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AIRPORT COOPERATIVE RESEARCH PROGRAM

ACRP RESEARCH REPORT 194

Using Disaggregated Socioeconomic Data in Air Passenger Demand Studies

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AIRPORT COOPERATIVE RESEARCH PROGRAM

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FOREWORD

By Joseph D. Navarrete
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ACRP Research Report 194 explores the potential benefits of using disaggregated socioeconomic data, such as regional household income distributions and air passenger and travel survey data, for air passenger demand studies. The report will be of particular interest to airport industry practitioners who prepare activity forecasts, marketing studies, and studies related to air service development, as well as to researchers studying air passenger demand.

Aviation demand is strongly correlated to socioeconomic activity, and analysts typically use aggregate socioeconomic data, such as gross regional product or average regional household income, to better understand current and potential future aviation demand. Because the United States is experiencing significant and ongoing demographic trends, such as an aging population, increased immigration, wealth concentration, geographic redistribution, and changing trends in the use of discretionary income, there is a question as to whether traditional methods and data sources will adequately capture these trends or would more detailed, disaggregated socioeconomic data, or even nontraditional data (such as credit card transactions and cell phone data), provide more accurate results. Research was needed, therefore, to identify and summarize these long-term socioeconomic trends, understand their potential impact, and provide guidance for incorporating disaggregated socioeconomic data into air passenger demand studies.

The research, led by GRA, Incorporated, began with a review of studies and models to assess the current understanding of the relationship between socioeconomic factors and air passenger demand. The research team identified sources of disaggregated socioeconomic data that are typically correlated with air travel propensity. It then conducted a set of case studies to test the effectiveness of using disaggregated socioeconomic variables in traditional air passenger enplanement models; this effort considered both simple models and more complex models that used a wider range of variables. The research also identified new, nontraditional data, including cell phone data and credit card transaction data, and explored whether the latter might be useful for modeling air passenger behavior. The cost of using disaggregated socioeconomic data was also examined. Lastly, the team identified areas for further research.

Because subsets of the population have different air travel propensities, as documented in the research, it is clear that gaining a better understanding of the effect of socioeconomic trends should improve air travel demand analysis. Yet the research obtained mixed results from the use of disaggregated socioeconomic data in traditional air passenger models, with the benefit more clearly seen when more complex models were used. Future research could explore alternative modeling approaches that might take better advantage of disaggregated data. The research also found that, while nontraditional data sources are increasingly available, there remain significant limitations to employing them in air travel demand studies.

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SUMMARY

Using Disaggregated Socioeconomic Data in Air Passenger Demand Studies

Research Results

The research team examined research on air passenger demand at the airport and system level, including research conducted by academic researchers, government agencies, and industry practitioners. Past studies generally relied on aggregate socioeconomic variables to explain air passenger demand patterns. Air passenger demand analyses conducted for airports rarely reported the details of the models used and the estimated coefficients and estimation statistics, although this may reflect the fact that the analyses were conducted as inputs to larger airport studies, such as master planning projects.

The research examined recent trends in the demographic and socioeconomic characteristics of U.S. households, especially related to age and household income in order to provide a profile of the characteristics in the population at large. Then, surveys of consumer expenditure and numerous air passenger and household travel surveys by airports and others were analyzed to illuminate how the characteristics of air passengers and their households were related to their propensity to travel by air. It was found that the propensity to travel by air increased progressively with household income and varied with the age of survey respondents, with the greatest use of air travel by those aged 45 to 54. The earlier analysis of broader socioeconomic trends indicated that these two characteristics—household income and the age of heads of households—are positively correlated for working age households. The distributions of other passenger characteristics, such as gender and travel purpose, also were analyzed and presented in Chapter 3.

A case study approach was used to explore how inclusion of disaggregated socioeconomic data might improve the performance of models of air passenger demand. Econometric models of annual airport passenger enplanements were estimated for seven individual airports and one multi-airport system. The case study analysis compared the results from models of airport passenger enplanements that included a variable that reflected the changes in the distribution of regional household incomes (along with other aggregate independent variables commonly used in air passenger demand models) with baseline models that used only the aggregate socioeconomic variables. The eight case studies compared the performance of relatively simple models of annual origin and destination (O&D) passenger enplanements. A more detailed analysis was conducted for the Baltimore-Washington regional airport system. This more detailed modeling explored the effectiveness of more complex models of air passenger demand that include disaggregated socioeconomic variables and reported in greater detail in Chapter 4.

The case study models were estimated on annual data for the period from 1990 to 2010 and used to generate out-of-sample forecasts for the period 2011 to 2015, using both forecast and actual data for the independent variables. These forecast scenarios compared the predicted passenger enplanements to the actual enplanements. In general, the inclusion of the household income distribution variable in the models resulted in a small improvement in the accuracy of the predicted enplanements, although for some case study airports neither the baseline nor the alternative simple models provided accurate forecasts.

Were there benefits to incorporating the disaggregated socioeconomic data variable that reflected information about regional income distributions into the case study regressions? Based on the analysis of broad socioeconomic trends and of the air passenger and other surveys, it is clear that the frequency with which household members travel by air varies considerably with household characteristics, so it seems reasonable that including disaggregated data in air passenger demand models will improve their predictive ability. However, the case study model performance results are mixed, at least for the simple model formulations:

- Model goodness of fit: Introducing the disaggregated socioeconomic variable to the model raised the adjusted R-squared consistently but modestly.
- Significance of model parameter estimates: In the baseline case study models, which relied only on aggregate socioeconomic variables, the coefficient estimates were usually statistically significant to a reasonable degree. Introducing the disaggregated socioeconomic variable, which tended to be highly correlated with one or more of the aggregate socioeconomic variables, sometimes resulted in none of the socioeconomic variables having statistically significant coefficient estimates, and sometimes only the estimated coefficient of the aggregate or the disaggregated socioeconomic variable was significant. Successfully incorporating disaggregated socioeconomic variables may require finding ways to overcome strong correlation with other socioeconomic variables.
- Out of sample forecasting accuracy: Here there were also mixed results. For some case study airports, the disaggregate model performed better and sometimes the aggregate model performed better.

Although the case study analysis of relatively simple econometric models did not indicate any large benefits from incorporating disaggregated socioeconomic variables, the modest cost of doing so suggests that further research and experimentation incorporating these variables is worthwhile. This conclusion is strengthened by the results of the more detailed analysis using more complex models for the Baltimore-Washington airport system, which explored a different way to measure household income distribution. The more detailed models resulted in significantly different implied elasticity of demand with respect to average household income when the household income distribution variable was included in the models. These results have important implications for the use of similar models to prepare air passenger forecasts, since average household income and income distribution can change in different ways in the future.

Given that the change in model performance represents modest improvements from incorporating disaggregated socioeconomic variables into simple models, the costs of doing so are important to consider. If the demographic and socioeconomic data to be used in air passenger modeling are acquired from a commercial data provider, the regional income and population distributions are often included in the data provided. Because of this, there may be no additional cost to acquire the disaggregated data, and only modest costs to add some additional model runs to those involving more traditional model specifications. In any case, the cost of air passenger demand modeling is trivial compared to the magnitude of the investment decisions based on the resulting forecasts of demand, so the real question is whether including disaggregated socioeconomic data improves the model performance.

In addition to examining the use of disaggregated socioeconomic data in the type of econometric modeling commonly used in analyses of air passenger demand, the research explored new sources of disaggregated data about air passenger activity as well as alternative approaches to incorporating disaggregated socioeconomic data into air passenger demand analysis. These results are presented in in Chapter 5.

First, there are new types of disaggregated data that result from the capture of de-identified individual travel and spending patterns through the analysis of cell phone and financial transaction data. These data are of increasing interest to transportation analysts, marketers and others because they provide insights into individual travel behavior and consumer purchasing patterns and decisions. This analysis found that while it proved possible to identify specific air trips from a sample of representative financial transaction data and some aspects of those trips, such as the destination and the number of household members making each trip, other aspects, such as the airports used for each trip, proved more difficult or impossible to determine. Therefore, although this type of disaggregated data shows some promise for use in air passenger demand studies, further research will be necessary to develop appropriate techniques to identify more details about each air trip and the individual household characteristics.

The research identified different ways of including disaggregated socioeconomic data in conventional econometric models and using the observed differences in propensities to travel by air that can be developed from the analysis of air passenger and other survey data. However, the resources available in the current project did not allow the relative effectiveness of these alternative approaches to be explored in more detail through their application in case study analyses, and this work is left for future research.

Research Opportunities

The current research project has generated a large amount of relevant information from a detailed analysis of air passenger, household travel, and other surveys, the full analysis of which will require much further work. It has also demonstrated that incorporating these effects in air travel demand models not only can improve the predictive ability of those models, but is essential for them to have good predictive ability, given the underlying changes in the socioeconomic composition of society. However, much work remains to develop robust models of air passenger demand that can be applied in a wide range of settings. This will require a sustained research effort over many years, in such areas as

- Air passenger and household travel survey design and implementation to collect data on air traveler socioeconomic characteristics and annual air travel use.
- Developing new modeling approaches and model specifications to successfully incorporate disaggregated socioeconomic variables in models of air passenger demand, including applying the modeling approach used for the more detailed analysis of the Baltimore-Washington region to other regions.
- Continued analysis of air passenger and household travel survey data to resolve apparent inconsistencies in findings from different surveys and enhance the understanding of how air travel demand varies with household socioeconomic characteristics.

These avenues for future research are discussed in Chapter 6.

CHAPTER 1

Introduction

Airports rely on air passenger demand studies and forecasts for a variety of purposes, such as airport planning, airport marketing, air service development, and passenger leakage. The models and forecasts developed for these purposes typically correlate an airport's passenger activity to aggregate regional socioeconomic aggregate measures, such as regional population, average household income, and various measures of regional economic output. Such an approach implicitly assumes that the distribution of socioeconomic factors in the passenger population served by an airport remains relatively constant over time, and therefore the air travel behavior of the population can be adequately explained by these aggregate measures. However, there is concern that socioeconomic changes, such as changes in the age, racial and ethnic composition of society, the distribution of household incomes, and changing views on the use of disposable income, may not be captured well in these current approaches to air passenger demand modeling.

The research project documented in this report explored whether the effects of these societal changes on air passenger demand may be better reflected in air passenger demand studies and models by using disaggregated socioeconomic data, such as regional distributions of age, gender, or household incomes. There has been little research to date that has investigated how disaggregated socioeconomic data can be incorporated into air passenger demand models or that evaluates potential benefits from using data that is more detailed in this way. By identifying examples and sources for disaggregated socioeconomic variables and exploring methods for incorporating them into traditional and more innovative models for air passenger demand, this research study can serve as an initial step toward a greater understanding of the opportunities—and potential difficulties—related to greater use of disaggregated socioeconomic variables.

This research project was organized around five specific areas of inquiry, one of them involving a thorough review of existing studies and models of air passenger demand for airports, regions, and other geographical entities. The other four areas of inquiry were more forward-looking or open-ended, representing new research conducted during the project that built on the foundation of the assessment of the existing state of practice. The following questions summarize the motivations for each of the five areas of research inquiry pursued during the project:

- How have airports, airport consultants, academics, government agencies, and others conducted past studies of air passenger demand, based on published reports and planning documents? What types of socioeconomic data were used in the formal modeling, and how were those models structured?
- How does air passenger behavior differ across socioeconomic subsets of the population, especially with respect to individual or household propensities to travel by air?
- Can disaggregated socioeconomic factors be introduced into traditional approaches to modeling air passenger demand at individual airports or systems of airports, and do those

variables provide new information compared to a baseline of traditional air passenger demand modeling using aggregate socioeconomic variables?

- Can new approaches to structuring econometric models or other approaches be developed and used to realize the value of incorporating disaggregated socioeconomic data in understanding or modeling air passenger demand?
- Are there new forms of disaggregated socioeconomic data, or new ways of collecting such data, that can be used to model or study air passenger demand at airports and in regions?

