeconomic variables.

The Appendix concludes with a discussion of the main findings which informed the research undertaken in the current project and a comprehensive bibliography of the studies identified in the literature review, whether or not they are specifically discussed in the Appendix. This provides source references for the studies specifically mentioned in the review of the literature and will serve as a resource for future studies. Finally, an Attachment summarizes key characteristics for the econometric models of air travel demand that were identified in the literature review. The Attachment is useful for understanding the variety of models, variables, markets, customer segments, and data that have been used to model air travel demand, as well as the range of different results that have been obtained from these studies.

A.2 Literature Review

The literature review was conducted in several steps. First, a comprehensive bibliography was assembled using keyword searches and reference lists from prior reviews of air travel demand studies. A database was used to record information for each document, including its bibliographic citation, executive summary, and model details. For each document, the Research Team reviewed the list of references cited by the authors and identified additional references for potential inclusion in the bibliography. In this way, the bibliography was progressively expanded and relevant information from each document recorded in a consistent format.

The literature review starts with a review of relevant ACRP reports, which illustrates how this project relates to and builds upon prior ACRP work. Next, past reviews of air travel demand studies from the academic literature are presented. The majority of the literature review focuses on reviewing academic air travel demand studies. An emphasis is placed on identifying the types of models, variables, data, and other factors these studies used to forecast air travel demand. The last two sections review selected intercity travel demand studies and socioeconomic trends that can impact future air travel demand forecasts.

a. ACRP Reports

Several past ACRP reports address airport issues that are related to airport forecasts of air travel demand. Most significantly, ACRP Synthesis 2, *Airport Aviation Activity Forecasting* (2007) reviews the methods and data that have been used to conduct aviation activity forecasting by airports, including passenger activity forecasts. The study covers the elements of aviation demand that an airport may seek to forecast, including aircraft operations and passenger enplanements, the information and data sources that may be used to develop forecasts, the methods available for creating forecasts, and the approaches that may be used for evaluating forecasts. The discussion of the drivers of airport aviation activity mentions the importance of economic and demographic factors, but does not address potential roles for disaggregated socioeconomic data. Practitioners will find this report to be a useful companion to the current report and Guidebook.

ACRP Report 18, *Passenger Air Service Development Techniques* (2009b), addresses the ways in which airports can assess the passenger air service that is available for their passengers and reach out to airlines to enhance and expand these services. The report notes that airlines would expect such an airport to provide credible forecasts of potential passenger activity, based on the airport's history and characteristics, but does not address how these forecasts can be developed.

ACRP Synthesis 7, *Airport Economic Impact Methods and Models* (2008), presents an overview of economic impact modeling. Frequently conducted by airports of all sizes, this type of analysis identifies the scale of regional economic activities that can be associated with the operations of an airport. Although these impacts will be related to the level of passenger activity at an airport, the report does not cover the passenger forecasting process.

ACRP Report 26, *Guidebook for Conducting Airport User Surveys* (2009a) provides guidance on designing and conducting airport-user surveys, including surveys of air passengers, airport employees and tenants, area residents and businesses, and collection of air cargo data. Although not addressing air travel demand directly, the data generated by surveys of air passengers, households, and local businesses can be a source of information for air travel demand studies. By its very nature, such data is highly disaggregated, allowing a level of analysis not possible with more aggregate data.

ACRP Report 76, *Addressing Uncertainty about Future Airport Activity Levels in Airport Decision Making* (2012), provides a guidebook to assist airport planning and management personnel in addressing uncertainty about future air traffic levels in making airport development decisions. The report contains a number of examples of airports where air passenger activity has evolved in a different pattern from that projected in successive forecasts over a period of years and describes various techniques that can be used to address the uncertainty inherent in forecasts of air passenger demand and resulting aircraft activity. The report mentions the use of causal models of air passenger demand, but does not discuss specific models.

ACRP Report 98, *Understanding Airline and Passenger Choice in Multi-Airport Regions* (2013), addresses the factors that influence airline decisions on what air service to offer at different airports in a multi-airport region and the factors that influence air passenger decisions on which airport to use for a given trip in the light of the air service offered at each and any fare differences. The report includes five regional case studies that describe the geographic and economic context in each region, the evolution of air service at the airports serving the region, and the resulting air passenger traffic levels. Although the report discusses many of the underlying socioeconomic factors that drive the demand for air travel, it does not address how those interact to influence the total regional air travel demand. The report does not present a formal model for predicting airport choice in a multi-airport region, but it does include a fairly comprehensive literature review that contains summaries of many prior studies that have developed such models.

ACRP Synthesis 51, *Impacts of Aging Travelers on Airports* (2014), addresses the preparations and accommodations that airports can make as the percentage of air travelers who are older grows, reflecting trends in the general population. Although this report does not address passenger forecasting as such, it does raise socioeconomic and demographic issues that overlap with potential uses of disaggregated socioeconomic data by airports in their forecasting activities. The report provides a detailed study of changing U.S. demographics, in particular the growing size of the older or elderly populations. Such populations have unique characteristics and specific needs, and they are likely to make up an increasing share of the air traveling public. For this reason, airport managers and staff should be aware of the expectations and needs of these airport users, especially in such areas as mobility within airports and the availability of clear information for these airport users. Although the report contains demographic information about older travelers, there is no discussion of their demand for air travel.

ACRP Web-Only Document 22, *Passenger Value of Time, Benefit-Cost Analysis, and Airport Capital Investment Decisions* (2015b), reports the findings of ACRP Project 03-19. As part of the project, a web-based survey was undertaken of the most recent air trip undertaken by survey respondents within the preceding six months. Although the primary purpose of this

survey was to perform a set of stated-preference choice experiments in order to estimate differences in the perceived values of time for different components of the air trip by the survey respondents, the survey also collected detailed information on the most recent air trip, including the trip purpose, as well as information on household characteristics of the survey respondents. The potential use of these data in the current project will be discussed in more detail as part of Task 2.

ACRP Report 132, *The Role of U.S. Airports in the National Economy* (2015c), includes an analysis of the effect of changes in air service on business productivity by different sectors of the economy and an analysis of the effect of changes in airfare on consumer surplus and hence macroeconomic indicators. Although the project did not develop explicit models of air passenger demand, it included a review of the literature on air travel demand modeling in order to identify prior estimates of price elasticity for non-business travelers. It also assembled a database of prior air passenger surveys in order to estimate the proportion of non-business travel in a sample of 100 domestic airport-pair markets. These surveys provide disaggregated data on a range of air passenger characteristics, as will be discussed further as part of Task 2.

ACRP Report 142, *Effects of Airline Industry Changes on Small- and Non-Hub Airports* (2015a), identifies airport policy and planning options that provide a response to recent changes in the airline service patterns and offerings at smaller airports. It offers managers of these airports background resources and information for planning for and responding to changes in airline services. Although the report does not explicitly address passenger forecasting and the use of disaggregated socioeconomic data for passenger forecasting, improving an airport's ability to forecast future passenger demand may be able to contribute to those small airports' responses to a changing air transportation industry.

To summarize, one ACRP report notes the importance of accounting for economic and demographic factors in forecasts of air travel demand when addressing service expansion, but does not address potential roles for disaggregated socioeconomic data. Prior ACRP reports provide valuable guidance for airports in specific areas, such as how their facilities and operations can be adapted to better accommodate the mobility needs of an elderly population. These reports also provide disaggregated datasets that can be leveraged for the current project to better understand the role of disaggregated socioeconomic factors in producing airport activity forecasts.

b. Prior Reviews of the Literature

Since 2000, there have been a number of articles and reports that have provided extensive reviews of the air travel demand literature, summarized key findings across studies, and provided an assessment of how the state of practice in air travel demand modeling has evolved. This section identifies prior studies that synthesized the air travel demand literature.

A major focus of the prior reviews of the literature has been to identify the values of the price elasticity of air travel found across studies. A widely quoted study by Gillen, *et al.* (2002) for the Canadian Department of Finance reviewed 21 studies that provided estimates for 254 price elasticity values for different market segments. The distributions of elasticity estimates were assembled for different market segments. A similar study by Brons, *et al.* (2002) reviewed

37 studies that provided 204 price elasticity estimates and undertook a meta-analysis of these elasticity values. The meta-analysis regressions attempted to explain why elasticities across different studies varied. Specifically, the meta-analysis explored whether these differences were due to different data collection periods, different types of data (cross-sectional or time-series), market distances, geographic regions, the fare class for which the elasticities were estimated (business class or other), whether an income variable was included, and whether short-run or long-run elasticities were estimated. The meta-analysis regression results suggest that the price elasticity values obtained in the prior studies were significantly influenced by the markets studied, the data used, and whether or not an income variable was included in the analysis. Although many of these studies included in the Gillen, *et al.* (2002) and Brons, *et al.* (2002) reviews provided estimates of the demand elasticity of various socioeconomic variables, these estimates were not summarized in their reviews.

Two subsequent studies by InterVISTAS Consulting, Inc. conducted for the International Air Transport Association (InterVISTAS, 2007) and the Airports Council International – North America (InterVISTAS, 2014) undertook an updated review of the literature on air travel demand elasticities, with a particular focus on price elasticity, although income elasticity values were also noted in the summary of the literature. The 2007 review identified 21 prior studies, although only 14 of these contained original estimates of price elasticity and even fewer contained estimates of income elasticity. The 2014 study identified an additional 18 studies, of which 12 contained original estimates of price elasticity (one used jet fuel price as a proxy for airfare) and six contained estimates of income elasticity (one used wealth instead of income). Both studies also estimated econometric models of air travel demand, which are discussed in the review of Industry Studies.

A recent paper by Wang & Song (2010) undertook an extensive review of air travel demand studies from 1950 to 2008 that identified 115 studies. The paper does not provide details of the models or variables used in each of the studies, but it does discuss the general trend in the types of studies and models used.

As with the prior ACRP reports, these articles that synthesize the literature on air travel demand modeling are a useful resource for airports.

c. Air Travel Demand Studies

Understanding demand for air travel has been an active area of research. This section reviews academic, government, and industry studies published during the past fifty years (or since 1965).

Academic Studies

The academic studies of air travel demand vary across multiple dimensions. Some of these dimensions, shown for each study in the accompanying Appendix, include: (1) demand measures used as the dependent variable (*e.g.*, modeling the number of passengers on an origin-destination pair or revenue passenger miles); (2) the explanatory variables used as the independent variables, including disaggregate and aggregate socioeconomic variables; (3) the type of model, defined as the functional form used to relate the dependent and independent

variables; (4) the type of data (*e.g.*, panel, time series) used for estimation; (5) whether these data were aggregate or disaggregated; (6) the market segments used in estimation (*e.g.*, business or leisure travelers); and, (7) the time periods on which the models were estimated.

This section focuses on describing how academic studies modeled air travel demand along these dimensions. The discussion is organized into subsections covering the first six dimensions described above.

Dependent Variables

The dependent variable in most air travel demand studies is typically a direct measure of the number of air passengers. The level of route aggregation used to predict the number of air passengers differs across studies.

Studies of air travel to or from specific countries, regions, cities, or airports typically consider air passengers without regard to their trip origins (for inbound travel) or destination (for outbound travel). Examples of studies using arriving and/or departing passengers at a single airport, city, region, or country include Abed, Ba-Fail & Jasimuddin (2001), Karlaftis (2008), Clewlow, Sussman & Balakrishnan (2014), and Valdes (2015). Studies estimating city-pair or airport-pair air travel demand are more common in the academic literature and include Verleger (1972), Ippolito (1981), Andrikopoulos & Terovitis (1983), Fridstrom & Thune-Larsen (1989), Oum, Zhang & Zhang (1993), Suzuki & Audino (2003), Bhadra (2004), Chi, Koo & Lim (2010), and Elwakil, Windle & Dresner (2013).

Models of air travel by country-pair, city-pair, or airport-pair markets consider air passengers traveling in the market. Some studies of city-pair (or airport-pair) air travel demand use the true origin and destination (O&D) trips in each market (*i.e.*, passengers beginning and ending their air trip at each end of the market). Other studies use the number of passengers on nonstop flights in each market, including passengers connecting to or from other flights at either end of the market. The choice of which demand measure to use is often dictated by data availability.

The existence of multiple airports serving some metropolitan regions raises the issue of how to define a “city-pair.” A related issue is how to define the geographic extent of a “city” and assemble population and economic data for each “city.” Air travelers in a given city-pair market may have true trip origins or destinations geographically distributed over a wide area. For metropolitan areas served by multiple airports, as in the San Francisco Bay Area or the Baltimore/Washington region, it is usual for “city-pair” air travel demand models to combine air passenger trips from all airports serving the metropolitan area to avoid the need to address the allocation of air trips across multiple airports.

Since most city-pair air travel demand models include some measure(s) of the socioeconomic factors influencing air travel demand for the cities at either end of the market (*e.g.*, population or income), true O&D passengers are preferable as a dependent variable to the passenger traffic on nonstop flights in the market for two reasons. First, passengers on nonstop flights who are connecting at either end of the market are not influenced by the socioeconomics of their connecting cities. Second, in many markets the air travel demand between two cities is

served by both nonstop and connecting flights, so only counting the passengers on nonstop flights can omit a significant part of the market. Jorge-Calderon (1997) attempted to address the first of these limitations by including dummy variables for the presence of an airline hub at either end of the market (allowing for higher traffic in markets that include a significant amount of connecting traffic), while Abrahams (1983) attempted to address the second limitation by restricting the analysis to markets that are well-served by non-stop flights (thereby minimizing the number of O&D passengers in the market who are likely to use connecting flights). However, neither of these solutions is entirely satisfactory and each only addresses part of the problem.

Studies that use true O&D passengers for the dependent variable typically count passengers in both directions, either as the total passenger trips in the market or as the directional passengers (obtained by dividing round-trip passengers by two). Ideally, one would like to be able to distinguish between residents of city A who make a trip to city B and residents of city B who make a trip to city A. For example, it is not likely that the number of residents of Chicago making a trip to Orlando in a given period is the same as the number of residents of Orlando making a trip to Chicago. This is not possible if the dependent variable combines outbound passengers from city A with returning travelers to city B, as occurs with directional O&D passenger data. Although the U.S. data on O&D passengers allows the airport of origin of each round trip to be identified, the literature did not identify any studies that made use of this to develop directional air travel demand models.

Finally, it is important to note that although the dependent variable in air travel demand studies is typically the number of air passengers, other measures of demand have also been used. Some studies, such as Verleger (1972), Talley & Schwarz-Miller (1988), Richards (2009), and Chi & Baek (2012), use revenue passenger-miles (RPMs), particularly when modeling air travel at a national level. Battersby & Oczkowski (2001) used revenue passenger-kilometers (RPKs) per capita in a model of domestic air travel in selected Australian city-pair routes. Some studies (*e.g.*, Taplin, 1980; Oum & Gillen, 1983) modeled travel expenditure rather than actual travel, in order to account for expenditure on other components of trip costs (*e.g.*, accommodation), relative costs of other modes, or non-travel consumption. Oum, Gillen & Noble (1986) modeled fare expenditure share by fare class for a large sample of U.S. domestic city-pair markets. This allowed the authors to calculate an average fare for each city-pair, which was then used in a model of O&D passengers in each market.

Explanatory Variables

A wide range of explanatory variables have been used to model air travel demand. These include variables reflecting different demographic¹ characteristics of travelers, socioeconomic variables that reflect the underlying economic drivers of air travel, measures of air travel service (most notably price), and service measures for competing modes.

A variety of aggregate and disaggregate demographic variables have been used in the literature to model air travel demand as a function of traveler characteristics. For aggregate models, Long (1968) included the number of people with one or more years of college. Dargay (2010) included the fraction of the population who were women and the fraction of the

¹ For this section, it is useful to distinguish between demographic and socioeconomic variables. We do not make this distinction elsewhere in the report, and refer to both as “socioeconomic variables” outside this section.

population who lived in one-adult households to model domestic person-miles of travel by mode for the UK. For disaggregate models, Taplin (1980) included the age of the head of household in a model of travel expenditures for different components of an air trip using data from Australian household expenditure surveys. Morrison & Winston (1985) included the travel party size and the number of travelers less than four years old in a mode choice model for vacation travelers. Dargary (2010) included gender, years of residence at the current address, household composition, and type of home in a household-level model of domestic person-miles of travel. Kressner & Garrow (2012) used the proportion of households in selected lifestyle clusters in each zip code to model the average number of home-based air trips per household for zip codes in Atlanta.

Population is commonly included in models of air travel demand in city-pair markets (*e.g.*, Long, 1968; Ippolito, 1981; Abrahams, 1983; Oum, Gillen & Noble, 1986; Jorge-Calderon, 1997; Castelli, Pesenti & Ukovich, 2003; Bhadra & Kee, 2008; Elwakil, Windle & Dresner, 2013), although whether the populations of the cities at either end of the market are combined or included as separate variables differs across studies. Bhadra (2004) and Bhadra & Kee (2008) included separate variables for the population of the origin and destination cities. Ippolito (1981), Abrahams (1983), Castelli, Pesenti & Ukovich (2003) and Elwakil, Windle & Dresner (2013) used the product of the population in each city. Chi, Koo & Lim (2010) used the average population of both cities, and Jorge-Calderon (1997) used the sum of the populations, which is effectively the same thing. Clewlow, Sussman & Balakrishnan (2014) used the geometric mean of the population in each city.

Population density (instead of population) has also been used in the literature, but tends to be more difficult to interpret. Bhadra (2003) included variables for the population density (in persons per square mile) for both the origin and destination metropolitan regions. Although the estimated coefficients for these variables in many of the models for different distance ranges were statistically significant, the signs were not consistent and produced a mixture of negative and positive values. In addition, the interpretation of the variables was problematical. It is not clear why a region that has a higher population density would generate more air trips than a region of the same population and per-capita income but with a lower population density. What these variables may be measuring is not population density *per se*, but other characteristics of major metropolitan regions (such as New York, Chicago, the San Francisco Bay Area, or Washington, DC) that happen to have a higher population density than smaller metropolitan regions. Clewlow, Sussman & Balakrishnan (2014) also included population density in both their model of passengers on nonstop flights between metropolitan regions and their model of airport passengers. The estimated coefficients for these variables were also difficult to interpret, as they were negative for the nonstop flight model but positive for the airport passenger model.

In addition to population, measures of economic activity, such as income or gross domestic product (GDP) are major determinants of air travel demand. Most air travel demand studies (although not all) include some socioeconomic variables that reflect the underlying economic drivers of air travel, although there is little consistency in which variables are used. Income can be measured in a number of different ways (*e.g.*, household income, personal income, total income, disposable income) and at different levels (*e.g.*, for a country, region, or city, or on a per-capita or per-household basis). Of the 45 models reviewed in the accompanying Appendix, 34 used some form of an income measure. Ten models used GDP or Gross Regional

Product (GRP), seven used personal income or personal disposable income, six used household income, seven did not specify how the income variable was defined, and four models used other measures of income. Specifically, Long (1968) used the number of people with income above a certain level (\$10,000), Alperovich & Machnes (1994) used the average wage rate, Fridstrom & Thune-Larsen (1989) used total taxable personal and corporate income, and Battersby & Oczkowski (2001) used the national industrial production index for Australia (which was considered a surrogate measure for income). For models that included a measure of population, the income variable typically was expressed on a per-capita basis to avoid problems with multicollinearity.

Many of the air travel demand studies also included other socioeconomic variables describing economic activity. Four studies included measures of employment. Long (1968) included a variable for the employment in larger firms (those having 100 or more employees), Richards (2009) estimated alternative models that included non-farm employment or GDP, and Dargay (2010) estimated two different models. The first used the fraction of the population who were employed and the second (a disaggregate household-level model based on responses to the UK National Travel Survey) used a categorical variable for the employment status of the survey respondent. Two studies (Alperovich & Machnes, 1994; Bhadra, 2012) included measures of household wealth. Alperovich & Machnes distinguished between financial and non-financial assets and also included average wage as a measure of current income. Bhadra did not include an income variable, but included household credit worthiness as well as wealth. Both studies found that changes in household wealth was a significant factor in air travel demand and that omitting this from models of air travel demand could lead to biased estimates of income variables. Verleger (1972) used the number of telephone calls between two cities as a measure of the level of economic interaction between them. Oum & Gillen (1983) included average weekly work hours in a time-series model of Canadian travel expenditure by mode. Valdes (2015) included variables for foreign direct investment and changes in consumer prices in a model of annual air passenger levels in middle-income countries.

In addition to sociodemographic and socioeconomic variables, several air travel demand models have included measures of air service. Ippolito (1981) included variables for the number of flights and average load factor in each city-pair market. Abrahams (1983) included a variable for the average daily flights in each city-pair market. Bhadra (2003) and Elwakil, Windle & Dresner (2013) included measures of airline market concentration in each city-pair market. Anderson & Krause (1981) included the value of travel time in a model of passengers on nonstop flights in U.S. domestic markets, although they were unable to estimate a value for this and ended up estimating the model for three different assumed values of time.

Airfare is the most common measure of air service included in air travel demand studies. Most studies included some measure of airfare, although how airfares were defined varied according to the scope of the study. Measures of airfare have also evolved over time. Many of the earlier studies of city-pair or airport-pair markets used published airfares. For example, Oum, Gillen & Noble (1986) used published fares for three different fare classes to develop a model of expenditure shares by fare class, which then allowed them to calculate average fares in each market. Other studies (*e.g.*, Abrahams, 1983; Jorge-Calderon, 1997) used the published economy fare as a representative fare for each market. However, as the number of fares offered in any given market proliferated following airline deregulation, this approach no longer worked and

subsequent studies (*e.g.*, Oum, Zhang & Zhang, 1993; Bhadra, 2004; Chi, Koo & Lim, 2010; Elwakil, Windle & Dresner, 2013) used the average airfare in a market. For the U.S. this can be calculated from the fare data in Databank 1B (DB1B), which is a ticketing database maintained by the U.S. Department of Transportation that collects 10 percent of all tickets used by passengers boarding flights on U.S. airlines. Determining average fares in non-U.S. markets is considerably more difficult and as a result studies of these markets typically use surrogate variables for fare, such as jet fuel price (*e.g.*, Chèze, Gastineau & Chevallier, 2010; Clewlow, Sussman & Balakrishnan, 2014; Valdes, 2015) or an airfare price index published by national statistical agencies (*e.g.*, Kopsch, 2011).

The inclusion of airfare in air travel demand models allows for the calculation of price elasticities. Conceptually, price elasticities provide information on how much air travel will decrease when airfares increase (and *vice versa*). Demand elasticities can also be calculated for other factors that influence demand, such as population or income. Although not the focus of this study, given the importance of using elasticities for air travel demand forecasting applications, the demand elasticities for demographic and socioeconomic variables estimated from the studies are included in the accompanying Appendix and discussed as part of this review.

Some care is needed in interpreting demand elasticities with respect to population (referred to hereafter as population elasticities). *A priori* one would expect population elasticities to be around unity (or close to one). If the population grows by 1 percent, all other factors remaining unchanged, one would expect air travel to increase by about 1 percent, since each person faces exactly the same situation and therefore would presumably make the same number of air trips in the market, but there are 1 percent more people doing so. Nonetheless, in some studies of air travel in city-pair markets (*e.g.*, Fridstrom & Thune-Larsen, 1989; Oum, Gillen & Noble, 1986) the population elasticity is significantly greater than unity. However, this may reflect the greater attractiveness of larger cities relative to their population, due to the nature of the economic or recreational activities in those cities. If appropriate controls are not included in the model to capture the effect of these economic or recreational activities, this will increase the estimated population elasticity.