This report summarizes the project's research effort and results in these areas. Chapter 2 surveys past models and studies of air passenger demand, examining research conducted by academics, government agencies, and airport practitioners of many areas of expertise. The research discussed in Chapter 2 includes past models of air passenger demand and past efforts to identify passenger preferences and characteristics through their responses to passenger or consumer surveys.

Chapter 3 assesses potential sources of disaggregated socioeconomic data that could be used in models of air passenger demand modified to include such inputs. This chapter covers sources for and examples of disaggregated regional socioeconomic data, in which regional populations and households are divided into distinct cohorts according to specific socioeconomic categories such as age or household income. It also provides examples of the trends in income and age distributions at the national level that motivate the growing interest in introducing into models new forms of data that capture how these divisions of populations into distinct cohorts has evolved in recent years.

Chapter 3 then examines the results of a wide range of surveys of households and air travelers to explore how air travel propensity, expressed as the average number of air trips taken per year, varies with disaggregated socioeconomic characteristics and the implications of these findings for studies of air travel demand. This identification of the distribution of socioeconomic characteristics among air passengers is the core of the Chapter 3 analysis because if population subgroups are more or less likely to use air transportation than others, changes in the distribution of socioeconomic traits in the general population (at the national or regional level) may have implications for the volume and patterns of air passenger demand over the same time period.

Chapter 3 shows that across the airports analyzed there are common patterns of use of air travel by different socioeconomic or demographic cohorts, such as household income strata, age groups, or genders. The analysis of air passenger surveys indicates that air travel propensity, expressed as the average number of air trips per year by an individual or household, varies widely with a broad range of respondent socioeconomic characteristics, including household income, age, race/ethnicity, and educational attainment. It can be expected that changes in the distribution of any of these characteristics across the population will have an effect on air travel demand. It also follows that the common practice in air passenger demand models of using aggregate or average measures of household income will fail to reflect the effect of changes in the distribution of household incomes as a percentage of the average income level.

In addition, analysis of recent trends in age and income distributions for U.S. households indicate widening disparities in household incomes, with incomes growing more vigorously for higher income households—a finding that resonates with those of many recent analyses of the U.S. income distribution—as well as some correlation between such variables as household income levels and the age of the heads of U.S. households.

Chapter 4 contains the results of the research project's case study of the effectiveness of adding disaggregated socioeconomic variables to traditional air passenger enplanement models that are based on the use of aggregate regional socioeconomic data, such as regional population, income, or economic output. The case study sample includes eight U.S. airports or airport systems of differing size and circumstance. For each of these, the case study exercise, using annual data from 1990 to 2010, compares model and forecast performance of a "traditional" regression model using aggregated socioeconomic variables with those of an "alternative" model that also includes a regional disaggregated household income variable. In the second half of the chapter, air passenger demand in the three-airport Baltimore-Washington region, which is included among the eight case study airports or regions, is analyzed in greater detail using more complex models.

The analysis in Chapter 4 indicates that including disaggregated socioeconomic variables in regressions that also use aggregate regional socioeconomic variables can modestly improve model fit to the sample data, as measured by the adjusted R-squared, although the strong positive correlations among the socioeconomic variables often result in statistically insignificant regression parameter estimates. This is especially true in the case study regression results presented in the first half of Chapter 4. The case study regressions without and with a disaggregated socioeconomic independent variable are also analyzed for each case study airport or airport system by comparing out of sample forecast performance. The results for this performance measure are mixed, because for some case study airports the forecast accuracy is poor at best, and adding the disaggregated socioeconomic variable to the model does not always improve the forecast accuracy compared to the baseline model using only the aggregated socioeconomic variable.

In the first half of Chapter 4, the case study regression models that are compared use a fairly simple functional form with a limited number of variables in each model. In the second half of Chapter 4, more complex models with additional variables, including dummy variables to account for year-specific effects, are used in a more detailed analysis of air passenger demand in the Baltimore-Washington metropolitan region. Because that region is served by three major commercial service airports, it is possible to analyze regional demand while avoiding distortions from changes in the regional share of specific airports. Along with the exploration of more complex models, the analysis explored the use of an alternative disaggregated measure of household income that was not strongly correlated with aggregate measures of household income, an important difference from the strong correlations between socioeconomic variables that were present in the initial case study analysis.

This more detailed analysis of passenger demand in the Baltimore-Washington region confirms the finding from the case study analysis that relies on much simpler model specifications and a limited number of variables. Including a disaggregated household income variable improves the model fit and can improve forecast accuracy over a 5-year out of sample period, although for both measures the improvements over the same model with only an aggregate household income variable are not large. Over longer forecast periods, a disaggregated household income variable in an air passenger demand model allows forecasts to be prepared, assuming different scenarios of future changes in household income distribution and an analysis to be performed of the sensitivity of forecast levels of air passenger demand to possible changes in household income distribution.

As found in the initial case study results, the inclusion of the disaggregated household income variable in the more detailed models of Baltimore-Washington airport system O&D enplanements resulted in a significant change in the parameter estimate for the aggregate household income variable that was included in the baseline specification and the specification that also included the disaggregated variable.

Chapter 5 covers the research project's work on the final two motivating questions: are there effective new approaches or specifications for modeling air passenger demand using disaggregated socioeconomic variables and are there new forms of disaggregated socioeconomic variables that can support new types of air travel demand models? Answers to the first of these rely in part on the prior research work on identifying passenger propensities to travel by air for passengers of differing socioeconomic characteristics. Four distinct approaches to modeling air passenger demand in ways that may allow the incorporation of disaggregated socioeconomic data into the set of independent model variables are explored. Each of these represents a direction for future research in this area.

Answers to the second question are developed through a detailed examination of records of air travel expenditure activity found in (personally dis-identified) financial transaction records, a data source of increasing interest (and use) by many marketing organizations. Based on this analysis of the financial transaction database, the research team concludes that although financial transaction data show promise for use in the future, these data currently are deficient in critical ways, most notably in the inability to consistently identify the airports used by the travelers identified in the data. Further research is needed to determine how complete and representative these financial transaction databases are.

Chapter 6 summarizes the project's research findings in greater detail, identifying issues that remain unresolved and proposing potential opportunities for future air passenger demand research.

CHAPTER 2

Survey of Past Analyses of Air Passenger Demand

This chapter reviews existing studies of air passenger demand. These studies were undertaken by a variety of individuals and organizations and for a variety of purposes: the relatively pure research motivations of academic researchers, educational or informational purposes exhibited by governmental researchers and reports, or the highly practical objectives of airport professionals and consultants preparing analyses and forecasts of air passenger demand for individual or systems of airports. In this last case, air passenger demand models and forecasts are principal inputs for airport planners and decision makers who must make decisions regarding long lived airport capital investments based in part on uncertain passenger demand forecasts.

The purpose of the present research project was to identify and assess options for introducing disaggregated socioeconomic data into efforts to understand and anticipate passenger demand at airports. We used examples of existing practice to identify opportunities for introducing or improving the use of disaggregated socioeconomic data. In the remainder of this chapter, we first summarize past analyses of air passenger demand from academic and government researchers and organizations.

We then turn to examples of air passenger demand studies (considered broadly) from past ACRP-managed research. In many of these examples, the authors of the ACRP reports present state-of-the-art standards for practices related to modeling air passenger demand to the ACRP's readership of airport practitioners and consultants.

Surveys of passenger choice are an important source of data regarding how passenger travel choices are related to sociodemographic cohorts and characteristics, and the next subsection provides a survey of the project's research findings in this area.

The subsection is a review of examples from the types of airport documents and studies that are likely to include a treatment of air passenger demand modeling and forecasting. Examples of these documents are airport master plans, airport studies of local passenger demand, and other airport documents in support of airport planning or financing. A final subsection concludes.

Academic, Government, and Industry Studies

Understanding demand for air travel is an active area of research that has generated a large number of academic, government, and industry studies over the past 50 years that are summarized in this section and reviewed in detail in Appendix A.

Academic Studies

Academic studies of air travel demand vary across multiple dimensions that include: (1) demand measures used as the dependent variable (e.g., modeling the number of passengers on an O&D

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 in terms of 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.

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). Studies estimating city-pair or airport-pair air travel demand are more common in the academic literature and include Verleger (1972), Ippolito (1981), Fridström and Thune-Larsen (1989), Suzuki and Audino (2003), Bhadra (2003), and Chi, Koo, and Lim (2010).

Although the dependent variable in air travel demand studies is typically the number of air passengers, other measures of demand also have been used, including revenue passenger-miles (or revenue passenger kilometers) and travel expenditures.

Explanatory Variables

A wide range of explanatory variables have been used to model air travel demand. These include variables reflecting different demographic 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. Among recent models, 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 and 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., Castelli, Pesenti, and Ukovich 2003; Bhadra and Kee 2008), although whether the populations of the cities at either end of the market are combined or included as separate variables differs across studies. Population density has also been used in the literature, but tends to be more difficult to interpret.

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 for the project and discussed in Appendix A, 34 used some form of an income measure, including GDP or gross regional product (GRP), personal income or personal disposable income, and household income.

In addition to sociodemographic and socioeconomic variables, several air travel demand models have included measures of air service, including average daily flights and measures of airline market concentration in each city-pair market (e.g., Abrahams 1983; Bhadra 2003). Airfare is the most common measure of air service included in air travel demand studies, although how airfares were defined varied according to the scope of the study. The inclusion of airfare in air travel demand models allows for the calculation of price elasticities. Income elasticities estimated in the different studies varied across studies and across markets and/or market segments within the same study, as discussed in more detail in Appendix A.

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.

Functional Form

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. 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. A few studies have used more complex model forms, such as the translog model, which includes second-order terms (e.g., Oum and Gillen 1983; Oum, Gillen, and Noble 1986).

Estimation Data

Air travel demand studies have been based on many 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, where panel data combines the strengths of cross-sectional and time-series data by tracking multiple markets over time. Of the 45 models used in the academic studies reviewed, 14 used time-series data, 13 used cross-sectional data, and 16 used panel data. One model relied on ticket sample data and another used passenger data from air passenger surveys.

Aggregated versus Disaggregated Data

The review of the academic literature found relatively few examples of air travel demand studies that used disaggregated data. More recent studies include those by Dargay (2010), who developed a model of person-miles of domestic intercity travel by mode (including air) in the United Kingdom (UK) at the household level for five different trip purposes using data from the UK National Travel Survey from 1995 to 2006, and Kressner and Garrow (2012), who developed a model of the number of home-based air trips generated by households at the zip code level in Atlanta. Two studies examined air travel demand using airline booking data (Granados, et al. 2012; Mumbower, Garrow, and Higgins 2014).

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).

Market Segmentation

Only five of the 45 air travel demand models reviewed for the project distinguished between demand for business and non-business purposes. Morrison and 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.

Although factors that determine the level of air travel for business trips are likely to be different from those that determine the level of nonbusiness 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.

Government and Industry Studies

The research reviewed a number of government studies of air travel demand that were conducted for Australia and the UK and two industry studies that 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 (domestic and international) were performed by or for Australian government agencies over a 16-year period from 1982 to 1998, reflecting the importance of air travel to Australia. 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. 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. The second study, undertaken as part of an independent review of economic regulation of domestic aviation in Australia (May, Butcher, and 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, Australia. Bureau of Transport Economics (1986) issued a report that provided forecasts of domestic air passenger and air freight demands in Australia. 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. 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.

A later report by Australia. 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. A subsequent paper by Hamal (1998) presents the results of a regression analysis of Australian resident holiday travel in two long-haul (UK and United States) 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), used as a proxy for a price index of destination travel and accommodation costs, and the annual average exchange rate.

United Kingdom Aviation Forecasts

Since the 1990s, 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 and its use 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, less developed countries, 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 9/11 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 models.

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 (Inter*VISTAS* 2007; Inter*VISTAS* 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 2007 study developed nine models: a world model and separate models for eight global regional markets, including the U.S. domestic market, transpacific, and transatlantic markets.