Income elasticities estimated in the different studies varied across studies and across markets and/or market segments within the same study. Verleger (1972) estimated demand elasticities with respect to average household income across 115 city-pair markets. Verleger's estimates varied between 0.16 and 5.43. Anderson & Kraus (1981) estimated income elasticities across seven different city-pair markets for an assumed value of travel time of \$10 per hour. Their estimates ranged from 1.22 to 5.95. Oum, Gillen & Noble (1986) estimated a somewhat narrow range of per-capita income elasticities over 200 U.S. city-pair markets. Their estimates varied from 1.45 for non-vacation markets to 2.08 for vacation markets. Bhadra (2003) estimated separate elasticity values for per-capita income of the origin and destination metropolitan areas for a large number of U.S. O&D markets that varied by market distance. Estimates from the Bhadra study varied from 0.48 to 2.89 for the origin metropolitan area and from 0.50 to 1.77 for the destination metropolitan area. A subsequent study (Bhadra, 2004) of average daily O&D passengers in markets to and from small communities found an even wider range of per-capita income elasticities for the trip origin area that varied by market distance. Those estimates ranged from 0.04 to 8.42, although the income elasticities for the trip destination area only varied from 0.24 to 0.58.

Not only do these estimates of income elasticity vary widely, but many of the values appear implausible. Higher levels of income generally result in an increase in discretionary spending, which could be expected to lead to a disproportionate increase in air travel, at least over most of the range of household incomes. Thus, *a priori* one would expect income elasticities somewhat above 1.0. However, income elasticity values above 2.0 (implying that an increase in income of 10 percent would lead to increase in air travel of more than 20 percent) would seem unlikely. What may be occurring is that the model estimation is attributing to changes in the income variable changes in air travel that are due to other factors omitted from the model. Given the importance of the value of income elasticity used in air travel demand forecasting models in the context of projected future increases in real income, this is an issue deserving of more analysis.

The great majority of air travel demand studies include airfare, or proxies for airfare, as the only cost variable. Yet the cost of an air trip is influenced by other cost components, including local travel and accommodation at the destination. A handful of studies have included these additional trip costs. For example, Morrison & Winston (1985) included the daily rate for rental cars in their model of destination choice and intercity travel mode choice for vacation trips. Alperovich & Machnes (1994) included a variable for the real price index of travel abroad that included both air travel and expenses at the destination in a study of the role of wealth in the demand for international air travel from Israel.

The demand for air travel is also likely to be influenced by the relative travel time and cost of alternative modes. Some studies have included cost and travel time variables for alternative surface modes. Oum & Gillen (1983) included variables for the price of rail and bus, as well as air travel, in a model of Canadian travel expenditure by mode. Andrikopoulos & Terovitis (1983) included variables for the ratio of airline economy fare to the equivalent fare on the best alternate mode and the ratio of travel time by air to that by the best alternate mode in a model of domestic air travel in Greece. Morrison & Winston (1985) included variables for the total round-trip travel time and total round-trip transportation cost by each mode in their models of destination choice for vacation trips and intercity travel mode choice for vacation and business trips. Fridstrom & Thune-Larsen (1989) included variables for the fare and travel time on the fastest competing surface public mode in a model of domestic air travel in Norway. Battersby & Oczkowski (2001) included a variable for the national transportation price index as a proxy for surface transportation costs in a model of domestic air travel in Australia. Dargay (2010) included variables for the motoring cost index, rail cost index, and average revenue per kilometer for intercity bus and coach in a set of models of person-miles of intercity domestic travel in the UK. Kopsch (2011) included variables for the price index of the cost of driving and the price index of train fares as well as a dummy variable for the introduction of high-speed rail service in a model of domestic air travel in Sweden. Clewlow, Sussman & Balakrishnan (2014) included a variable for rail travel time in a model of city-pair air travel in Europe and a dummy variable for the presence of high-speed rail service in a model of airport passenger traffic at European airports.

Functional Form

There are multiple functional forms that have been used to model air travel demand. Conceptually, a “functional form” refers to the mathematical function used to model the

relationship between the dependent variable (*e.g.*, number of air trips) and independent variables (*e.g.*, distance, airfare, population). For example, does the model predict the number of trips as a linear function of the independent variables or express the dependent and independent variables in logarithms (a log function)?

The majority of econometric models estimated in academic air travel demand studies have adopted a functional form in which the dependent variable and the continuous independent variables (such as travel time, distance or cost) are expressed in logarithms. These models are referred to by multiple names, including log-linear, log-log, or Cobb-Douglas models. For consistency and clarity, such models will be referred to hereafter as log-log models. This model form has the advantage that the estimated values of the coefficients of the continuous variables give the elasticity of demand with respect to that variable. However, this implies that the elasticity is constant.

Some studies (*e.g.*, Abrahams, 1983) have used a standard linear regression without expressing the variables in logarithms (referred to hereafter as linear models). Depending on the variables included in the model, this can be conceptually questionable. A linear model implies that each explanatory variable contributes to the dependent variable (typically the volume of air passenger traffic) separately with no interaction with the other variables. Since such models generally include some measure of price as well as socioeconomic factors, this means that a change in the socioeconomic factors (*e.g.*, income) has the same effect on air travel irrespective of any changes in price, and vice versa. This may not be a reasonable assumption for models that predict the demand for air travel in a market. However, a linear model may be appropriate in situations where the effect of each of the explanatory variables on the dependent variable can be assumed to be additive. For example, Kressner & Garrow (2012) developed a model of average number of air trips per household in Atlanta zip codes as a linear function of the proportion of households in the zip code in a number of different lifestyle clusters. Since each household in different lifestyle clusters generates a different number of air trips on average, adding the effect of each cluster to give the overall value for the zip code is a reasonable assumption.

It should be noted that the effect of any dummy variables in a demand model is different in linear and log-log models. Dummy variables (or indicator variables that provide information on whether a condition applies) are typically included in the model as a zero or one value. For example, if a data point was collected during a special event, the special event dummy variable would be set to one. In the case of linear models, the effect of the dummy variable is to change the value of dependent variable by a constant *amount*, whereas in the case of log-log models, the effect of the dummy variable is to change the value of the dependent variable by a constant *proportion*. In most cases, the effect of some event or situation (*e.g.*, the September 11, 2001 terrorist attacks or the 2002/2003 Severe Acute Respiratory Syndrome epidemic), the effect on different air travel markets is more likely to be proportional to the traffic in those markets than a constant amount across all markets.

A few studies have used more complex model forms, such as the translog model, which includes second-order terms. A paper by Oum (1989) presents the results of an analysis of the relative performance of five different model functional specifications for freight transportation in Canada: linear, log-linear (log-log), Box-Cox, logit, and translog. The models were estimated on the same dataset for two market segments: (1) commodities; and, (2) fruits, vegetables, and other

edible foods. The models used cross-sectional data on inter-regional freight flows by rail and truck from 1979. The translog model fit the data better, and all of its coefficients were significant and provided the expected signs. Importantly, the demand elasticities across the five different model functions differed. Although the Oum paper modeled freight flows by surface modes, the conclusions about model functional form may apply equally to air travel demand models. No comparable studies of air travel demand were found in the literature, thus this is a potential area of future research.

Estimation Data

Air travel demand studies have been based on different data sources. In some cases this is due to the different markets that were studied (*e.g.*, U.S. domestic markets vs. European markets). However, even when the same data source was used, such as the U.S. O&D passenger data from DB1B, different studies used different city-pair markets, different time periods, or different temporal resolution (quarterly vs. annual data). Combined with differences in model functional specification and explanatory variables, this makes it difficult to isolate the underlying reason why results differ across studies.

Estimation data can be broadly classified as time-series, cross-sectional, or panel. Of the 45 models summarized in the accompanying Appendix, 14 used time-series data, 13 used cross-sectional data, and 16 used panel data. Cross-sectional data allow models of air travel demand to account for differences in airport-pair, city-pair, or country-pair markets. However, models estimated on cross-sectional data cannot explicitly account for changes in the level of air travel in a given market over time. Use of such models for forecasting future levels of air travel implicitly assumes that the relationships among the amount of air travel and the causal variables that have been estimated across different markets at a single point in time will remain constant over time. This assumption may not be valid, in which cases time-series data are more appropriate to use. Air travel demand models estimated using time-series data explicitly attempt to account for changes in the level of air travel over time, typically for a single city-pair or country-pair market (*e.g.*, see Verleger, 1972 and Battersby & Oczkowski, 2001).

Panel data combines the strengths of cross-sectional and time-series data by tracking markets over time. Panel data can provide a much larger dataset on which to estimate a demand model; however, because observations are no longer random (because we are observing the same market multiple times), advanced econometric techniques are required in order to ensure the coefficients and model fit statistics are “correct.” Advanced econometric techniques such as including lagged variables in the model specification, may also be required for both time-series and panel data to account for serial autocorrelation of the error terms. Some, but not all, of the studies reviewed in the Appendix incorporated these advanced econometric techniques.

Aggregated versus Disaggregated Data

A primary focus of the current project is on the potential use of disaggregated socioeconomic data in air travel demand studies. The extent of data disaggregation can take various forms. At the most disaggregated level, data from air passenger or other surveys reflect behavior of individual travelers or households. A somewhat less disaggregated level would include data that provide distributions of socioeconomic characteristics, either as proportions of

some population in various categories (such as household income ranges) or a distribution function. Data can also be disaggregated on a geographic basis, such as measures of air travel and socioeconomic characteristics for smaller zone (*e.g.*, postal zip code areas) within a larger region. Although models of air travel demand that consider different airport-pair or city-pair markets may be thought of as a type of disaggregation, they are not considered disaggregated models in the sense used in the current project if the models use aggregate socioeconomic and other data for the cities or regions.

The review of the academic literature found relatively few examples of air travel demand studies that used disaggregated data. Verleger (1972) included household income distribution in a model of O&D passengers for a sample of 115 city-pair markets, where the trip propensity distribution by household income was assumed to follow an exponential distribution, the coefficients of which were estimated for each market. The estimated values of these coefficients were not always statistically significantly different from zero. Taplin (1980) developed models of household air travel expenditure in Australia from national household expenditure surveys, where data were grouped into six income ranges. The models included the average age of the head of household on each income group, although this was therefore really an aggregate measure since the data was not tabulated by both household income and age of head of household.

Morrison & Winston (1985) developed models of the probability of choosing a destination and a travel mode for U.S. domestic intercity trips using data for a large sample of intercity trips reported by respondents to the 1977 Census of Transportation National Travel Survey. The authors considered two household income ranges in the model (households with incomes under \$20,000, presumably in 1976, and all others).

Dargay (2010) developed a model of person-miles of domestic intercity travel by mode (including air) in the UK at the household level for five different trip purposes using data from the UK National Travel Survey from 1995 to 2006. The models included a range of household characteristics including household income, household composition, type of home, and the gender and employment status of the survey respondent. The estimated models were linear in the explanatory variables, which implicitly assumed that travel propensity increased linearly with household income. Since other studies (*e.g.*, Gosling, 2014) have demonstrated this to be an oversimplification (at least in the U.S.), this may have resulted in biased coefficients for the other variables correlated with income (such as household composition or type of home).

Kressner & Garrow (2012) developed a model of the number of home-based air trips generated by households at the zip-code level in Atlanta. They modeled the home-based air trips on the proportion of households in several different lifestyle clusters defined by a credit-reporting agency that provided data on a large sample of households in the Atlanta region that included estimated household income and assigned each household to one of 26 different lifestyle clusters. Their model is not a full air travel demand model (as only home-based air trips could be linked to the credit reporting data, so non-home-based trips were not included). Rather, the focus of their paper is on explaining differences in air travel propensity in terms of lifestyle clusters.

Two studies examined air travel demand using airline booking data. Granados, *et al.* (2012) developed a model of O&D passengers in international travel markets on an unidentified airline during two periods in 2009 and 2010. The model did not include any socioeconomic variables, but did provide an analysis of the demand for four different standard bundles of airfare, class of cabin, and fare restrictions offered by the airline and the use of two different booking channels, one of which allowed more customization of fare class features. The model also included dummy variables for each O&D market, but the estimated values for the coefficients for these variables are not reported in the paper. Although this paper provides some insight into the role of fare class restrictions and flexibility of the booking channel on the demand for air travel in a given market, since the model only included travel on the airline in question, it could not account for whether changes in the total number of passengers in a given O&D market were due to travelers choosing not to travel or choosing to fly on other airlines. Although this distinction may be effectively the same for the airline in question, it is clearly not the same for the total air travel demand in each market.

Mumbower, Garrow & Higgins (2014) developed a model of daily bookings by flight for a sample of 13 flights operated by JetBlue Airways over a 21-day period that considered the extent of advance booking, the day of week of booking and travel, and the departure time, in addition to the fare available at the time of booking and the existence of a fare sale by Virgin America at the time of booking. The model does not include any socioeconomic variables or consider air passenger traffic on other flights in the markets served by the sample flights, so it is not strictly an air travel demand model. However, it provides useful insights into how the time of day and day of week of travel and the amount of advance booking influences the airfare paid in a given market.

Although relatively few of the academic studies reviewed used air passenger survey data, this represents a valuable source of potential information about air passenger characteristics that could improve studies of air travel demand. Gosling (2014) discussed the potential role of disaggregated air passenger survey data in air travel demand forecasts. The paper includes an analysis of changes in airfares and O&D passenger traffic in 25 major domestic markets from the San Francisco Bay Area (SFBA) over the period from 2000 to 2010. The paper suggests that the change in traffic in individual markets is due to other factors in addition to changes in the average airfare. The paper discusses the air passenger characteristics collected in a sample of six recent air passenger surveys covering 11 major airports in the U.S and presents the results of an analysis of air passenger household income distribution and air trip propensity by respondents to a 2006 air passenger survey undertaken at two SFBA airports.

Market Segmentation

Five of the 45 air travel demand models reviewed distinguished between demand for business and non-business purposes. Abrahams (1983) estimated demand models for seven different groups of markets, two of which were characterized as major vacation markets (Florida and Hawaii). The other five groups, which were based on geographic regions and distance, included a mix of business and non-business travel. Morrison & Winston (1985) used U.S. National Travel Survey data to estimate separate models for vacation and business travel. Dargay (2010) used data from the UK National Travel Survey to estimate two different models of person-miles of travel within the UK by mode (including air) for five different trip purposes.

Granados, *et al.* (2012) developed separate models for business and leisure travel, using airline booking data. The authors inferred trip purpose from the ticket class, the day of travel, the trip duration, and frequent flier program membership.

Although factors that determine the level of air travel for business trips are likely to be different from those that determine the level of non-business trips, the lack of efforts to assemble reliable data on trip purpose on an on-going basis other than in the UK has limited the development of air travel demand models that account for differences in demand by trip purpose. This is a potential area of future research.

Government and Industry Studies

This section reviews government and industry studies of air travel demand where “government” studies include those conducted by or for government agencies “industry” studies comprise those conducted for industry organizations. The government studies were conducted for Australia and the United Kingdom (UK) and the industry studies were conducted for the International Air Transport Association (IATA) and the Airports Council International – North America (ACI-NA).

Australian Studies

A number of air travel demand studies in the literature were performed by or for Australian government agencies over a 16-year period from 1982 to 1998. This most likely reflects the importance of air travel to Australia, both for domestic and international travel. Domestic travel is important given Australia’s large and relatively sparsely populated continent. International travel is important given Australia’s relatively isolated geographical location and cultural connections between Australia and Europe, particularly the UK. Further, in the 1990’s, foreign tourism became an important component of the Australian economy, particularly from Asia.

Two early studies used elasticity values for Australian air travel obtained in prior studies to understand the sensitivity of air travel demand to price and other factors. The first study, a conference paper by Lubulwa (1986), describes the development of demand functions for long distance travel in Australia by air, rail, long-distance bus, and private car, using elasticity estimates from prior studies. Lubulwa examined direct and cross-elasticities of demand with respect to price and travel time, as well as direct elasticities with respect to population, income, and tourist accommodation costs. Separate demand functions were developed for business and non-business air travel. The second study, undertaken as part of an Independent Review of Economic Regulation of Domestic Aviation in Australia (May, Butcher & Mills, 1986), analyzed the sensitivity of air travel demand to changes in airfares. Their analysis reported price elasticities for selected Australian domestic routes estimated in a 1985 study by the Bureau of Transport Economics.

The same year, the Australian Bureau of Transport Economics (1986) issued a report that provided forecasts of domestic air passenger and air freight demands in Australia. These forecasts were produced for five-year intervals through 2000. The report reviewed recent trends in passengers and air fares for trunk, regional, and commuter markets. Econometric models were

then estimated for each of these markets using quarterly data for 1977 to 1984. Forecasts were produced at the route level for 30 trunk routes and at the state and sub-market levels for regional and commuter air services. For the 30 trunk routes, equations were estimated for: (1) each route; (2) three stage-length categories; (3) summer holiday destinations; and, (4) winter sunspot destinations. For regional air services, forecasts were produced for: (1) four state groupings (New South Wales, Queensland, South Australia, and Western Australia); and, (2) eight New South Wales (NSW) sub-markets categorized by stage length, community size, region, and airline. For commuter air service, forecasts were produced for: (1) six states (the above four plus Tasmania and Victoria); and, (2) two sub-markets for NSW (by stage length) and South Australia (Kangaroo Island and mainland services).

The models predicted the number of passengers on nonstop flights using city-pair or regional population as explanatory socioeconomic variables together with GDP (for trunk routes and regional air services) or average male weekly earnings (for commuter air services) as income variables. Other explanatory variables included airfares and measures of the cost of alternative surface travel, both expressed as a price index. The estimated population elasticity values for trunk routes ranged from -6.82 to 4.99, and the estimated regional population elasticity values for regional or commuter air services ranged from -0.14 to 3.59. The estimated income elasticity values ranged from 0.04 to 4.85 for GDP and from 0.24 to 2.98 for average weekly earnings. The width of these ranges suggests that there may be additional factors affecting the demand in each market that are not included in the models.

A later report by the Australian Bureau of Transport and Communications Economics (1995) documents the development and estimation of econometric models of the demand for air travel between Australia and 12 foreign countries using quarterly data from 1986 to 1993. For each country-pair, separate models based on a double-log or linear functional form were estimated for four market segments: Australian residents traveling for business, Australian residents traveling for leisure, foreign residents traveling for business, and foreign residents traveling for leisure. The explanatory variables and number of lag terms included in each model differed and were selected based on the statistical fit of the estimated coefficients and data availability. Estimated elasticity values ranged from 0.21 to 11.6 for Australian private consumption; 1.88 to 4.50 for foreign private consumption expenditures; and 0.44 to 5.51 (and 0.39 to 4.36) for leisure (business) trips for Australian or foreign GDP. Estimated values for airfare elasticities ranged from -0.14 to -1.86 (and -0.01 to -0.62) for business (leisure) trips, with foreign visitors tending to be more price elastic than Australian residents. Estimated values for exchange rate elasticities ranged from 0.20 to 4.46 (and -1.09 to 0.79) for Australian residents traveling on leisure (business) and -9.45 to 0.69 (and -5.13 to 0.99) for foreign residents traveling on leisure (business). The wide range of these estimated elasticity values suggests that there are other economic factors influencing the demand for air travel that were not included in the models.

A conference paper by Hamal (1998) presents the results of a regression analysis of Australian resident holiday travel in two long-haul (UK and U.S.) and four short-haul markets (Fiji, Indonesia, New Zealand and Singapore) using annual data from 1974 to 1996. The models predicted per-capita resident vacation departures as a function of per-capita real household disposable income, the price index of domestic travel and accommodation, the destination country's consumer price index (CPI), which was used as a proxy for a price index of destination

travel and accommodation costs, and the annual average exchange rate (destination country's currency to the Australian dollar). The preferred model for some markets omitted the exchange rate variable.

The estimated elasticity values of household income varied from 0.01 for trips to New Zealand to 0.84 for trips to the UK. The estimated elasticity values for the destination country's CPI varied from -0.20 for Indonesia to -2.23 for Fiji. The estimated cross-price elasticity values for domestic travel varied from 1.16 for trips to New Zealand to 2.35 for trips to Fiji. Although it is clear that a change in domestic travel costs will affect the demand for overseas travel, it is less clear why there would be a different effect in different overseas markets. However, it should be noted that the models do not include a variable for airfare, so the estimated coefficients for the two variables for domestic and overseas destination travel costs may be distorted by an omitted variable bias. Four of the six models include a variable for the exchange rate (although not adjusted for changes in relative Australian and destination prices). The estimated values for the exchange rate elasticity vary from 0.11 to 1.42, all positive as would be expected. However, the three lowest values vary from 0.11 to 0.15 are lower than expected, given that local travel and accommodation costs at the destination are typically a significant component of an overseas holiday, particularly for trips that do not involve visiting family or friends.

United Kingdom Aviation Forecasts

Since the 1990's, the UK Department for Transport (DfT) and its predecessor agencies have been developing a sophisticated set of aviation forecasting models. The overall modeling framework reflects policy needs of the DfT to address airport capacity issues in the London region and to develop a national airport policy. The UK aviation forecasting model divides the UK into 455 analysis zones and distributes air trips to and from each zone to the national system of commercial service airports.

The most recent report on the national aviation forecasts (UK DfT, 2013) describes the modeling framework developed by the Department and its predecessor agency over more than ten years to prepare forecasts of commercial aviation activity at all UK airports with significant levels of commercial air service. The framework consists of several linked models that: (1) generate forecasts of air passenger traffic for the country as a whole in six different geographic market sectors; (2) allocate the national passenger traffic in each market sector to airports; and, (3) estimate the number of air transport movements (aircraft operations) at each airport resulting from the passenger allocation. Separate models were estimated for six geographic market sectors: Western Europe, other Organisation for Economic Co-operation and Development (OECD) countries, newly industrialized countries (NIC), less developed countries (LDC), UK domestic traffic, and international-to-international connecting traffic using UK airports (primarily London Heathrow). Passenger traffic between the UK and the four overseas market sectors was further stratified into four trip purpose segments: UK residents or foreign residents making business or leisure trips. UK domestic passenger traffic was stratified into business and leisure trips and international connections were not stratified by trip purpose. The explanatory socioeconomic variables varied with the market sector, with one or two variables for a given sector, selected from UK GDP, UK consumption, UK imports, UK exports, or foreign GDP. Dummy variables for years in which there was a special event (such as a recession or the September 11, 2001 terrorist attack) that were statistically significant were included in some

models. The general form of the econometric demand models used a log-log structure. Lagged as well as “difference” terms (defined as the difference in a variable from the previous year) were included in the model. The inclusion of difference and lagged variables in the model specification complicates the interpretation of estimated coefficients as elasticities (see the DfT report for derivations of long-run and short-run elasticities).