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 nine models varied). These explanatory variables included airfare, income measures based on 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, and quarter and market dummy variables.

ACRP Reports and Other ACRP Documents

Several past ACRP reports address airport issues related to airport forecasts of air passenger 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.

ACRP Report 18: Passenger Air Service Development Techniques (2009) addresses the ways in which airports can assess the passenger air service 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 (2009) 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 factors that influence airline decisions on what air service to offer at different airports in a multi-airport region and factors that influence air passenger decisions on which airport to use for a given trip depending on air service offered 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 increases, 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 (2015) reports the findings of ACRP Project 03-19. A web-based survey of the most recent air trip undertaken by survey respondents within the preceding six months was part of the project. Although the primary purpose of this survey was to perform 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, and information on household characteristics of the survey respondents.

ACRP Report 132: *The Role of U.S. Airports in the National Economy* (2015) 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 to identify prior estimates of price elasticity for non-business travelers. It also assembled a database of prior air passenger surveys to estimate the proportion of non-business travel in a sample of 100 domestic airport-pair markets.

ACRP Report 142: Effects of Airline Industry Changes on Small- and Non-Hub Airports (2015) 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.

One of the ACRP reports reviewed 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. Other 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.

Surveys and Studies of Traveler Behavior and Choice

Analysis of traveler behavior underlies all attempts to model air passenger demand, and more generally intercity travel demand, although often this analysis is implied by the form of the model used. Air passenger traffic at a given airport is the result of several choices made by potential travelers, including the choice of whether to make a trip at all, which mode to use, and if air travel is chosen, which airports to use. Other travel choices (in the case of air trips) include how to travel to and from the O&D airports used and the airlines and flights chosen. Although these choices are often viewed as separate or dependent decisions once the basic decision to make an air trip has been taken, in reality one cannot separate these decisions from the overall level of air travel demand. This is most apparent in the case of air passenger traffic at smaller airports or secondary airports in metropolitan regions, where airport choice directly determines the level of traffic. At many smaller airports some air travelers make the choice of using surface modes to travel to or from a more distant airport where better or less expensive air service is available (an issue sometimes referred to as "leakage").

Intercity travel demand studies were 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 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 and 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 explaining past levels of air travel, many intercity travel demand studies have been undertaken with the explicit purpose of generating projections of future travel demand, including air travel demand. This forward-looking aspect is likely to be of particular 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.

Intercity travel demand studies typically 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 United States from national household travel surveys show that for trips of up to about 750 miles each way a higher proportion of travelers use surface modes, particularly personal vehicles, than use air travel (Figure 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.

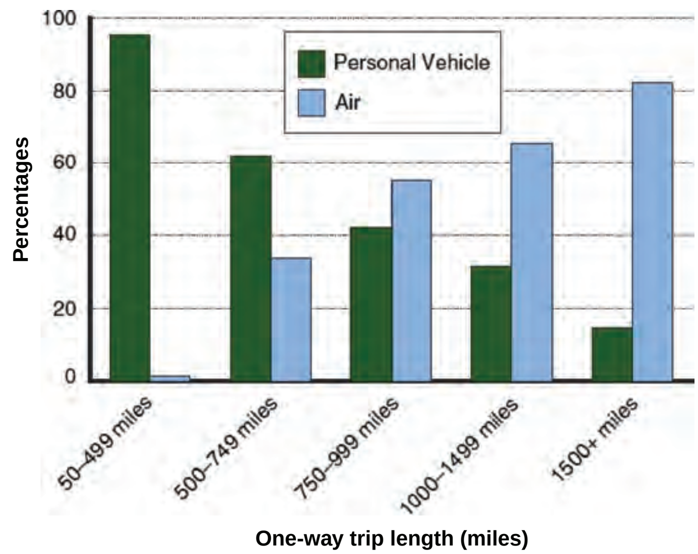

Figure 1. Mode use by trip distance. Source: U.S. Bureau of Transportation Statistics, 2006 (Figure 2).

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 1960s (e.g., Baumol and Quandt 1966). Two NCHRP reports (Horowitz 2006; Cambridge Systematics 2008) provide an overview of the evolution of these analysis techniques. A number of more recent studies discussed in more detail in Appendix A document subsequent developments and the current state of practice.

Several of these studies developed or applied intercity node choice models. Baik, et al. (2008) developed a mode choice logit model to allocate intercity trips across two existing transportation modes, including commercial air travel, and one hypothetical mode. Cambridge Systematics (2014a and b) presented results from a long distance travel demand model developed to estimate ridership on proposed California High Speed Rail (HSR) passenger services. Outwater, et al. (2015) summarized a multi-year research project using a tour-based simulation framework to model long distance passenger travel by U.S. households involving trips by air, rail, bus, and automobile.

Air Passenger Demand Studies by Airports

Air passenger demand and passenger enplanements are, not surprisingly, important elements in many types of analyses of airport performance and prospects. For both internal and external audiences, these airport planning analyses naturally involve the preparation of forecasts of passenger demand and activity at the airport. This section examines how a variety of airports have used socioeconomic data in their air passenger forecasting efforts for use in these varied analytic contexts and purposes. The following examples are presented in much greater detail in Appendix B.

Master Plan Studies

An airport master plan is an analytic tool or document for determining the long term development plans for an airport. It includes planning elements from every facet of airport operations, all of which have an objective of contributing to the airport's ability to handle future passenger demand as a shared performance requirement or objective. Airport master plans nearly always include forecasts or projections of air passenger activity, and they are a natural place to look for examples of the ways airports and their consultants model and predict passenger activities such as annual enplanements.

An important part of the baseline research for this project was to analyze and assess the modeling approaches used by and for airports to model air passenger demand and air passenger activity. Similar studies that are strongly driven by an underlying model of air passenger activity at individual airports are airport environmental or noise assessments and other forms of demand study. Of the 47 studies of air passenger demand conducted by airports or by consultants sponsored by airports that were reviewed as part of this research (master plans, demand studies, and environmental or noise assessments) a majority acknowledge the role of socioeconomic data in determining air passenger activity, although socioeconomic factors were included in the air passenger demand forecasting models developed in the studies less often. Three of the documents did not provide enough detail to identify how or whether the airport used socioeconomic data in its analysis, but of the 44 that did refer to a use of socioeconomic data, 39 also contained information about the forecasting approaches that were used. Only 21 of the 39 reported using socioeconomic data in their forecasting calculations.

Some of the airports use forecasts from the FAA's Terminal Area Forecast (TAF) to project their passenger demand, while others develop their own analyses and forecasts based on the specific conditions present at their airport and in the surrounding region, including socioeconomic factors. For these forecasts, airports or their consultants tend to use one of three broad types of analysis. The first, time series or trend analysis, reviews the history of an airport's passenger activity and bases its passenger enplanements forecast on that history, under the assumption that in the absence of major industry changes, observed trends will continue into the future. A second approach, market share analysis, reviews forecasts for the U.S. aviation industry as a whole, or for the region containing the airport, and develops predictions for passenger activity using the assumption that the airport's share of that overall aviation market will remain as it had been, or will change in a well-defined way. These two types of analysis differ in that time series analysis extrapolates past trends, whereas market share analysis may allow for adjustments that can reflect the effect on the airport's market share of changes in the aviation industry, such as mergers, creation of new flight services, or moves towards certain types of flights.

The third type of analysis, econometric or regression modeling, uses statistical methods to estimate the historical relationship between the airport's passenger enplanements and sets of selected independent variables, such as national variables, local or regional socioeconomic variables such as population, economic activity (GDP), or income. These models typically use linear or logarithmic regression techniques. Whereas the first two methods may indirectly take into account socioeconomic changes (e.g., an increased preference for low-cost carriers nationwide would increase flight forecasts for those carriers across the country, which would be reflected in market share analyses at airports used by these low-cost carriers), econometric models use a more explicit treatment of the links between socioeconomic variables and the airport's overall passenger demand as represented by passenger enplanements. The regression approach also allows the analysis to examine the significance (in scale and precision) of the relationship between air passenger demand at the airport and the individual independent variables.

Of the airports that reported they used regional socioeconomic variables in their forecasting efforts, the majority stated that population, income or economic activity, and/or employment were relevant for understanding and forecasting air passenger traffic. To calculate forecasts of passenger enplanements with these models, forecasts of the independent variables used in the models must also be available to the analyst. Such projections for socioeconomic variables are commercially available (from firms such as Woods & Poole Economics, Inc.) as part of the data products prepared for use by entities and organizations in academia, government, and the private sector (including airports) that conduct quantitative economic research that relies on relationships between socioeconomic variables.

Among the airports examined in our research, regional population, regional GDP or GRP, and regional income are frequently used independent socioeconomic variables for statistical estimations. Among those airports, regional variables were often more statistically significant than employment levels for individual airports, although airports created models using different geographical areas [e.g., city, metropolitan statistical area (MSA), and state level socioeconomic data and projections] and often defined variables differently. Other socioeconomic variables mentioned or used in some of the airport master plan forecasts included cost of living, employment by sector, and, for areas with economies that were particularly reliant on tourism, variables such as de facto population due to tourism or the prevalence of second homes in the region served by an airport.

The analysis of the sample of airport master plan forecasts is presented in Appendix B. The airports' use of forecast modeling techniques or approaches for air passenger demand is summarized in Table 1. In the table, trend analysis is time series and all types of regression methods (linear and logarithmic) are categorized together as regressions. One non-hub airport created forecasts of passenger enplanements by predicting a future annual growth rate in passengers. This is similar to the time series method, but because this airport used other information to determine the preferred growth rate, it has been categorized separately. Ten airports used multiple models to develop passenger activity forecasts, while seven relied on the FAA's Terminal Area Forecast. Fifteen airports used a regression model of some kind to model air passenger demand and estimate forecasts for annual enplanements at their airport.

Other Types of Airport Studies

Examples of other types of air service studies or airport studies that use forecasts of airport passenger activity or rely on socioeconomic variables in some way were studied. These examples are analyzed in Appendix B, and are briefly summarized here. Because the principal business or activity of most commercial service airports is accommodating demand for flight services and air travel, it is not surprising to find interest in modeling and predicting passenger activity present in a variety of types of airport studies.

FAA Terminal Area Forecast

The FAA prepares forecasts of aviation activity at each active airport in the National Plan of Integrated Airport Systems (NPIAS) which are published annually as the FAA Terminal Area

Table 1. Passenger air travel demand models used in sample of airport forecasts.

Preferred Model	Large	Medium	Small	Non-Hub	Total
Growth Rate	-	-	-	1	1
Market Share	1	2	2	1	6
Regression	7	4	3	1	15
TAF	3	1	1	2	7
Time Series	-	-	-	2	2
Multiple Models	3	3	3	1	10
Not Specified/Unknown	1	-	3	2	6
Total	**15**	**10**	**12**	**10**	**47**

Forecast, or TAF. As of the end of 2017, the most recent TAF provides forecasts for the period 2016 to 2045 (FAA 2017). The TAF provides historical data and forecast activity levels on a Federal fiscal year basis for the following measures of aviation activity for each airport:

- Enplanements (enplaned passengers) by air carriers and regional airlines (separately and total)
- Itinerant aircraft operations by air carriers, commuters and air taxis, general aviation, and military aircraft (separately and total)
- Local aircraft operations by civil (general aviation) and military aircraft (separately and total)
- Total aircraft operations
- Based aircraft

In addition the TAF includes historical data and forecast activity for total aircraft operations under radar control at each Terminal Radar Approach Control (TRACON) facility.