The estimated values of the long-run demand elasticities varied across the different market sectors, residency, and trip purpose. Comparing these demand elasticities across the market sectors is challenging because of the use of different socioeconomic variables and the presence of two socioeconomic variables in the models for some market sectors but not others. For market sectors with two socioeconomic variables in the model, adding the elasticities generally gives similar elasticities to those sectors with only one variable, suggesting that the two variables are strongly correlated and each is explaining part of the overall macroeconomic influence on air travel demand. The overall elasticities for the socioeconomic variable(s) for UK resident leisure travel range from 1.11 to 1.85, while those for business travel range from 0.97 to 1.28. The elasticities for foreign resident leisure travel range from 0.46 to 1.21, while those for business travel range from 0.55 to 1.11.

The foreign resident leisure travel from the NIC and LDC market sectors have the lowest elasticities of the socioeconomic variables (foreign GDP in each case) at 0.51 and 0.46 respectively. This is rather surprising, since one would have expected that increasing GDP in these countries would have had a much stronger effect on leisure travel to the UK than for developed economies, such as Western Europe (elasticity of 1.21). However, this comparison is complicated by the use of UK consumption as the socioeconomic variable for foreign resident leisure travel from Western Europe. Interpreting the surprisingly low value of the elasticity of foreign GDP for foreign resident leisure travel from other OECD countries (0.55) is complicated by the inclusion of the nominal UK exchange rate in the model for this market sector, the only sector that included this variable. Of course, the largest country in this market sector is the United States. While the leisure travel market from the U.S. to the UK is probably one of the most mature, it also appears that changes in the exchange rate have a much stronger effect (elasticity of -2.11) than changes in GDP. This seems inherently reasonable. The U.S. GDP does not change much from year to year while the dollar to pound exchange rate fluctuates to a much greater extent, significantly affecting the affordability of a UK vacation for U.S. residents. However, this is also true for the other foreign resident market sectors, suggesting that the models for these sectors should have also included the exchange rate. This has important implications for use of the resulting elasticities in forecasting air travel demand, since exchange rates are likely to be much more stable in the long run than in the short run. If changes in air travel volume that are really due to changes in the exchange rate are attributed to changes in the foreign GDP, the resulting models are likely to overstate the long-run contribution of growth in GDP to air travel.

The elasticity of the socioeconomic variable (foreign GDP) in the model for international to international connecting traffic (0.47) appears surprisingly low, given the elasticity values for travel to the UK from Western Europe and other OECD countries (principally the U.S.). Most international travelers connecting through London Heathrow (the traffic covered by this market sector) are traveling between Western Europe and other OECD countries, particularly the U.S. and Canada. It would be surprising if the elasticity of this traffic with respect to the GDP of the

country of origin differs significantly from that for travel between those countries and the UK. The elasticity values for foreign resident travel to the UK from Western Europe are above 1.1. While the elasticity values for foreign resident travel from other OECD countries are lower (both 0.55), the socioeconomic variable for business travel is UK exports, not foreign GDP, while the model for leisure travel includes the exchange rate, as discussed above, so whether these elasticity values are comparable to the elasticity for international connecting traffic is unclear.

In addition to the socioeconomic variables, most (but not all) of the market sectors included an airfare variable. This was defined differently for UK residents and foreign residents. The average air fare was determined from air passenger surveys undertaken by the UK Office of National Statistics (UK residents) or the UK Civil Aviation Authority (foreign residents). The estimated long-run elasticities of demand with respect to airfare vary from -0.27 to -0.86 for UK residents and -0.16 to -0.76 for foreign visitors. As has been observed regarding other studies, some of these elasticities appear to be unrealistically low. Omitting the airfare variable from some market sectors and travel segments may have distorted the estimated coefficients for the socioeconomic variables (and their corresponding elasticities).

There has been additional work published in addition to the DfT work discussed above. A paper by Njegovan (2006) presents the results of an analysis by the UK Civil Aviation Authority of expenditure on leisure air travel abroad by UK residents over the period from 1993 to 2003. The paper modeled expenditure as a function of air travel costs, domestic tourism costs, and non-air travel costs of tourism abroad. The analysis generated own-price and cross-price elasticities for these three components of leisure expenditure, as well as income elasticities. The estimated income elasticity of demand for air travel expenditure was 1.5, the income elasticity of demand for expenditure on tourism abroad was 1.9, and the income elasticity of demand for expenditure on domestic tourism was 0.6. The corresponding elasticities of demand for expenditures on air travel, tourism abroad, and domestic tourism with respect to airfares were -0.7, -0.2, and 0.1, respectively. Cross-elasticities of demand for air travel expenditure with respect to the prices of tourism abroad and domestic tourism were -0.5 and 0.6 respectively. This indicates that the demand for vacation air travel abroad, expressed in terms of expenditures rather than actual trips, is influenced significantly by changes in the costs of local travel, accommodation, and food at the destination, as well as changes in the costs of domestic tourism.

Industry Studies

In recent years two consultant studies have been undertaken for industry organizations that have included the development of models of air travel demand (InterVISTAS, 2007; InterVISTAS, 2014). Although the primary focus of both studies was on air travel demand price elasticities, both studies developed models of air travel demand that included socioeconomic variables. The studies reflect the interests of the sponsors, the International Air Transport Association (IATA) and the Airports Council International – North America (ACI-NA). The 2007 study conducted for IATA developed several models of air travel between or within ten global regions, including U.S. domestic markets. The 2014 study conducted for the ACI-NA built upon the initial study by updating models for U.S. domestic markets using more recent data.

The models for non-U.S. global regions in the 2007 study used two different sources for air travel and airfare data. One model was estimated for UK outbound travel to Western Europe

using quarterly data for the period from 2003 to 2006 from the International Passenger Survey performed by the UK Civil Aviation Authority. The other eight models were estimated using data from the IATA Passenger Intelligence Service (PaxIS) database, which is based on the IATA Billing and Settlement Plan (BSP) and adjusted to account for traffic not included in the BSP, such as direct sales by airlines and airlines not involved in the BSP. The eight models consisted of a world model and seven separate models for the following regions: intra Europe, intra South and East Asia, intra Latin America, intra Sub-Saharan Africa, transatlantic, transpacific, and Europe to Asia.

The models for the U.S. domestic market in both the 2007 and 2014 studies used essentially the same data and model structure, although for different years. The 2007 study developed a model of O&D passengers for the top 1,000 city-pair markets defined on a metropolitan area basis for the period 1994 to 2005. The 2014 study updated this model using data for the period 2000 to 2010, but limited the analysis to the top 500 city-pair markets.

The 2007 study used several explanatory variables (the variables included in the eight models varied). These explanatory variables included airfare, income measures based on GDP (*e.g.*, GDP or the geographic mean of per-capita GDP), populations of each country-pair, market distance, and quarterly and monthly dummy variables. Explanatory variables used in the 2014 study included the metropolitan area population, real per-capita personal income, real average fare in the market (calculated in different ways), dummy variables for the hub size of airports at each end of the market (using FAA hub size definitions), and quarter and market dummy variables.

The 2007 study estimated demand models using two different regression approaches. For the U.S. domestic market the models were estimated using ordinary least squares (OLS) and two-stage least squares (2SLS) to correct for correlation between airfare and distance, although no statistical tests were reported to show that using distance as instrumental variables provided a valid correction. For the other global markets the models were estimated using OLS or a lagged structure to account for potential autocorrelation in the error terms. The 2014 study used a 2SLS regression approach, since this had been felt to give better results in the 2007 study.

The 2007 study found different value for the airfare coefficient (price elasticity) in the models for the U.S. domestic market, depending on the estimation approach, specifically -0.83 for the model estimated using OLS and -1.46 in the 2SLS model. The 2014 models all used 2SLS estimation and found elasticities that ranged between -1.48 and -1.82 depending on the definition of airfare variable (whether expressed in real or nominal dollars and whether adjusted for airline ancillary revenue, such as checked bag fees). Additional elasticity estimates were reported for the non-U.S. markets and modeling methods in the 2007 study. For example, the estimated elasticity values for airfare in the 2007 study are all negative (as they should be) and vary between -0.36 and -1.30 in the model estimated using OLS and between -0.09 and -0.37 in the lagged model. The former values are more consistent with values typically found in other studies. The intra-Europe market had the largest estimated elasticity value in the OLS estimation at -1.30, which is consistent with the expectation that competition from high-speed rail in many intra-Europe city-pairs could result in a fairly price-elastic demand.

Income (expressed as per-capita GDP) elasticities were also reported. The estimated elasticity values of household income varied from 0.01 for trips to New Zealand to 0.84 for trips to the UK. The estimated elasticity values for the destination country's CPI (proxy for local travel and accommodation costs) varied from -0.20 for Indonesia to -2.23 for Fiji. The estimated cross-price elasticity values for domestic travel varied from 1.16 for trips to New Zealand to 2.35 for trips to Fiji. Although it is clear that a change in domestic travel costs will affect the demand for overseas travel, it is less clear why there would be a different effect in different overseas markets. However, it should be noted that the models do not include a variable for airfare, so the estimated coefficients for the two variables for domestic and overseas destination travel costs may be distorted by an omitted variable bias. Four of the six models include a variable for the exchange rate (although not adjusted for changes in relative Australian and destination prices). The estimated values for the exchange rate elasticity vary from 0.11 to 1.42, all positive as would be expected. However, the three lowest values vary from 0.11 to 0.15, which seem unduly low, given that local travel and accommodation costs at the destination are a significant component (possibly the largest component) of an overseas holiday.

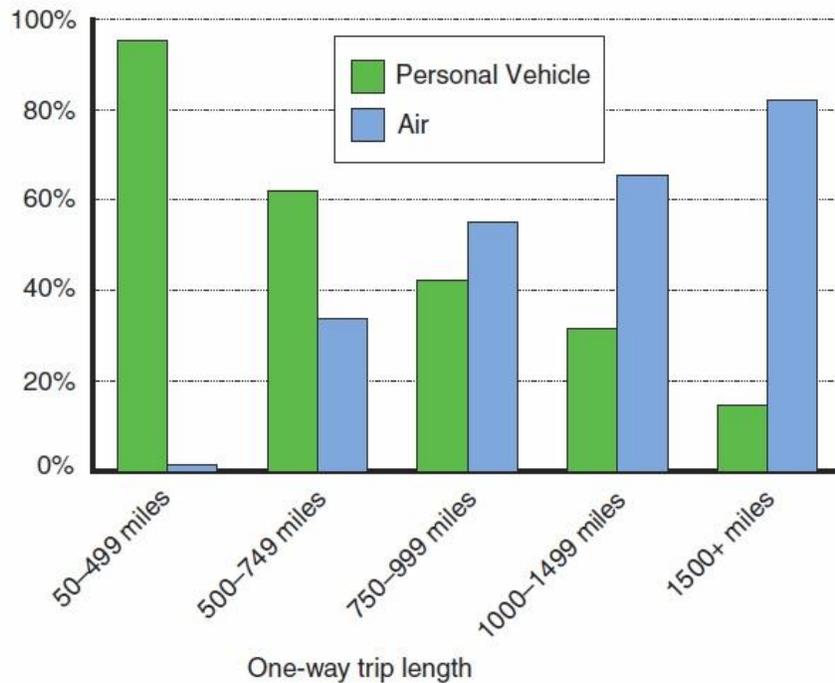
d. Intercity Travel Demand Studies

Intercity travel demand studies examine the choices made by travelers for trips between cities with respect to travel mode and may also consider the number of trips made. These trips, often referred to as long distance trips, include nearly all commercial air trips. These studies typically construct models of traveler choice between the travel alternatives faced by these travelers that express these travel choices as probabilistic functions of traveler characteristics and modal features. Data on intercity travel mode choices in the U.S. from national household travel surveys show that for trips up to about 750 miles each way a higher proportion of travelers use surface modes, particularly personal vehicles, than use air travel, as shown in Figure A-1. Even for one-way trips between 750 and 1,500 miles personal vehicles account for a significant share of all travel. This suggests that changes in the relative costs, travel times, and convenience of air travel and surface modes are likely to have a significant effect on air travel demand, at least in markets below about 1,500 miles. The choice of mode for a trip of a given distance is also likely to be affected by the socioeconomic characteristics of the travelers, which will influence how they trade off the different attributes of each mode.