With effect from the 2014 TAF, a new forecast process was adopted, termed the Terminal Area Forecast Modernization (TAF-M) (Bhadra 2013 and 2014). This is based on a set of formal, bottom-up models of air travel demand and aircraft operations (LeBoff 2016). The new forecast process represents an ambitious attempt to develop a comprehensive air travel and aircraft activity forecasting process for the United States at a national level. Among the aspects of the process is a consistent forecasting approach for all airports in the United States that is based on an underlying model of air travel demand that reflects the influence of socioeconomic factors (currently limited to total personal income) as well as differences in air service in each O&D market (currently incorporated as average airfares in the market and the number of available routes serving the market). An important benefit of the bottom-up approach to modeling O&D passenger demand is that the resulting forecasts of enplaned passengers and commercial aircraft operations can be made on a flight segment basis, rather than simply on the basis of total activity at a given airport. This new degree of specificity provides benefits for use of the resulting forecasts in a wide range of planning activities, from aircraft noise analysis at airports to airspace and air traffic management planning, and is a significant improvement over what was essentially trend analysis of airport activity.

However, there are many aspects that appear deserving of continued research and improvement. Because the TAF has to cover a very large number of airports (essentially all those in the NPIAS) and needs to be updated on an annual basis, a considerable effort has been devoted to the extensive data management issues involved. Now that the data management challenges have been largely overcome, the influence of different socioeconomic factors on air travel demand and how the influence of these factors may vary in different markets can be addressed.

State Aviation and Regional Airport System Plans

Five state aviation system plans (Alabama, Florida, Kansas, Minnesota, and Washington) were reviewed; two used the TAF forecasts directly and one primarily adopted airport master plan forecasts, supplemented with the TAF forecast for one airport that presumably did not have a master plan forecast that could be used. The system plan for Minnesota developed forecasts for all the commercial service airports in the state. These forecasts were generated using an econometric demand model with only one socioeconomic variable, the aggregate total personal income in the catchment area of each airport. The system plan for Washington state used a combination of approaches for forecasts for different airports in the state. For Seattle-Tacoma International Airport, the principal airport in Washington (as of the date of this report the system plan accounted for about 87% of the total enplanements in the state), the forecast was adopted from the TAF. For the next eight largest airports in terms of passenger enplanements, which account for a further 13% of total enplanements in the state, forecasts were prepared using three different methods. The average of the forecasts generated by each method was used for each airport, although the details of the three methods are not described in the technical report documenting the forecasts. The forecasts for the remaining airports, which account for less than 1% of the enplanements in the state, were basically assumptions, either by the study team or based on discussions with the air taxi operators serving the airports or the airport management.

Four of the five system plans included a discussion of socioeconomic trends in the state, typically including population, employment, and personal income, although only one of the system plans actually used these data in developing the forecasts. Although the socioeconomic data often was presented at the county or regional level, it was generally not disaggregated in any way other than geographically with the exception of the Florida Aviation System Plan, which presented data on historic trends and projections of population by age range and regional differences in the growth rate of population due to in-migration versus natural increase, although these data were not apparently used in developing the forecast.

Airport system studies for five regions also were examined: the New England, Baltimore-Washington, New York/New Jersey, the San Francisco Bay Area, and southern California. The forecast approach followed in the regional system planning studies varied in the approach to modeling air travel demand and in the level of detail the modeling was performed. Two different studies for the New York/New Jersey region that used different approaches were reviewed. The studies for all five regions (only the earlier of two studies in the case of the New York/New Jersey region) developed models or procedures to allocate regional or airport O&D demand to regional analysis zones. The resulting distribution of ground trip ends was then used in most studies to assign forecast regional demand to individual airports under different air service scenarios or to forecast airport ground access trip patterns. Two studies, the earlier study for the New York/New Jersey region and the study for the San Francisco Bay Area, estimated trip generation models, while the other studies used a demand allocation procedure based on population, households, employment, and/or income.

Based on these regional studies, there appears to be no consistent approach to preparing air passenger forecasts for regional airport system planning studies, although generally some form of econometric model is used, at least for domestic O&D passengers. These models typically use one or two aggregate socioeconomic variables as well as average airline yields. There is no consistency in whether the models predict passenger traffic at the market, airport, or regional level, or how the ground origins or destinations of the air trips given by the resulting regional forecasts are allocated to travel analysis zones in the region.

Airport Planning Studies Outside the United States

Six international demand forecasting studies were examined in the review of international practices. These studies used a variety of analysis methodologies, and they also varied in the extent to which the reports described methodological details. The six examples include studies of the London region by the United Kingdom Airports Commission (2015), and individual airport studies by the Geneva, Switzerland, Airport Authority (2014), the Dublin Airport Authority (2006), the Airport Authority Hong Kong (2011), the Sydney Airport Master Plan 2033 (2014), and the Greater Toronto Airport Authority (2007).

As best can be determined from the documentation for each study, all but one used a multiplicative (log-linear) model structure, although two studies (for the London region and Canada) used a more complex variation on a traditional log-linear formulation. The study for the London region used lagged and difference terms (described as an unrestricted error correction model) while that for Canada used a Box-Cox model structure. All six studies used aggregated values of GDP as the primary (or only) socioeconomic variable. The forecasting model for the UK (which formed the basis for the forecasts for the London region) also used consumption, imports, and exports as socioeconomic variables in different market sectors, for some market sectors in conjunction with GDP, and for other market sectors in place of GDP. However, the decision of which variables to use for a given sector appears to have been based on which variables gave the best statistical fit rather than any underlying causal logic.

Air Service Development and Passenger Leakage Studies

Air service development studies and passenger leakage studies are customarily products prepared for airports by aviation consulting firms. Air service development studies may be used by airports for marketing efforts about individual travel markets (rather than an airport's overall passenger demand), which are directed at airlines, often specific airlines. In contrast, passenger leakage studies are generally informational studies for airport stakeholders, with the potential to be used as background for subsequent air service development efforts. For these reasons these studies are often regarded and treated by consultants and their airport clients as proprietary products rather than public documents.

Airport air service development studies and the factors customarily considered in them have been described in detail in *ACRP Report 18: Passenger Air Service Development Techniques* (2009). Along with financial, marketing, and route structure considerations that may be included in an airport's efforts to develop new passenger services with airlines, the study stresses the value of passenger demand projections and regional demographic and economic factors in influencing decision makers at potential airline service providers.

The report identifies the types of socioeconomic data that could inform these studies, but does not propose specific modeling approaches or formulations for use in preparing passenger demand projections. The importance of demographic data for air service development analyses was recently assessed for an audience of airport practitioners (Dietz 2014). Demographic data about the characteristics of the population served by an airport provides airlines with important information about the likelihood that airline service could be successful. Important factors affecting air service development assessments in these data are the size and characteristics of the airport region's overall population, the characteristics of the region's business community, and the characteristics of the region's potential leisure travel and travelers. *ACRP Report 18* also identifies the competitive challenges that are posed by larger airports within driving distance as the principal cause of passenger leakage from a given airport. Such airports are likely to be able to provide business travelers with a wider range of destinations, often at lower fare levels. Lower fare levels will also be attractive for leisure travelers, who are more price sensitive than business travelers in most instances.

Airport Choice and Airport Ground Access Mode Choice Studies

Although airport demand allocation and airport ground access models are not air travel demand models in the sense that they predict how the overall demand for air travel is influenced by changes in socioeconomic and air service factors, they typically make use of disaggregated socioeconomic data. By predicting how air travel demand in a region distributes itself among the airports serving the region, they can shed light on the level of air travel activity that occurs at a given airport. While airport ground access mode choice models are designed to predict the use of different access modes at a given airport, and do not directly attempt to model the level of air travel activity at that airport, they can form an important component of airport demand allocation models. Since air travelers' choice of airport in a region served by multiple airports is influenced by the relative accessibility of each airport (Parrella et al. 2013), which depends on the different ground transportation models available for travel to each airport and the relative level of service of each mode, including travel times, frequency, costs, reliability, and number of changes of mode or line required, airport ground access mode choice models can be used to help define the overall accessibility of a given airport from a given location. As such, they will often form a lower-level nest in a nested model of air traveler airport choice.

Both airport choice and ground access mode choice models are inherently disaggregate in approach, generally modeling the airport choice or mode choice decisions of individual air parties. These individual choices will reflect the different circumstances faced by each air party, including trip ground origin, air trip destination, time of day of travel, and travel party characteristics, all of which influence each air party's decisions. Typically these studies use data from an air passenger survey to define the travel and air party characteristics of a reasonably large sample of air travelers to estimate disaggregate behavioral choice models, which can then be applied to develop forecasts of future airport use patterns or ground access travel. The extent to which these models include demographic or socioeconomic factors varies, often depending on the data available from the air passenger survey from which they are estimated.

Airport Ground Access Mode Choice Models

The state of practice of airport ground access mode choice models was reviewed in an early ACRP Synthesis study (Gosling 2008). This study included a detailed review of nine airport ground access mode choice models. Five of the nine models included household income as an explanatory variable, although the way that this was done varied across the five studies. A model to analyze the potential diversion of air trips to intercity rail from improved rail service that was developed as part of a recent ACRP research study on integrating aviation and passenger rail planning (Resource Systems Group, Inc. et al. 2015) included a sub-model of airport choice or station choice.

In another study, the joint airport choice and ground access mode models developed in the New York Regional Air Service Demand Study (RASDS) and the West of Hudson Regional Transit Access Study (WHRTAS) incorporated a limited number of socioeconomic variables in the access mode utility functions. The RASDS models included gender, age, and income, although age and income were only expressed in three ranges. The WHRTAS models included the average number of automobiles per household member, but only in the utility function for the drive and park mode for trips by residents of the region and used the average value for the analysis zone of the trip origin (presumably because the data on household automobile ownership and household size were not available from the air passenger survey, although this was not explained in the report).

There has been limited experience using socioeconomic variables in airport ground access mode choice models. Where these have been included, they have been limited to gender, age, household income, household size, and automobile ownership (number of automobiles per household). Only one model identified in the review of relevant literature included gender or age, with the age variable based on three age ranges. Only one other model included household size, and this was limited to a dummy variable for single-person households. Two models considered household automobile ownership, with one using the average ratio of automobiles to household members for the analysis zone of the trip origin and the other using a dummy variable for households with fewer automobiles than employed household members. Household income was considered in several models, but the way in which income was incorporated in the models varied widely from dummy variables for incomes in a specified range to continuous functions of income. Thus while it appears from the findings of past studies that household income, and possibly gender and age, influence airport ground access mode choice, there is no consensus yet on how best to incorporate these factors into airport access mode choice models.

Airport Bond Prospectus Documents

Six airport bond prospectus documents were reviewed and all include some mention of socioeconomic factors as determinants of air travel demand that can be used to develop forecasts or projections of future air passenger enplanements. While none of the documents provide information on air travel demand model structure or parameter estimates, in several cases the forecasts were made using a regression model that includes some aggregate socioeconomic factors as independent variables. Some of the documents rely on more than one forecasting methodology to characterize the factors that affect air passenger demand at the airport. Of special interest for this study, three of the studies treat region-specific disaggregated socioeconomic factors related to income distribution, age distribution, and ethnicity or national origin as contributors to the regional economic basis for air travel demand at the airport, but these factors are not included in air passenger demand modeling portions of the reports. In some cases the bond documents use arguments about the contribution of disaggregated socioeconomic community features in qualitative rather than quantitative or computational ways.

Passenger Demand Studies by Airlines and Other Industry Stakeholders

This section examines interest in passenger demand modeling and forecasting for other commercial aviation industry stakeholders such as airlines and commercial jet manufacturers. Not surprisingly, airlines pay greater interest to details that distinguish among individual travel markets than manufacturers, who take a much broader perspective on passenger demand issues.

An overview of one airline's approach to using socioeconomic data to better understand and serve passenger demand was presented at the TRB Annual Meeting in 2014 by Andrew Watterson of Southwest Airlines (Watterson 2014). The airline objective for using these data was described as "better understand[ing] passengers and best match[ing] [Southwest's] supply to their demand." With regard to these passengers, the airline was interested in these questions:

- Why they fly?
- Where they fly?
- Can they afford to fly?
- Which airport do they prefer?