There is an extensive literature on intercity travel demand that shows how analysis techniques have evolved since some of the early abstract mode work on the U.S. Northeast Corridor in the 1960's (*e.g.* Baumol & Quandt, 1966). Two recent National Cooperative Highway Research Program reports (Horowitz, 2006, Cambridge Systematics, 2008) provide an overview of the evolution of these analysis techniques. A number of more recent studies discussed below document subsequent developments and the current state of practice.

Baik, et al. (2008) developed a mode choice logit model to allocate intercity trips across two existing transportation modes and one hypothetical mode. The modes considered are travel by automobile, travel by commercial passenger flights, and a hypothetical air taxi mode that provides a transportation option that is similar in many ways to commercial aviation but is able to use more convenient small general aviation airports rather than commercial service airports. (Rail was not considered as another intercity mode because of the limited presence of rail in the U.S. intercity travel data.) The analysis uses the Transportation Systems Analysis Model

(TSAM) developed at Virginia Tech to generate U.S. intercity travel demand at the county level. This traffic is based on trip rates from the American Travel Survey of 1995 and on projections at the county level for socioeconomic variables. Trip distribution among the counties also relies on information from the American Travel Survey. These trips are then allocated to modes using a nested logit model linking trips to the probability of using one of the modes. The utility function uses travel time and travel cost, with parameters varying by trip purpose and by the traveler’s household income. The model is used to compare modal shares under different travel time and travel cost scenarios, allowing high level assessments of the effects of changes in aviation infrastructure and policy.



Source: U.S. Bureau of Transportation Statistics 2006 (Figure 2)

Figure A-1. Mode Use by Trip Distance

Rohr, et al. (2010) presented a model of long-distance travel in the UK. For this analysis, long distance travel included trips within the UK of 50 miles or greater, representing less than three percent of all UK trips but around one third of the distance traveled within the country. Reflecting the size of the UK, only a very small proportion of these long distance trips are air trips. Because of the small share of long distance trips in overall UK travel, long distance trip characteristics are often poorly represented in UK traveler survey data and statistics. Nevertheless, UK long distance travel patterns do show some relationship with socioeconomic variables, with the frequency of long distance trips increasing with household income and middle aged people traveling more frequently than those 60 or older or 30 and younger.

Zhang and Xiong (2011) reviewed several approaches to inter-regional travel demand modeling. The authors contrasted inter-regional travel demand analysis with the types of analysis undertaken in many statewide travel demand modeling efforts, which are said to often have

limited focus on long distance travel. They contrasted the existence of numerous statewide travel demand studies with the limited number of examples of national or regional travel demand studies, acknowledging the data challenges and deficiencies that these studies usually face, especially for long distance travel. They listed several types of studies, including direct studies of travel demand and travel elasticities, which link travel activity to economic, demographic and infrastructure characteristics; four-stage trip-based models, which use socioeconomic and demographic factors to project the generation of trips, the distribution of trips to travel markets, and the choice of mode of travel; and more bottom-up approaches based on traveler survey and facility survey information. Data limitations affect these alternative approaches in different ways, although a common data challenge is the infrequency or irregularity of the collection of actual passenger trip and behavior data, in contrast to socioeconomic and demographic data on populations, which is regularly and systematically collected in much of the world, although it is typically not collected or organized with travel modeling in mind.

Moeckel, et al. (2013) developed a nested long distance travel mode choice model for the U.S. The model initially characterized a travel choice as either automobile travel or non-automobile travel, and subsequently characterized automobile travel (by travel party size) and other travel as bus travel, rail travel or air travel. Total long distance trips in the model are taken from the 2002 National Travel Survey. Citing “limited data availability” with regard to long distance travel, the parameters for mode choice were developed heuristically from prior experience and existing literature. Mode choices in the model are determined by mode costs and amenities and trip characteristics. Examples of applications of the model for assessing mode choices and transportation alternatives in North Carolina are presented.

Cambridge Systematics (2014a,b) presented results from a long distance travel demand model developed to estimate ridership on proposed California High Speed Rail (HSR) passenger services. The overall model, which projected HSR ridership and revenues, includes models of long distance trip frequencies by California households, models of destination choice for those trips, and mode choice models for traveler selection of travel by automobile, air, conventional rail or high speed rail. Mode choices in the model are related to household socioeconomic variables, such as income, as well as mode and trip characteristics. California Household Travel Survey results are used in the estimation process along with other data sources. Given these data and model parameters, HSR ridership and the impact of HSR on competing modal ridership is estimated for HSR fares relative to other modal fares.

Outwater, et al. (2015a,b) summarized a multi-year research project using a tour-based simulation framework to model long distance passenger travel by U.S. households. The model generated household long distance travel over a year through simulations at a micro level of household travel choices and planning. Trips were by air, rail, bus and automobile, and the process of generating trips and mode choices based on household budget options and travel propensities is based on tools from several existing models, including data from the comprehensive 1995 American Travel Survey. Numerous socioeconomic variables affect the model results, such as household income, household location, household size and demographic detail, and employment status. Project research continues, with the aim of achieving a long distance passenger travel demand model based on household characteristics and travel propensities for the U.S. population.

In addition to the foregoing studies, several of the studies reviewed in the earlier section on air travel demand studies (*e.g.* Oum & Gillen, 1983, Morrison & Winston, 1985, Dargay, 2010) were primarily intercity travel demand studies that examined travel demand by multiple modes as well as air travel.

Several of these references from the intercity travel demand literature report quantitative models comparable to those developed in the air travel demand literature, whereas others discuss the development of such models or review other studies that address such models. All these studies make it clear that for many journeys, an air itinerary is one of several travel options available to travelers. Many of these studies have also shown that differences in travel costs among modes interact with differences in the socioeconomic characteristics of the travelers to influence their travel mode choices. Such effects may well result in significant socioeconomic differences between the air traveling public and those using surface modes. The nature and extent of such differences will be explored further as part of the research for this project.

e. Socioeconomic Trends

It is apparent from the review of the air travel demand literature that air travel demand is influenced by the socioeconomic characteristics of those traveling by air. Thus, changes in the underlying socioeconomic characteristics of a population are likely to affect air travel demand and the demand for services that airports provide to those traveling. Several federal agencies and organizations have produced reports that identify socioeconomic and demographic changes in the U.S. that could affect air travel demand in coming decades.

A Congressional Research Service report (Shrestha 2011) notes that the U.S. population is increasing, both due to natural population growth (birth rate minus death rate) and positive net immigration. In addition, the U.S. population is aging, which is expressed in both an increased median age and an increased portion of the population above the age of 65. This trend is expected to continue through the year 2050. Finally, the population is becoming more ethnically diverse. The portion of the population that was non-Hispanic white was about 70 percent in the year 2000, but is predicted to be less than 50 percent by the year 2050. A recent U.S. Census Bureau report (Colby & Ortman, 2015) reported similar expectations regarding trends in the size, aging and increasing diversity of the U.S. population.

The 2015 Social Security Trustees report (Social Security Administration, 2015) addresses long range socioeconomic and economic trends that affect disability trust funds managed by the Social Security Administration. The report also finds similar conclusions regarding trends in the size of the aging population, noting that the life expectancy is expected to increase. Male life expectancy at birth is forecast to be between 80.9 and 87.6 years, and female life expectancy is forecast to be between 84.7 and 90.2 years.

The 2015 Trustees report also projects U.S. economic trends such as productivity², price inflation, average earnings, and GDP ranging across three alternative scenarios. For the intermediate scenario, productivity is expected to increase to 1.92 percent for 2016, gradually decline to 1.67 percent for 2022 and 2023, and then rise to 1.68 percent for 2024 and later. The

² Defined as the ratio of real GDP to hours worked by all workers

annual change in the CPI under the intermediate assumptions is 0.20 percent for 2015, 2.97 percent for 2016, 2.76 percent for 2017, and 2.70 percent for 2018 and later. The expected growth rate in average nominal U.S. earnings from 2025 to 2089 is expected to be about 3.88 percent under the intermediate scenario. Under the same scenario, the average annual growth in real GDP is 2.8 percent from 2014 to 2024.

Economic projections are also discussed in Chapter 2 of the 2015 *Economic Report of the President* (Council of Economic Advisors, 2015). Real GDP is projected to grow 3 percent at an annual rate during 2015 and 2016 and then to grow 2.7 percent during 2017, 2.5 percent in 2018 and, 2.3 percent from 2019 to 2025. The CPI is expected to grow 1.8 percent in 2015, 2 percent in 2016, 2.2 percent in 2017 and then 2.3 percent from 2018 to 2025. Lastly, the unemployment rate is expected to be 5.4 percent in 2015, 5.1 percent in 2016, 4.9 percent in 2017, 5.0 percent in 2019, 5.1 percent in 2020 and 5.2 percent from 2021 to 2025.

Socioeconomic trends in U.S. labor markets from 2010 to 2020 are addressed by Toossi (2012). The Bureau of Labor Statistics (BLS) anticipates a modest slowing of the rate of growth of the labor force over that decade, compared to the preceding decade. This change is the result of several contributing factors, including a slowdown in the rate of overall population growth, a decline in the labor participation rate among prime working age individuals, and the movement into retirement by increasing numbers of the Baby Boomer generation. Thus, there will be socioeconomic changes affecting both leisure and business air passenger travel choices and their uses of airports.

Socioeconomic trends in U.S. transportation are addressed in a report by the U.S. Department of Transportation (2015), which describes projected shifts in U.S. transportation patterns through the year 2045. Although transportation costs remain the second largest expense of U.S. households, preferred modes of transportation vary by age, location, and income. Use of cars is decreasing rapidly, especially among the younger generation: millennials drove 20 percent fewer miles in 2009 than the equivalent age group drove in 2001. Although cities are still popular among younger Americans, Americans of all ages are moving to the suburbs and as a result, suburban areas of major cities are growing much faster than urban and rural areas. In addition, the U.S. population is moving from the Northeast and Midwest regions of the country to regions in the South and West. Consequently, transportation facilities such as the airports serving these areas can expect to see shifts in their passenger numbers as well as the types of passengers they serve over the next few decades.

Global socioeconomic and demographic factors are addressed in a recent report on the future use of worldwide passenger and freight rail service (Arup, 2015) which projects that increased urbanization, high rates of population growth in developing countries, and the impacts of climate change will increase demand for passenger and freight rail services around the world. Additionally, advances in technology will also increase demand. The report projects that the “internet of things” will allow transport modes to “to communicate with each other and with the wider environment” and lead to more fully integrated multi-modal transportation. New types of lighter, stronger materials, the wider use of 3-D printing, and the use of automated robots will improve production processes, maintenance and repairs. The report also identifies several barriers to the accommodation of increased demand for rail travel, such as infrastructure and

capacity restraints, congestion and operational efficiency, and reduced availability of government subsidies.

A second report examines the global highway sector (Arup, 2014). The urbanization of populations through 2050 is expected to create a number of megacities around the world, especially in India and China. This means increased traffic that will require new technologies and new alternatives to driving a car. The world is expected to rely less on current energy sources like oil and more on alternative energy. This report deals specifically with alternative energy sources for these cities, using innovations like pedestrian-powered streetlamps and solar highways. Urban transportation systems will also have to adapt to the impacts of climate change, creating more durable infrastructure and preparing far ahead of time for the extreme weather events that may impact cities across the world. This is especially true of the developing world; although all cities must be ready for climate disasters, areas with unpaved roads, poorly-maintained bridges, and minimal access to power stand to lose significant resources and would take much longer to recover than more developed regions. The uneven nature of economic progress also means that much of the economic growth of the next few decades is likely to come from East, South, and Southeast Asia, meaning that future highway technology may not come from the western researchers who create it today.

For airports, the significance of these trends may also be related to their variability across the country. For example, immigration patterns can be uneven across the U.S., with over 60 percent of immigrants moving to the same six states. Similarly, certain metropolitan areas are well established as retirement locations, and others are seen as catering to young professionals or families with children. Regional unevenness of this sort in socioeconomic trends in the U.S. highlights the importance of monitoring regional as well as national socioeconomic trends. For airports, what was true for a given airport's catchment area a decade ago may change in ways that will affect not only passenger volumes but also the characteristics of the passengers who use that airport. At the same time, the effect of these trends is likely to vary across different airports.

A.3 Summary

This document reviewed a large body of literature published over the past five decades on air travel demand and the related topic of intercity travel demand. Recent accounts of socioeconomic trends were also summarized. This establishes the context of the present understanding of air travel demand within which the current project will explore the potential contribution of the use of disaggregated socioeconomic data to enhancing future studies of air passenger demand.

Key findings from the literature review include the following:

- At least one prior ACRP study notes that it is important for airports to produce credible forecasts of air travel demand that account for economic and demographic factors, but the potential roles for disaggregate socioeconomic data in this objective are not addressed.
- Different levels of “data disaggregation” have been reported in the literature and range from data from air passenger surveys of individual customers to distributions of socioeconomic characteristics, to averages of socioeconomic characteristics for small geographic areas, such as zip codes.
- Prior studies of air travel demand vary widely in terms of how they model demand, which explanatory variables (including socioeconomic factors) are included, how markets were segmented, and other factors.
- Among the prior studies of air travel demand, a third or more have included
 - Some socioeconomic variables, although there is little consistency in which variables were used.
 - Population measure(s) and measures of economic activity, such as income or gross domestic product (GDP).
 - Airfare and other measures of air service.
 - Market segmentations by trip purpose, distance, and/or world regions.
- Many of the same modeling challenges that existed 30 or more years ago exist today. These challenges include
 - Data availability
 - Understanding which explanatory variables to include in models
 - Identifying when advanced modeling techniques should be used to account for such data issues as autocorrelation in error terms for time series and panel data or price endogeneity (situations where the airfare in a market varies with the level of demand).
- Price elasticity is often reported in air travel demand studies, due to the desire to predict how demand will change in response to changes in airfares and total trip costs. However, there is a wide variation in reported elasticity estimates across studies, many of which appear to be unreasonable. This will be discussed more in the Task 3 Gap Analysis.
- There are wide ranges of values also reported in the air travel demand studies for the income elasticity of demand, and these ranges include some unusual or implausible values. Because passenger income is an important socioeconomic

variable, these results for air travel demand income elasticity will also be examined in greater detail in the Task 3 Gap Analysis.

- The wide range of results reported in air travel demand studies may also be due to bias caused by omitted variables, *i.e.*, leaving out variables that are important to predict air travel demand.
- Data from the National Household Travel Survey have shown that a significant proportion of total intercity trips use surface modes (generally private vehicles, but rail may attract a significant mode share in some markets) for distances up to about 1,500 miles. Intercity travel demand studies have developed models that quantify the mode share of air and surface modes in a given market and have shown that travelers' choice of intercity travel mode is influenced by socioeconomic factors, particularly income, as well as by the costs, travel time, and other attributes of the available modes. This suggests that air travel demand studies may need to consider the effect on demand of competition from surface modes.
- The U.S. population is increasing and is becoming older and more diverse (the second due in part to immigration). Airport managers will need to be aware of the unique mobility and other needs of these passengers. Differences in regional trends mean that these changes will affect different airports differently.
- There are many unanswered research questions related to air travel demand forecasting that may be of interest to professionals and researchers involved in the field as well as students pursuing graduate degrees in aviation-related fields. These questions, outside the scope of the current work, include the following:
 - What are the benefits of using directional (*i.e.*, outbound and inbound) passenger demand for airport forecasting applications?
 - How can the individual effects of income, GDP, and other economic indicators be estimated for air travel demand studies?
 - Does a translog model of air travel demand fit the data better and provide more intuitive results than more traditional models used?
 - Why do price elasticity estimates vary so much across different studies?
 - What can be learned from differences that may exist between the role of socioeconomic variables in intercity travel demand modeling of traveler mode selection and the role of those variables in air travel demand modeling specifically?

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Attachment

Characteristics of Air Travel Demand Models Reviewed

The following tables list the academic, government and other studies reviewed that included formal models of air travel demand. The studies are characterized according to several model elements or dimensions. Model elements reported in the tables include:

- The type of model, defined as the functional form used to relate the dependent and independent variables
- The type of data (*e.g.*, panel, time series) used for estimation
- The time periods on which the models were estimated
- Degree of aggregation of socioeconomic and other data used for model estimation (aggregate or disaggregated)
- Demand measures used as the dependent variable (*e.g.*, modeling the number of passengers on an origin-destination pair or revenue passenger miles)
- The explanatory socioeconomic variables used as the independent variables
- The market segments, if any, that are used in estimation (*e.g.*, business or leisure travelers)

Table A-1: Academic Studies

Reference	Model Type	Data Type	Data Period	Aggregate/ Disaggregated (A/D)	Travel Market	Dependent Variable	Socioeconomic Variables	Estimated Elasticity	Market Segments	Comments
Long, 1968	linear (gravity model form)	panel	1953-1958	A	U.S. (dom)	Sum of coefficients of dummy variables for each city in a city pair from a prior model	Population; People with income >\$10k; People with 1+ yrs of college; Employment in larger firms	 not calculated 	Yes (3)	Larger firms defined as having 100+ employees; Market segments based on traffic level (<50, 50-999, 1000+ pax in sample period)
Verleger, 1972 (gravity model)	log-log	cross-section		A	U.S. (dom)	O&D market pax	Aggregate income product; Telephone calls	-0.32 to +0.35 +0.18 to +0.99	Yes (5)	Market segments by distance range
Verleger, 1972 (aggregate model)	log-log	time series	1958-1965	A	U.S. (dom)	National revenue pax miles	Per-capita personal income	+2.35 to +2.39	No	
Verleger, 1972 (city-pair model)	nonlinear	time series	1960-1967	D	U.S. (dom)	O&D market pax	Average household income	+0.16 to +5.43 (omit -9.1)	No	Household income distribution used in model
Taplin, 1980	log-log	panel	1974-1975 & 1975-1976	D	Australia	Travel expenditure	Household income; Age of head of household	+0.79 to +1.47 +1.30 to +2.64	Yes (4 air)	Market segments: domestic vs. overseas; independent travel vs. package tour
Anderson & Krause, 1981	log-log	time series	1973-1976	A	U.S. (dom)	Pax on nonstop flights	Income; Value of travel time	+1.22 to +5.95 n/a	No	Value of travel time (VTT) assumed; income elasticities for VTT = \$10/hour

Table A-1: Academic Studies (cont.)

Reference	Model Type	Data Type	Data Period	Aggregate/ Disaggregated (A/D)	Travel Market	Dependent Variable	Socioeconomic Variables	Estimated Elasticity	Market Segments	Comments
Ippolito, 1981	log-log	cross-section	1976	A	U.S. (dom)	O&D market pax	Population; Income	+0.34 +2.35	No	
Abrahams, 1983	linear	panel	1973-1977	A	U.S. (dom)	Pax on nonstop flights	Population; Personal income; GDP growth rate	 not calculated (1) 	Yes (7)	Market segments: vacation markets (2), geography and distance (5)
Andrikopoulos & Terovitis, 1983	linear	cross-section	1970-1980	A	Greece	O&D market pax	Population	+1.48 to +25.5	No	A time-series model was estimated with no socioeconomic variables
Oum & Gillen, 1983	translog	time series	1961-1976	A	Canada	Travel expenditure	Household income; Avg weekly work hours	+1.59 to +2.53 found not to influence expenditure	No	Estimated cross-elasticities between modes and with non-travel spending
Agarwal & Talley, 1985	log-log	cross-section	Dec 1981	A	U.S. (int'l)	Pax on nonstop flights	None		No	
Morrison & Winston, 1985	logit	cross-section	1977	D	U.S. (dom)	Prob of choosing destination & mode	Household income; Travel party size; Travelers under age 4	n/a (2) not calculated (3) 	Yes (2)	Market segments: vacation vs. business
Fridstrom & Thune-Larsen, 1985	log-log	panel	1972-1983	A	Norway	Pax on nonstop flights	Population; Per-capita taxable income	+1.13 to +1.47 +0.95 to +1.50	No	Model used a gravity formulation and included fare and time on surface mode

Table A-1: Academic Studies (cont.)

Reference	Model Type	Data Type	Data Period	Aggregate/ Disaggregated (A/D)	Travel Market	Dependent Variable	Socioeconomic Variables	Estimated Elasticity	Market Segments	Comments
Oum, Gillen & Noble, 1986 (exp model)	translog	cross-section	1978	A	U.S. (dom)	Expenditure share by fare class	None		No	
Oum, Gillen & Noble, 1986 (pax model)	log-log	cross-section	1978	A	U.S. (dom)	O&D market pax	Population; Per-capita income	+1.67 +1.45 to +2.08	No	
Talley & Schwarz-Miller, 1988	log-log	cross-section	1983	A	U.S. (dom)	Revenue pax miles	None		No	Model estimated from data for 22 airlines
Oum, Zhang & Zhang, 1993	log-log	panel	1981-1988	A	U.S. (dom)	O&D direct market pax (10% sample)	Total income	+0.16	No	Total income = population * per-capita income for market dest MSA
Alperovich & Machnes, 1994	log-log	time series	1970-1989	A	Israel	Air pax per capita	Average wage; Financial assets; Non-financial assets; Total assets	+1.55 to +2.06 +0.24 to +0.38 +0.56 to +0.72 +0.84 to +0.85	No	Elasticities vary by variables included in alternative models; total assets combine financial and non-financial assets
Jorge-Calderon, 1997	log-log	cross-section	1989	A	Europe	Scheduled pax on EC airlines on route	Population; Per capita income	-0.03 to +0.13 +0.05 to +0.21	Yes (7)	Market segments by distance range (3) and market density (4); elasticities vary by distance range
Abed, Ba-Fail & Jasimuddin, 2001	linear	time series	1971-1992	A	Saudi Arabia (int'l)	Total pax to/from Saudi Arabia	Population	not calculated (1)	No	

Table A-1: Academic Studies (cont.)

Reference	Model Type	Data Type	Data Period	Aggregate/ Disaggregated (A/D)	Travel Market	Dependent Variable	Socioeconomic Variables	Estimated Elasticity	Market Segments	Comments
Battersby & Oczkowski, 2001	linear	time series	1992-1998	A	Australia	Rev pax-km per capita	National industrial production index	+0.26 to +1.92	Yes (7)	Market segments by fare class (3) and route (4)
Bhadra, 2003	log-log	panel	1999-2000	A	U.S. (dom)	Quarterly O&D pax	Orig population density; Dest population density; Orig per-capita pers income; Dest per-capita pers income; Orig total personal income; Dest total personal income	-0.13 to +0.21 -0.26 to +0.29 +0.48 to +2.89 +0.50 to +1.77 -0.37 to +0.28 -0.44 to +0.09	Yes (11)	Market segments: markets by stage length ranges (steps of 250 miles to 2,500 miles, 2,500-3,000 miles)
Castelli, Pesenti & Ukovich, 2003	log-log	panel	1999-2002	A	Italy	Pax by route and fare class	Population; GDP per capita	+0.13 +0.13	Yes (2)	Market segments by fare class: business, economy
Suzuki & Audino, 2003	linear; log-log	panel	1990-1997	A	U.S. (dom)	Market O&D pax	None (air cargo volumes used as surrogate)		No	Model estimated on medium-hub airports serving single-airport regions
Bhadra, 2004	log-log	panel	1999-2000	A	U.S. (dom)	Average daily O&D pax	Orig population; Dest population; Orig per-capita personal income; Dest per-capita personal income	-0.74 to +0.46 +0.16 to +0.58 +0.04 to +8.42 +0.24 to +0.58	Yes (2)	Market segments: small communities by hub size (small hubs, non-hubs)

Table A-1: Academic Studies (cont.)