The presentation identified several sources for socioeconomic data, including federal sources [Census Bureau, Bureau of Labor Statistics (BLS), Bureau of Economic Analysis (BEA), Bureau of Transportation Statistics (BTS)]; survey and research firms providing data that was purchased by the airline; local sources of data such as community and regional convention and visitors' bureaus; research sponsored by airports served by the airline; and internal airline data on passenger behaviors, preferences, and destinations.

A number of aircraft manufacturers, airline industry associations, and other industry organizations prepare forecasts of future growth in air travel demand, primarily to project the expected future demand for their products or services. These forecasts are typically updated on an annual basis. Although these forecasts do not address air travel demand at the level of individual airports, the forecast growth in air travel demand at a world regional level projected in these studies is often cited in forecasts prepared for specific airports or airport systems as a "reality check" on the growth in demand projected in those forecasts.

Because of the global or national nature of industry forecasts, they generally forecast air travel demand in terms of revenue passenger-miles (RPM) or revenue passenger-kilometers (RPK) and use aggregate measures of economic activity, such as national GDP. The forecast reports may discuss more disaggregate factors affecting air travel demand, but from the limited details on the forecast methodology that are typically reported, it is unclear how these factors are incorporated into the forecasts.

Summary and Conclusions

The preceding examples illustrate the wide range of approaches for modeling and forecasting air passenger demand, and the wide range of uses for such models and forecasts that exist across the airport and air transportation community. At the same time, the estimated demand

and forecast models are nearly always a means of calculating passenger enplanement forecasts to justify or calibrate airport plans and financing instruments. These models usually represent a relatively small portion of the overall airport analysis, especially in the case of a master planning exercise. For these reasons, the statistical parameters for the models underlying air passenger demand forecasts, especially as used in airport master plans and other airport studies of enplanements, are rarely reported in any detail.

This relative silence regarding the numerical and statistical details of the estimated models for passenger enplanements is understandable because those models serve as stepping stones to the passenger demand forecasts that underlie a wide range of airport planning concerns. Since most passenger demand modeling is done by airport consultants, there may also be reasonable proprietary concerns about revealing too much of a firm's "analytic toolkit" to the eyes of competitors. However, greater transparency in the reporting of model parameters and other statistical details could encourage a growing and improving base of common industry knowledge about passenger demand modeling at the airport level, which could serve the overall airport community well.

CHAPTER 3

Sources of Disaggregated Socioeconomic Data

Two broad categories of disaggregated socioeconomic data are especially important for modeling and forecasting air passenger activity at airports or larger regions. This chapter is a summary of these data and their sources. A more detailed discussion is available in Appendix C available on the TRB website.

The first sort of disaggregated socioeconomic data includes the distribution of socioeconomic characteristics within a national, regional, or airport catchment area population. This can include age distributions, income distributions for households or individuals, levels of educational attainment, identification of ethnic or racial cohorts, and others. Cataloging such characteristics for a population provides not only a richer picture of that population, but also important information for businesses and public service organizations for understanding how to best serve (or market towards) that population. However, it is important to bear in mind that this second source of value from awareness of the distributions of socioeconomic characteristics within populations can truly provide this value only if these different cohorts exhibit different tastes and preferences for goods and services.

The second sort of valuable disaggregated socioeconomic data in the context of passenger aviation is do different socioeconomic cohorts tend to travel by air more or less than other cohorts? An important way to collect this type of data is the passenger or consumer survey. In these surveys, interviewers capture the socioeconomic data of the respondent (age, annual household income, educational background, ethnic, racial, or gender identification, and so forth) and (in the case of an air travel survey) information about the respondent's use of air travel (how frequently air trips are taken, travel party size, mode of transportation used to travel to the airport, destination information, use of business or economy class, use of airport terminal facilities and amenities, and others).

An effective survey of this type can provide an airport or a regional transportation planning organization with a nuanced picture of the air traveling public it serves. These data may be useful in the near term because they provide airport managers with information about the preferences and expectations of those using the airport. The survey data may also identify differences in these tastes, expectations, and propensities to fly between socioeconomic cohorts. With a survey-based picture of these differing cohort preferences and an understanding of how the distribution of cohorts is expected to change over time, airport and other aviation analysts may be able to develop more informative models of air passenger demand, and better forecasts of future passenger activity, compared to those results using aggregate socioeconomic data alone.

This chapter summarizes sources of disaggregated socioeconomic data about communities and regions served by airports and recent socioeconomic trends, which provide information about how distributions of socioeconomic traits appear to be changing over time. It also presents an analysis of several air passenger and travel survey efforts that have provided data on how different socioeconomic groups choose to travel by air, contributing to the understanding of how general societal characteristics are distributed within the air traveling public—which is also the airport using public. Future research needs that could help improve and focus the use of disaggregated socioeconomic data in the analysis of air travel demand also is discussed.

Availability of Disaggregated Socioeconomic Data

This section presents an overview of sources for socioeconomic data. Aggregate national socioeconomic data is reported by federal sources and includes such variables as population, GNP, price indices (such as CPI), employment and unemployment levels and rates, and measures of economic activity in specific sectors of the economy. These data are reported on an annual, quarterly, and sometimes monthly basis. These aggregate data are compiled by specific government agencies and departments; data for employment statistics, household incomes and price indices are gathered by the BLS (part of the Department of Labor), GDP data are gathered by the BEA (part of the Department of Commerce), and population data is developed by the Bureau of the Census (also part of Commerce). Historical values for these aggregate national measures are collected and reported by a number of government organizations with economic responsibilities, such as the President's Council of Economic Advisers and the Board of Governors of the Federal Reserve. These historical data series are readily available at the websites of these and other agencies.

The agencies that originate data for these socioeconomic variables also report the data for regional, demographic, and socioeconomic subsections of the country. These federally provided data are free to the user and available for download on the internet. In recent years, the level of detail reported by these federal data sources has grown and expanded as the ability of the internet to host larger and richer databases has improved. The availability of a greater breadth of socioeconomic data has made the processes used to identify and use more refined datasets more complicated, but the agency webpages provide explanatory and largely user-friendly support. Important examples of the categories of data that are available, and their sources, include

- **Population:** The Bureau of the Census 2010 Census Tool is an interactive tool that allows the user to examine and extract data on population size and characteristics (age, ethnicity, and household composition) at the county or parish level for all states. The provision of these data at the local level makes the Bureau of the Census a fundamental source of many categories of disaggregated socioeconomic data, especially demographic data. Interactive Population Maps and other data tools make it possible to examine relatively complex population dynamics, such as migration patterns across counties in the United States. These capabilities represent the application of recently developed visualization tools to recently collected population and demographic data, which limits their availability to past Census data in many ways. The Bureau of the Census web pages also provide detailed instructions for users regarding data availability, data acquisition, and data interpretation. Bureau of the Census databases can be browsed and searched at http://www.census.gov/data.html and data that is developed from the most recent 2010 Census can be accessed at http://www.census.gov/2010census/data/.
- **Employment:** BLS maintains an extensive online database for employment and compensation for 100 industries at the national, state, county, and local (selected) levels. The BLS databases also report values and indexes for consumer and producer prices, as well as data on labor productivity, occupational trends, and consumer expenditure patterns. Like the demographic data available from the Bureau of the Census for population characteristics, the BLS data provides a detailed picture of labor market conditions in aggregate and by industry sectors. BLS data can be accessed at http://www.bls.gov/data/. Much of the BLS regional data

is available at links related to each of the eight BLS Regional Offices, which can be found at http://www.bls.gov/data/#regions.

- **Economic Activity:** BEA develops and maintains databases for GDP, personal income and personal consumption expenditures at the national, state, county, and MSA levels. GDP estimates for individual industries are provided at the state level, beginning in the early 2000s. Explorations of these data can be fine-tuned and focused by the user and extracted using BEA's online interactive data tools. BEA's national, industry specific, international accounts, and regional data can be accessed at http://www.bea.gov/itable/index.cfm with an additional set of pages devoted to regional economic data available at http://www.bea.gov/regional/.
- **Economic and Socioeconomic Data:** Another source of socioeconomic data is the Federal Reserve System. The Federal Reserve tracks socioeconomic data as part of its management and oversight of the nation's financial system. The board of governors of the Federal Reserve maintains databases on financial system economic data, and these data may be of limited use for air passenger demand studies. Each Federal Reserve regional bank, however, is a source for regional economic and demographic data at the state and MSA level. The website of the Federal Reserve Bank for each District (listed with links at https://www.federalreserve.gov/otherfrb.htm) includes a section on Research and Data where extensive data about the states and metropolitan areas within a district can be downloaded (although most of these data come from the data services of the Bureau of the Census, the BLS, or the BEA described above). While there is similar content in the pages of each District bank, the websites are not identical from district to district. Finally, the Federal Reserve Bank of St. Louis maintains a uniquely comprehensive collection of socioeconomic data, the *Federal Reserve Economic Data,* or *FRED.* These data cover economic variables in the United States and the international economy, and include more than 350,000 individual data series. As with the other federal data sites described here, FRED data can be downloaded, and it is also possible to create new data variables and data graphs. Accessing FRED data requires the creation of a user account, which can be done at https://research.stlouisfed.org/fred2/.

Many of these aggregate socioeconomic data are also provided at metropolitan, regional and state levels by the individual states at demographic data pages hosted by the states themselves. These state level data pages typically, though not in all cases, report data taken from federal data sources, presenting the data from the perspective of the individual state. Some regional organizations, such as councils of governments and metropolitan planning organization areas also maintain online databases of regional information and data, including demographic and socioeconomic data, also typically but not always derived from federal data sources.

While they do provide data at no cost, the federal, state and local data sources identified here may be cumbersome or difficult to use in some cases or for some users, depending on the complexity or specificity of the data of interest. However, there are commercial firms that provide access at a cost to these local and regional socioeconomic data, in what is often a more user-friendly format. These commercial providers also frequently provide projections of future values for some variables. Having such projections of socioeconomic variables is necessary for developing forecasts of air passenger demand from econometric models that estimate historical relationships between these socioeconomic data elements and air passenger activity, such as annual enplanements.

A widely used commercial private provider of socioeconomic data is Woods & Poole Economics, Inc. Woods & Poole provides historical data and future projections for population, income, employment, retail sales and households for states, regions, metropolitan and micropolitan statistical areas, and the nation as a whole. These data are downloadable and are provided at a cost to the user. Data from Woods & Poole were used for the case study analysis described below.

The Woods & Poole socioeconomic data for a given geographical area are reported starting with 1970 values. After the most recent year of actual data (2015 for the case studies conducted as part of this project), smooth projections for future years are calculated by Woods & Poole through the year 2050. An area's socioeconomic data is reported with several distributional details, such as

- Total area population and area population by age cohort, gender, and ethnicity;
- Total area households and the numbers of area households within a span of income ranges;
- Area mean household income;
- Total area employment and area employment by industry or sector;
- Total area earnings and area earnings by type of compensation and by industry;
- Total area income and income by type of income, area per capita income;
- Total area retail sales and retail sales by industry; and
- Gross regional product.

Socioeconomic Trends

The U.S. socioeconomic trends reported in this section show recent changes in some of the disaggregated socioeconomic factors that air travelers in passenger surveys commonly report about themselves or their households. The trends represent an important piece of the puzzle that may link changes in social demographics to changes in air travel demand. A major objective of the research undertaken in this project is improving understanding of these links, the ways in which the future evolution of these socioeconomic trends may influence future air travel demand, and the ways consumers spend on air travel.

Demographic Trends and the Distribution of Household Incomes

To estimate passenger demand models, either for forecasting future demand or for analyzing and modeling the factors that influence that demand, it is necessary to rely on historical socio-economic data at different degrees of aggregation. The U.S. Census Bureau is an important source of these historical data, and the online availability of these data has improved in recent years. At the national level, Census sources provide a baseline for demographic and socioeconomic variables that influence air passenger demand, such as household income, revealing national trends in household income stratification along a variety of economic and demographic factors.