Reference	Model Type	Data Type	Data Period	Aggregate/ Disaggregated (A/D)	Travel Market	Dependent Variable	Socioeconomic Variables	Estimated Elasticity	Market Segments	Comments
Wei & Hansen, 2006	log-log	cross-section	2000 Q2	A	A	Connecting pax at hub	Total MSA income at hub	-0.36	No	Model includes total initiated trips at spoke, local traffic to hub
Bhadra & Kee, 2008	log-log	panel	1995-2006	A	U.S. (dom)	Average daily O&D pax	Origin population; Dest population; Origin personal income; Dest personal income	not reported not reported +0.04 to +0.65 +0.04 to +0.66	Yes (4)	Market segments: markets by density (pax/day: <=10, 10-50, 50-100, >100)
Karlaftis, 2008	log-log	time series	1989-2006	A	Corfu, Greece	Passenger arrivals	Greece GDP per capita; European GDP per capita	+0.45 +0.24 to +0.31	Yes (2)	Market segments: domestic, international; model also estimated for flight arrivals
Richards, 2009	linear; log-log	time series	1951-2007	A	U.S. (dom)	National RPM	GDP; Non-farm employment	+1.01 to +1.65 +0.68 to +1.56	No	Separate regression for three time periods (1951-69, 1970-87, 1989-2007) Elasticities given for log-log model
Chi, Koo & Lim, 2010	log-log	cross-section	2000, 2005	A	U.S. (dom)	Market O&D pax	Average population; Average disposable income	+0.39 to +0.42 +0.79 to +0.87	No	Separate model estimations for 2000 and 2005; models also estimated for segment pax and on-flight market pax

Table A-1: Academic Studies (cont.)

Reference	Model Type	Data Type	Data Period	Aggregate/ Disaggregated (A/D)	Travel Market	Dependent Variable	Socioeconomic Variables	Estimated Elasticity	Market Segments	Comments
Dargay, 2010 (model 1)	log-log	time series	1995-2006	A	UK (dom)	Person-miles of travel by mode	GDP; Population fraction of women; Population fraction of one-adult households Population fraction employed	+1.01 -0.44 +0.10 to +0.18 +0.45 to +0.95	Yes (5 for air)	Market segments by trip purpose (5); other modes by distance band (2) Variables and elasticities shown for air travel; population fraction elasticities derived from model 2
Dargay, 2010 (model 2)	linear	time series	1995-2006	D	UK (dom)	Person-miles of travel by mode	Household income; Gender; Employment status; Years residence at address; Household composition; Type of home	+1.26 to +1.63 -0.44 (4) +0.45 to +0.95 (4) varies with category (5) 	Yes (5 for air)	Market segments by trip purpose (5); other modes by distance band (2) Other variables included categorical variables for region of country and urban size/rural area Elasticities shown for air travel
Chèze, Gastineau & Chevallier, 2010	log-log	panel	1980-2007	A	Global	Rev ton-km	GDP	+0.28 to +0.36	No	
Kopsch, 2011	log-log	time series	1980-2007	A	Sweden (dom)	Monthly departing pax	Population; GDP per capita	-6.05 to + 6.09 +0.44 to +0.47	No	

Table A-1: Academic Studies (cont.)

Reference	Model Type	Data Type	Data Period	Aggregate/ Disaggregated (A/D)	Travel Market	Dependent Variable	Socioeconomic Variables	Estimated Elasticity	Market Segments	Comments
Bhadra, 2012	log-log	time series	1990-2010	A	U.S. (dom)	Quarterly pax trips	Household wealth; Household credit worthiness	+0.42 +0.12	No	Estimated model also includes household wealth squared
Chi & Baek, 2012	vector auto-regression	time series	1995-2010	A	U.S. (dom)	National revenue pax miles	Population; Personal disposable income	 not calculated 	No	
Granados <i>et al.</i> , 2012	log-log	ticket sample	2009 (2 mo) 2010 (3 mo)	D	Int'l airline (unknow)	O&D pax (tickets sold)	None		Yes (2)	Market segments: business vs. leisure (trip purpose inferred from ticket class, day of travel, trip duration, and frequent flyer status)
Kressner & Garrow, 2012	linear	air pax survey; household characteristics	Jul 2009; Jan 2011	D	Atlanta	Average air trips per household	Lifestyle cluster; Household income	 not calculated 	No	Model estimated on data by zip code; models used either lifestyle clusters or income
Huang <i>et al.</i> , 2013	log-log	cross-section	2010	A	Global	City-pair O&D pax	Population; GRP per capita at purchasing power parity (6)	 model details not available 	No	Model used DB1B, Canadian and European O&D data to "train" and validate model

Table A-1: Academic Studies (cont.)

Reference	Model Type	Data Type	Data Period	Aggregate/ Disaggregated (A/D)	Travel Market	Dependent Variable	Socioeconomic Variables	Estimated Elasticity	Market Segments	Comments
Elwakil, Windle & Dresner, 2013	log-log	panel	2004-2008	A	U.S. (dom)	City-pair O&D pax	Population (product); Per-capita income (product)	+1.06 +1.81	No	A model of average fare in each city-pair market was used in a 3-stage least squares estimation
Sismandou <i>et al.</i> , 2013	CQI ratio (7)	cross-section	2004	A	Spain (int'l)	O&D pax attracted	None		No	
Clewlou, Sussman & Balakrishnan, 2014 (city-pair & airport-pair models)	log-log	panel	1995-2009	A	Europe	Pax on nonstop flights	Regional GDP; Population; Population density	+5.19 to +5.47 +0.81 to +1.82 -0.38 to +2.48	No	
Clewlou, Sussman & Balakrishnan, 2014 (airport model)	log-log	panel	1995-2009	A	Europe	Airport pax	Regional GDP; Population; Population density	+0.06 to +1.02 +0.72 to +0.90 +0.24 to +0.31	Yes (3)	Separate models estimated for domestic, intra-EU, and total (combined) markets
Mumbower, Garrow & Higgins, 2014	linear	panel	Sep 2010	D	U.S. (dom)	Daily bookings by flight	None		No	Booking data was assembled for 13 flights with departures on 21 days and a 28 day booking horizon
Valdes, 2015	log-log; linear	panel	2002-2008	A	Global	Total pax by country	GDP per capita; Foreign direct investment; Consumer prices	+1.26 to +1.83 +0.009 -0.25 to +0.26	No	

Notes: n/a = not applicable

1. In any case, in a linear model elasticity value(s) would vary with the value of the independent variable.
2. Household income was defined as a dummy variable for households with incomes under \$20,000.
3. In any case, given the relatively small integer values of the variables, an elasticity value would have no meaningful interpretation.
4. Elasticity values calculated at the sample mean. Since the values of dummy variables (gender) or categorical variables (employment status) are either zero or one, the sample mean has no meaningful interpretation (a survey respondent cannot be 35% female).
5. Model used separate categorical variables for each socioeconomic variable, each of which took a value of either zero or one.
6. GRP = gross regional product. Purchasing power parity expresses values given in different currencies for both the exchange rate and for differences in what a given market basket of goods and services costs in each country.
7. CQI = connection quality index (described in paper).

Table A-2: Government Reports and Studies

Reference	Model Type	Data Type	Data Period	Aggregate/ Disaggregated (A/D)	Travel Market	Dependent Variable	Socioeconomic Variables	Estimated Elasticity	Market Segments	Comments
Bureau of Transport Economics, 1986	log-log	time series	1977-1984	A	Australia (dom)	Pax on nonstop flights	Population (city-pair); Population (regional); GDP; Average weekly earnings	-6.82 to +4.99 -0.14 to +3.59 +0.04 to +4.85 +0.24 to +2.98	Yes (17)	Separate models estimated for trunk routes, regional air services (by state), commuter air services (by state)
Bureau of Transport and Communications Economics, 1995	log-log; linear	time series	1986-1993	A	Australia (int'l)	Total pax	Private consumption; Australian GDP; Foreign GDP	+0.21 to +11.58 +0.39 to +4.36 +0.23 to +5.51	Yes (4)	Separate models estimated for each of 12 country pairs Market segments: Australian vs. foreign visitors; business vs. leisure
Hamal, 1998	log-log	time series	1974-1996	A	Australia (int'l)	Per-capita resident vacation departures	Per-capita household disposable income	+0.01 to +0.84	No	Separate models estimated for each of 6 destination countries
Njegovan, 2006	linear-log	time series	1993-2003	A	UK (int'l)	Share of leisure expenditure	Income	+1.5	No	Leisure air travel abroad by UK residents; model included cross-price elasticities

Table A-2: Government Reports and Studies (cont.)

Reference	Model Type	Data Type	Data Period	Aggregate/ Disaggregated (A/D)	Travel Market	Dependent Variable	Socioeconomic Variables	Estimated Elasticity	Market Segments	Comments
InterVISTAS Consulting, 2007 (US model)	log-log	panel	1994-2005	A	U.S. (dom)	O&D market pax	Population; Per-capita personal income	+0.45 to +1.76 +0.99 to +1.72	No	Model based on top 1,000 city-pair routes; elasticities vary by estimation approach
InterVISTAS Consulting, 2007 (UK model)	log-log	panel	2003-2006	A	UK (int'l)	Total outbound pax	GDP	+0.43 to +1.45	No	Elasticity varies by estimation approach
InterVISTAS Consulting, 2007 (other markets)	log-log	panel	2005-2006	A	Global	Monthly market pax	GDP per capita	-0.08 to +0.32 -0.19 to +0.02	No	Separate models estimated for each of 7 world regions; elasticities shown for OLS (upper) and ARDL (lower) (1)
InterVISTAS Consulting, 2007 (world)	log-log	panel	2005-2006	A	Global	Monthly market pax	Population; GDP per capita	0.10 -0.03 to +0.03	No	GDP per capita elasticity varies by estimation approach
Department for Transport, 2013	log-log	time series	1984-2008	A	UK (int'l & dom)	Pax	UK GDP; UK consumption; UK imports; UK exports; Foreign GDP	+0.47 to +1.85 +0.62 to +2.26 +0.52 to +0.69 +0.49 to +0.58 +0.45 to +0.76	Yes (4)	Separate models estimated for each of 5 geographic market sectors plus international connections Market segments: UK residents vs. foreign visitors, business vs leisure trips

Table A-2: Government Reports and Studies (cont.)

Reference	Model Type	Data Type	Data Period	Aggregate/ Disaggregated (A/D)	Travel Market	Dependent Variable	Socioeconomic Variables	Estimated Elasticity	Market Segments	Comments
InterVISTAS Consulting, 2014	log-log	panel	2000-2012	A	U.S. (dom)	O&D market pax	Population; Per-capita personal income	+0.66 to +0.78 +0.74 to +1.47	No	Model based on top 500 city-pair routes; elasticities vary by price assumptions

Note: 1. OLS = ordinary least squares; ARDL = autoregressive distributed lag.