Figure 2 shows recent trends in household income distribution, reporting the upper limits of each household annual income quintile since 1967, as reported by the U.S. Census Bureau (U.S. Census Bureau 2017). Household income values are adjusted for inflation and reported in 2016 dollars. Shown are the inflation-adjusted household incomes received by the households at the 20th, 40th, 60th, 80th, and 95th percentiles in the national income distribution. For U.S. households at the 20th percentile of the distribution, annual income in 2016 increased by 27% since 1967, from $18,856 to $24,002, and households at the 40th percentile had 2016 incomes of $45,600, a 24% increase from the inflation adjusted level of $36,768 in 1967. The income received by U.S. households at the 60th percentile was 47% higher in 2016, having grown to $74,869 from its inflation-adjusted 1967 level of $52,186. Similarly, the income received by U.S. households at the 80th percentile was 63% higher in 2016, having grown to $121,018 from its inflation-adjusted 1967 level of $74,417. Finally, the income received by U.S. households at the 95th percentile was 89% higher in 2016, having grown to $225,251 from its inflation-adjusted 1967 level of $19,419. This income distribution trend expresses a slowly but steadily growing separation in incomes across the economy, with the real incomes of higher income households growing more rapidly than those of households with lower incomes. This trend,

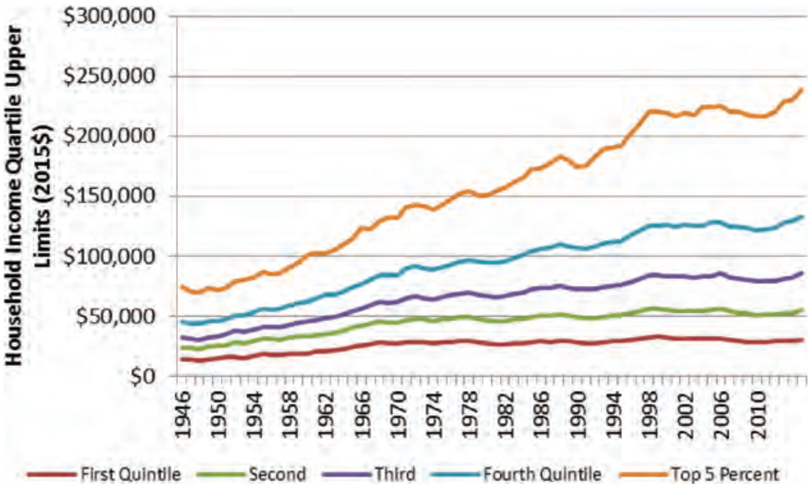

Figure 2. Quintile distribution of annual household income, 1967 to 2016 (Source: U.S. Census Bureau).

which in this form and others has been widely discussed and examined as evidence of growing income inequality in the United States, may also have important implications for understanding trends in air passenger demand to the extent that those with higher incomes have a greater propensity to use air transportation.

These national trends in income distribution can be related to other socioeconomic and demographic trends that can also be depicted with data from the Census Bureau. Figure 3 shows the number of U.S. households headed by someone in the reported age ranges for each year since 1960 (U.S. Census Bureau 2017). An important trend in these data is the increasing average age of heads of households. In 1960 around 45% of households were headed by someone aged 44 or younger. By 2016 this had fallen to less than 38% of households, with over 62% headed by someone 45 or older. It is possible to see the "baby boom" generational bulge (people

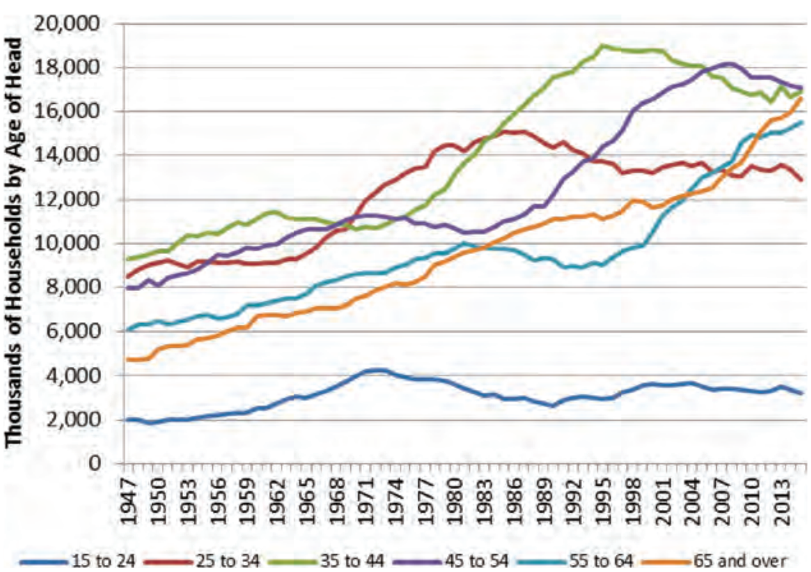

Figure 3. U.S. Households by age of head of household, 1960 to 2016 (Source: U.S. Census Bureau).

born between 1946 and 1964) moving through Figure 3, where they first show up as the bulge beginning around 1971 in households headed by someone between 25 and 34. This bulge moves along in time to other age cohorts, reflecting the aging of the boomers, until they begin swelling the ranks of households headed by someone aged 65 or older in around 2011.

This aging trend in the U.S. population is also related to air passenger demand trends. Household incomes customarily increase as the head of household ages, at least until the householder nears the end of his or her work career or has retired. When household income is correlated with the age of the head of the household in this way, it may be difficult to determine whether a household's increasing propensity to travel by air should be contributed to its growing income or its increasing age. This correlation will be seen in the analysis of air passenger survey results.

Figure 3 illustrates the changing distribution of the age of U.S. heads of households, which can be summarized or simplified as an increase in the average or median age of heads of household. One way this aging trend in the population may affect air travel demand is through the related changes in household income, since an older head of household is likely to be more experienced as a worker, with longer job tenure. Socioeconomic aspects of these changes in the age distribution are shown in Figure 4, which reports trends and recent history in average household income according to the age of the household head. The figure also shows a widening dispersion of incomes across these households, at least through the "age 45 to 54" cohort, at which point the growth in household median income begins to be reversed as some householders retire. Finally, the steady growth in median household income for those headed by someone 65 or older, although at lower levels of annual income, is in striking contrast with the household income trends for households headed by persons younger than 25. For these households, there was little if any growth in median household income since 1967.

These figures come together to tell a somewhat complicated story about how disaggregated socioeconomic factors can contribute to air passenger demand. Analysis of passenger surveys may conclude that wealthier households tend to travel by air more frequently and also that at least up to a point, households headed by a person in middle age (from 45 through 64) may also be more likely to travel by air. Since these two socioeconomic factors, when reported in a

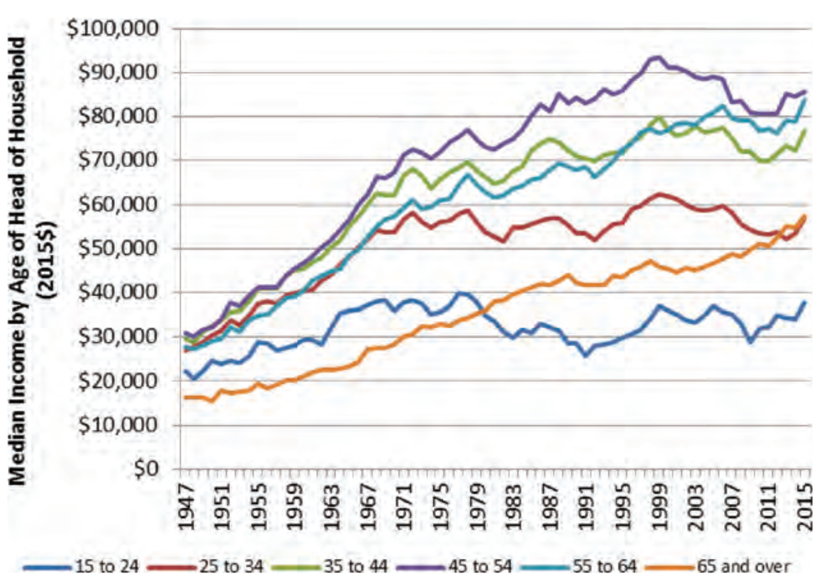

Figure 4. U.S. Household median income by age of head of household, 1967 to 2016 (Source: U.S. Census Bureau)

more disaggregated way are clearly positively correlated with one another, it may not be easily understood whether the observed increased propensity to travel by air is due to the household's greater wealth or its greater age.

Other similarly correlated disaggregated socioeconomic characteristics, such as educational attainment and household income, present similar analytic challenges for understanding and modeling how individual socioeconomic characteristics contribute to passenger demand for air travel.

Analysis of Air Passenger and Travel Survey Data

Surveys of air passengers and households provide the most disaggregated information on the way the use of air travel varies with household and air traveler characteristics, since the response data to these surveys provide information on air travel and respondent or household characteristics for individual travelers or households. The extent to which such surveys can be used to study how air travel varies with traveler or household characteristics obviously depends on what questions are asked in any given survey.

Surveys that ask how many air trips a respondent or household made in a previous year, or some other long period, allow the survey responses to be used to analyze how air travel propensity (expressed as air trips per year) varies with those respondent characteristics reported in the survey. When surveys ask how many air trips respondents have made in a period shorter than a year, care is needed in converting these air trip rates to an annual basis, since many people make relatively few air trips per year. The fact that a household reported no air trips in the previous three months does not mean that the household had not made any air trips in the previous year. Other difficulties can arise from the way that survey questions are worded, such as whether respondents are asked how many air trips they have made or all members of their household have made. In the case of air passengers surveyed at airports, obviously the respondents have made at least one air trip in the past year (the trip they were making when they were surveyed). However, such surveys will not include anyone who has not made an air trip in over a year (or ever). Only household surveys will collect data on those who have not made an air trip in the past year.

In order to collect data on infrequent air travelers, it would be desirable to ask those who report not having made an air trip in the past year when they last made an air trip, if ever. However, this is rarely done. It would also be helpful for surveys to ask how many of the air trips that a respondent reported having made in the previous year were made for business purposes and how many for personal purposes. These data can then be used to compare the responses to the trip purpose proportions reported for the current trip by air travelers surveyed at airports. Unfortunately, this too is rarely done.

Of course, many air passenger surveys performed at airports are done for purposes other than understanding the determinants of air travel demand, such as to measure traveler satisfaction with airport facilities and services or to collect information on ground transportation mode use. Even so, given the cost of performing such surveys, it would make sense to also use them to help improve the understanding of the factors that determine air travel demand. Similarly, household travel surveys are usually primarily interested in local travel rather than long-distance travel in general and air travel in particular. Although adding questions about long-distance travel does increase the length and complexity of the survey, the information that this provides significantly increases the value of the survey. This is particularly valuable since household surveys typically collect more data on the household characteristics than air passenger surveys at airports and also include households that rarely or never make air trips, as noted above.

The current project analyzed response data from a range of surveys of various types:

- General socioeconomic household surveys
  - CES
- Air passenger surveys
  - Airport intercept surveys
  - SIAT
  - Online surveys of air travelers
- Household travel surveys
  - National household travel surveys
  - State household travel surveys

Consumer Expenditure Survey

The Public-Use Microdata (PUMD) dataset of the U.S. Bureau of Labor Statistics CES includes detailed disaggregated socioeconomic information at the household and/or individual level, as well as data on household expenditures in a wide range of categories, including travel. The travel data include information on airfare expenditures. A significant attraction of the CES data is that it is national in scope, with annual data going back many years using a consistent survey methodology. Thus, these data can be used to explore whether the relationships among airfare expenditures and household characteristics have been changing over time. Although the CES survey only covers consumer expenditures, and therefore excludes reimbursed travel or business travel paid directly by employers, personal travel has been an increasing proportion of all air travel and currently accounts for about two-thirds of all air trips. However, the survey also covers non-reimbursed expenditures on trips largely paid for by employers or others, so some business-related travel is included. In addition, respondents report the number of fully reimbursed air trips that they have taken, although the survey does not collect expenditure data for those trips.

The actual data collection for the CES is performed for the BLS by the U.S. Census Bureau. The CES data is collected in two ways: a quarterly telephone interview of selected households that asks about detailed household characteristics and major expenditures over the previous quarter and a more detailed diary survey that collects expenditure data recorded by the sample households over a one-week period using an expenditure diary provided by the Census Bureau together with detailed household characteristics of the participating households. The households participating in the two different surveys are not the same. Data on air travel and vacations are primarily collected in the quarterly interview survey. A given household will generally be surveyed five times in successive quarters and report expenditures in the last four interviews. Each interview covers household expenditures in the previous three months. Since households are interviewed throughout the quarter, the reported expenditures are not always for a calendar quarter.

In addition, households rotate through the panel with new households being added in each quarter and those that have completed five quarterly surveys (or would have if they had been reached in each quarter) are dropped. Thus a given household's four quarters for which they report expenditure data are not necessarily for a calendar year. For the purpose of analyzing the number of reported air trips, only households that reported four quarters of data were included. Data for a given year included interviews conducted during the first quarter of the following year, since many of those interviews would have included air trips made during the fourth quarter of the previous year.

The CES expenditure files provide information on each air trip or vacation taken by a household, including the number of trips and the duration of each trip, as well as the airfare (and other) expenditures for each trip. This allows expenditures on air travel to be expressed in terms of the average number of air trips involved, which can then be compared to the data on air trips from the U.S. DOT 10% O&D survey. Thus the CES data provide a complementary perspective to more traditional sources of air passenger data that considers air travel expenditures rather than air trips per se.

In addition to the expenditures on airfares, the CES expenditure files also include the expenditures on a range of other travel cost categories, including lodging, meals in restaurants, alcoholic beverages in restaurants and bars, purchased food and beverages, and local transportation. Since most people do not keep detailed records of their expenditures while making personal trips and to the extent that they do have records (e.g., credit card statements) may not take the time to review these records when responding to the survey, it is almost certain that the reported figures are at best highly approximate. Nonetheless, the CES provides one of the few sources of data on the non-airfare costs of trips taken by air, and hence provides a way to study how these costs have changed relative to airfares over time.

In order to determine how the results from the CES compare to the air passenger traffic statistics reported by the U.S. DOT, the number of air trips reported by respondents to the 2014 CES was compared to the corresponding number of air trips estimated from the U.S. DOT data. This comparison required a number of assumptions, since there are significant differences between the air trips reported by CES survey respondents and the air passenger traffic data reported by the U.S. DOT, as discussed in Appendix C.

The principal difference is that CES respondents reported the number of air party trips made by household members whereas the U.S. DOT data report air passenger trips. The CES data do not indicate how many household members went on each trip. In order to convert the U.S. DOT air passenger enplanement data to air party trips by U.S. residents, it was necessary to adjust the data for the average air party size, as well as the average number of enplanements per round trip, and the percentage of U.S. domestic enplanements made by foreign visitors.

In summary it appears that the CES survey is missing at least half of the air trips being made by all U.S. households and quite possibly as much as 60% for reasons that are not clear. It is possible that CES respondents failed to report all the air trips made by members of their household. However, although the overall air trip propensity values from the CES should be viewed with some caution, the relative air trip propensities for different segments of the population may still be valid.

Trends in Air Travel by Household Characteristics

To examine changes of air trip making and household characteristics over time, the same analysis was undertaken of the relevant data from the 2006, 2010, and 2014 CES.

Household Income. The changes in the average number of air trips per household for survey respondents in different household income ranges are shown in Table 2, together with the percentage of respondents in each income range who reported making no air trips during the four quarters for which they reported expenditures.

As could be expected, the average number of air trips per year generally increased with increasing household income in each survey. However, the average number of air trips across all households declined progressively from 2006 to 2014, although this pattern does not appear for every income range, with some showing an increase or decrease from 2006 to 2010 that reversed in 2014 or even a progressive increase. There appears to be no obvious pattern in the changes in the average number of air trips for a given household income range, other than a progressive increase in the average number of air trips for survey respondents in households with an annual income of $300,00 or more.

Table 2. Air trips per household by annual household income.

Annual Household Income	2006		2010		2014	
	Percent w/ No Air Trips	Air Trips per H/H (All)	Percent w/ No Air Trips	Air Trips per H/H (All)	Percent w/ No Air Trips	Air Trips per H/H (All)
Less than $20,000	89	0.15	88	0.17	92	0.14
$20,000 - $39,999	84	0.28	88	0.17	88	0.19
$40,000 - $59,999	77	0.38	77	0.40	81	0.32
$60,000 - $79,999	71	0.53	78	0.39	75	0.37
$80,000 - $99,999	61	0.67	64	0.66	66	0.55
$100,000 - $124,999	55	0.68	58	0.78	69	0.55
$125,000 - $149,999	43	1.24	49	1.37	48	0.87
$150,000 - $199,999	42	1.49	50	1.03	47	1.20
$200,000 - $249,999	22	2.03	44	1.40	46	1.46
$250,000 - $299,999	24	1.76	19	2.22	38	1.77
$300,000 or more	25	1.94	24	2.04	26	2.97
Total	72	0.533	75	0.476	76	0.459

The percentage of households that reported no air trips in the past year declines with increasing income, as could be expected. Surprisingly, about 10% of households with incomes less than $20,000 reported making at least one air trip in the past year, with those households reporting an average of about 1.4 trips in 2006 and 2010 and 1.7 trips in 2014. In contrast, only about 25% of households with incomes of $300,000 or more reported making no air trips in the past year, with those households making air trips reporting an average of 2.6 trips in 2006, 2.7 trips in 2010, and 4.0 trips in 2014.

However, the results for respondents in the higher income ranges may be influenced by the relatively small number of survey respondents in these income ranges, as shown in Table 3.

The distribution of survey respondents across the different income ranges for each year shows a small progressive decrease in the percentage of survey respondents in households with an annual income in each range below $80,000. This is to be expected as real incomes increase, moving some households into a higher income range. However, there is no obvious pattern in the changes in the distribution of survey respondents in income ranges of $80,000 and over, although the percentage of respondents in each income range above $100,000 increased from 2006 to 2014 with the exception of respondents with household incomes from $250,000 to $299,999, the percentage of whom was essentially unchanged.

Table 3. Survey respondents by annual household income.

Annual Household Income	2006		2010		2014	
	All Households	Percent All H/H	All Households	Percent All H/H	All Households	Percent All H/H
Less than $20,000	496	19.3	489	19.1	397	18.2
$20,000 - $39,999	575	22.3	552	21.5	467	21.4
$40,000 - $59,999	440	17.1	434	16.9	360	16.5
$60,000 - $79,999	335	13.0	333	13.0	268	12.3
$80,000 - $99,999	241	9.4	257	10.0	181	8.3
$100,000 - $124,999	179	6.9	174	6.8	199	9.1
$125,000 - $149,999	87	3.4	119	4.6	83	3.8
$150,000 - $199,999	88	3.4	86	3.4	85	3.9
$200,000 - $249,999	78	3.0	69	2.7	84	3.9
$250,000 - $299,999	32	1.2	34	1.3	26	1.2
$300,000 or more	25	1.0	16	0.6	31	1.4
Total	2,576	100	2,563	100.0	2,181	100

Since the household income ranges are expressed in current dollars for each year, it is unclear to what extent the changes in the distribution from 2006 to 2014 reflect a shift into higher income categories as real incomes rise versus a shift in the distribution of real income from lower income to higher income households.

Respondent Age. The changes in the average number of air trips per household for survey respondents in different age ranges are shown in Table 4.

Although the analysis found no consistent pattern in the average number of air trips per household for survey respondents in the individual age ranges, when grouped into three broader age ranges there appears to be a somewhat different pattern for each range. For survey respondents ages 25 to 44, the average number of trips declined from 2006 to 2010, then remained unchanged in 2014. For survey respondents ages 45 to 64, the average number of air trips declined sharply from 2006 to 2010, then recovered slightly in 2014. For survey respondents ages 65 or over, the average number of air trips remained unchanged from 2006 to 2010, but declined in 2014.

The percentage of households with respondents who reported making no air trips in the past year was generally similar across the different age ranges up to about age 70 then generally increased in older age ranges, as could be expected.

The number of households with survey respondents in each age range is shown in Table 5. There were significantly more respondents in the 20-year age range from 45 to 64 than the 20-year age range from 25 to 44. It appears that this reflects the changing age distribution in the population as a result of the baby boom following the World War II, as can be seen from the progression of age ranges with the highest percentage of respondents into older age ranges over the period from 2006 to 2014.

The distribution of survey respondent ages over the three surveys shows the percentage of respondents in the age ranges below age 55 generally declined from 2006 to 2014, except for the age range 18 to 24, where the percentage increased. The percentage of respondents in the age range 55 to 59 declined from 2006 to 2010 but then recovered in 2014, while the percentage of respondents in age ranges of 60 or over generally increased from 2006 to 2014.

Table 4. Air trips per household by respondent age.

Respondent Age	2006		2010		2014	
	Percent w/ No Air Trips	Air Trips per H/H (All)	Percent w/ No Air Trips	Air Trips per H/H (All)	Percent w/ No Air Trips	Air Trips per H/H (All)
18 - 24	77	0.30	79	0.35	82	0.34
25 - 29	72	0.54	73	0.60	72	0.45
30 - 34	77	0.43	73	0.43	76	0.57
35 - 39	72	0.51	73	0.46	76	0.48
40 - 44	65	0.66	74	0.49	74	0.43
45 - 49	69	0.67	73	0.51	77	0.38
50 - 54	67	0.61	69	0.59	72	0.52
55 - 59	65	0.69	75	0.44	75	0.63
60 - 64	69	0.53	76	0.57	73	0.64
65 - 69	68	0.59	74	0.49	76	0.41
70 - 74	80	0.43	83	0.43	77	0.34
75 - 79	82	0.25	74	0.45	85	0.31
80 or over	88	0.23	90	0.15	88	0.14
Total	71	0.538	75	0.476	76	0.459
25 - 44	71	0.55	74	0.49	75	0.49
45 - 64	67	0.63	73	0.53	74	0.55
65 or over	79	0.38	80	0.38	81	0.31

Table 5. Survey households by respondent age.

Respondent Age	2006		2010		2014	
	All Households	Percent All H/H	All Households	Percent All H/H	All Households	Percent All H/H
18 - 24	61	2.4	66	2.6	67	3.1
25 - 29	151	5.9	130	5.0	122	5.6
30 - 34	194	7.6	196	7.6	169	7.7
35 - 39	254	9.9	217	8.4	168	7.7
40 - 44	283	11.0	232	9.0	169	7.7
45 - 49	289	11.3	298	11.5	182	8.3
50 - 54	289	11.3	293	11.4	236	10.8
55 - 59	271	10.6	254	9.8	229	10.5
60 - 64	211	8.2	255	9.9	226	10.3
65 - 69	165	6.4	202	7.8	215	9.8
70 - 74	110	4.3	140	5.4	146	6.7
75 - 79	121	4.7	138	5.3	103	4.7
80 or over	168	6.5	160	6.2	152	7.0
Total	2,567	100	2,581	100	2,184	100
25 - 44	882	34.4	775	30.0	628	28.8
45 - 64	1,060	41.3	1,100	42.6	873	40.0
65 or over	564	22.0	640	24.8	616	28.2

The survey findings shown in Tables 4 and 5 have interesting implications for future trends in air travel demand. Table 5 shows that the percentage of the population aged over 64, which make the lowest average number of air trips per household, can be expected to continue to increase while the percentage between ages 45 and 64, which make the highest average number of air trips per household, can be expected to continue to decline. Furthermore, within broad groups of age ranges the average number of air trips per household has declined from 2006 to 2014 despite increases in real incomes and a decline in real airfares over the period.

Race and Ethnicity. Differences in the average number of air trips per year per household by respondent race and ethnicity and changes in these air trip propensities over the period from 2006 to 2014 are shown in Table 6.

Households with an Asian respondent reported a significantly higher average number of air trips than those with a white respondent. In contrast, households with a Hispanic respondent reported

Table 6. Air trips per household by respondent race/ethnicity.

Respondent Race/Ethnicity	2006		2010		2014	
	Percent w/ No Air Trips	Air Trips per H/H (All)	Percent w/ No Air Trips	Air Trips per H/H (All)	Percent w/ No Air Trips	Air Trips per H/H (All)
White	69	0.61	74	0.49	73	0.54
Hispanic	79	0.28	83	0.28	86	0.23
Black	87	0.19	88	0.26	90	0.15
Asian	49	0.85	45	1.12	62	0.68
Native American	60	0.70	78	0.22	100	
Pacific Islander	50	1.13	57	0.71	40	1.00
Multiple races	63	0.58	69	0.59	77	0.55
Total	71	0.537	75	0.476	76	0.459
NA / PI / Multiple (*1*)	60	0.71	69	0.54	76	0.52

Note 1. Native American, Pacific Islander, and multiple races combined.

an average number of air trips less than half of that by households with a white respondent in 2006 and 2014, and slightly over half in 2010, while households with a black respondent reported an even lower average number of air trips than those with a Hispanic respondent. In 2006 and 2014, households with a black respondent reported an average number of air trips less than a third of that by those with a white respondent, although in 2010 they reported a significantly higher average number of air trips that was over half that reported by households with white respondents. Households with Pacific Islander respondents reported the highest average number of air trips of all race/ethnicity categories in 2006 and 2014 and the second highest in 2010, although, as noted below, the number of respondents was too small to give reliable results.

The changes in the average number of air trips per year across all households participating in the survey for each of the race/ethnicity categories over the three surveys does not show any obvious pattern other than an apparently progressive decrease in the air trip propensity of the combined category of Native American, Pacific Islander, and multiple race respondents. However, that pattern is heavily influenced by differences between the three categories.

Changes in the distribution of survey households by respondent race/ethnicity are shown in Table 7.

Although accounting for over two-thirds of the households participating in the survey, the percentage of households with white respondents declined progressively over the three surveys. In contrast, the percentage of households with a Hispanic or Asian respondent increased, although the increase from 2010 to 2014 was not a great as from 2006 to 2010. The percentage of households participating in the survey with black respondents varied, decreasing from 2006 to 2010 then increasing from 2010 to 2014 to the highest level over the three surveys. The changes in the percentages for the other race/ethnicity categories are not statistically significant due to the small number of such households in the survey.

As with the findings for the changes in the composition of the population by age and the associated average travel propensity, the survey findings shown in Table 6 and Table 7 have interesting implications for future trends in air travel demand, although the potential consequences are less clear. The percentage of Asian and Hispanic households in the population is increasing, while the percentage of white households is declining. Although households with a Hispanic respondent reported a much lower average travel propensity than those with a white respondent, those with an Asian respondent reported a higher average travel propensity. However, the percentage of households with a Hispanic respondent in 2014 was almost two and a half times larger than the percentage with an Asian respondent, so on balance these trends are likely to lead to a continuing decline in overall air travel propensity, at least for some time.

Table 7. Survey households by respondent race/ethnicity.

Respondent Race/Ethnicity	2006		2010		2014	
	All Households	Percent All H/H	All Households	Percent All H/H	All Households	Percent All H/H
White	1,867	72.6	1,803	69.8	1,484	67.9
Hispanic	283	11.0	320	12.4	290	13.3
Black	291	11.3	281	10.9	261	11.9
Asian	87	3.4	130	5.0	117	5.4
Native American	10	0.4	9	0.3	6	0.3
Pacific Islander	8	0.3	7	0.3	5	0.2
Multiple races	24	0.9	32	1.2	22	1.0
Total	2,570	100	2,582	100	2,185	100
NA / PI / Multiple (*1*)	42	1.6	48	1.9	33	1.5

Note 1. Native American, Pacific Islander, and multiple races combined.

It should also be noted that differences in air travel propensity between the different race/ethnicity categories are likely to be at least partly influenced by differences in household income rather than race/ethnicity per se, so care is needed to avoid double-counting the influence of both factors.

Overall Air Travel Propensity

The decline in the average number of air trips per year across all households from 2010 to 2014 (a decrease of about 3.6%) is somewhat unexpected in the light of the increase in total enplanements by U.S. commercial air carriers over the same period, which increased from 712 million passengers in fiscal year 2010 to 757 million passengers in fiscal year 2014 (FAA 2016), an increase of about 6.3%. However, during the same period the number of households increased from 117.5 million to 123.9 million (Proctor, et al. 2016), an increase of about 5.4%. The combined effect of the increase in the number of households and the decline in the average number of air trips per household would have given a net increase of about 1.8%, still well below the increase in air passenger enplanements. However, it should be noted that the CES may not include all business trips and the number of business trips may have grown faster from 2010 to 2014 than the number of personal trips, as the economy recovered from the 2007–2009 recession. This suggests the importance of accounting for changes in the percentage of business trips compared to personal trips when analyzing changes in air passenger traffic.

Lodging, Food and Beverage Expenses for Air Trips

The analysis also examined the changes in lodging expenses per night and food and beverage expenses per night for air trips, expressed in constant dollars. Details are provided in Appendix C. For both categories of expenditures the expenses per night declined from 2006 to 2010 and then increased in 2014, although food and beverage expenses in 2014 were still below their level in 2006 in constant dollars. The average expenditure on lodging (for those air trips where lodging expenses were incurred) was $105 per night in 2006, declining to $92 per night in 2010, and recovering to $107 per night in 2014 (all in 2015 dollars), whereas the average expenditure on food and beverages (for all air trips of one night or more where food and beverage expenses were incurred) was $56 per night in 2006, declining to $41 per night in 2010, and recovering to $51 per night in 2014 (all in 2015 dollars).

Air passenger demand models rarely consider the costs of making an air trip other than airfares. These data show that lodging and food and beverage expenses can be a significant part of the cost of making an air trip and that these costs change over time at different rates from airfares.

Summary and Conclusions

The analysis of the CES data has shown that air travel propensity not only varies with household income, as would be expected, but also that there are significant differences by survey respondent age and race/ethnicity. Current trends in the composition of the population by age and race/ethnicity combined with differences in air travel propensity across different age ranges and race/ethnicity categories appear likely to result in a decline in air travel propensity after allowing for changes in real household incomes and the real costs of air travel (including airfares, lodging, and other costs). This suggests that air travel demand studies need to take the changing composition of the population into account, although how to do this is less clear.

Although the CES provides a valuable resource to help improve the understanding of air travel demand that has received little previous attention, there are two issues that deserve further study as a matter of some urgency. The first is the apparent discrepancy between the number of air party trips reported by CES respondents and the number of air passenger trips reported in U.S. DOT data. The second is the extent to which differences in air travel propensity by different household income ranges and age ranges and race/ethnicity of survey respondents are interrelated. Ideally, one would like to know how average air travel propensity varies by households of a given income, age, and race/ethnicity of household members. Although the CES is a fairly large survey, the sample size is not large enough to support a three-way tabulation of the average number of air trips per year with sufficient resolution and reliability, so another analysis approach is needed.

Air Passenger Surveys

Air passenger surveys can provide disaggregated data on the socioeconomic characteristics of air travelers as well as their air travel frequencies, depending on the questions asked in the survey. The response-level data from these surveys allows an analysis to be undertaken of how air travel propensity (air trips per year) varies with socioeconomic characteristics.

Airport Intercept Surveys

Airport intercept surveys are the most common form of air passenger surveys and are typically performed at a specific airport or group of airports over a relative short period of time, such as one or two weeks, although they may be repeated at different times of the year to capture seasonal differences in air traveler characteristics. The research team identified 10 air passenger surveys conducted at eight airports in various years from 2006 to 2015. In addition, smaller sample surveys have been undertaken on a quarterly basis at a large number of airports as part of the Airport Service Quality (ASQ) survey program run by the Airports Council International (ACI).

Detailed survey response data have been obtained for recent surveys at seven of the eight airports, as well as for a number of surveys undertaken in prior years when similar surveys were undertaken at each airport. In addition, airport staff for the eighth airport, Boston Logan International Airport, provided survey response data for selected questions from a recent survey in place of providing complete survey response data, and ACI staff provided detailed ASQ survey response data for surveys undertaken at 28 de-identified airports in 2015.

Appendix C presents a detailed analysis of survey data from the following eight airports in addition to data from the 2015 ASQ survey:

- Boston Logan International Airport (BOS)
  - 2013 survey
- Los Angeles International Airport (LAX)
  - 2006 survey
  - 2015 survey
- Metropolitan Washington Council of Governments (MWCOG) surveys undertaken at Washington Reagan National Airport (DCA), Washington Dulles International Airport (IAD), and Baltimore-Washington International Airport (BWI)
  - 2011 survey
  - 2013 survey
- Oakland International Airport (OAK)
  - 2006 survey undertaken by the Metropolitan Transportation Commission
  - 2014/15 survey
- San Francisco International Airport (SFO)
  - 2006 survey undertaken by the Metropolitan Transportation Commission
  - 2014/15 survey
- Tulsa International Airport (TUL)
  - 2016 survey

The surveys were undertaken by the airport authority, except where noted. The MWCOG surveys were each undertaken using the same survey questions at each airport and at the same time of year. Since these surveys were performed at all three commercial service airports in the Baltimore/Washington metropolitan region, the survey results were combined to give a regional profile of air travel propensity. The 2006 and 2014/15 surveys at OAK and SFO were also each undertaken using essentially the same survey questions, differing only in response options relevant to each airport, and at the same time. Although there were some changes in the survey questions from 2006 to 2014/15, most questions were largely unchanged. However, the two LAX surveys differed in that the 2006 survey asked respondents how many air trips they had made in the past year from each commercial service airport in the Southern California region, while the 2015 survey only asked how many air trips they had made from LAX.

In order to explore how air travel propensity varies with respondents characteristics, an analysis was limited to responses by residents of each region, since visitors could (and doubtless many did) make many air trips to other destinations that would not have been reported in the surveys. In the case of the 2015 LAX survey, the analysis was restricted to residents of the West Side of the Los Angeles basin, the area surrounding LAX for which LAX is the closest airport. Since LAX has by far the most air service of any of the commercial service airports in the region, it was assumed that West Side residents would have had little reason to use other airports and thus their use of LAX was a good indicator of their total air travel.

The analysis of the airport intercept surveys gave broadly consistent results after making allowances for the range of years over which they were performed. The variation in air travel propensity (average total number of air trips per year) with household income for the nine surveys that asked both how many air trips the respondents had made in the past year and their household income is shown in Tables 8 and 9. The TUL survey did not ask how many air trips the respondents had made in the past year and the ACI ASQ survey did not ask the respondents' household income.

Since the nine surveys used different ranges of household income, the responses were adjusted to a consistent set of income ranges for comparison by assuming that the respondents within each income range were uniformly distributed across the incomes in the range and made the same number of air trips per year as the average for the income range. Since the surveys were performed over a wide range of years, the household income ranges used in each survey were converted to constant 2015 dollars, assuming that survey respondents reported their

Table 8. Average air trips in past 12 months by air passenger survey respondents by annual household income—earlier surveys.

Household Income (2015 $)	Average Annual Trips				
	LAX 2006 Survey	MWCOG 2011 Survey	OAK 2006 Survey	SFO 2006 Survey	Weighted Average *(1)*
Under $15,000	3.4	5.8	5.0	5.6	4.4
$15,000 - $24,999	3.4	5.1	5.0	5.6	3.8
$25,000 - $49,999	3.9	4.9	5.7	5.0	4.3
$50,000 - $99,999	5.3	6.3	7.8	6.8	5.8
$100,000 - $149,999	7.3	7.7	9.1	9.6	7.7
$150,000 - $199,999	9.3	9.0	12.9	10.6	9.5
$200,000 and over	13.4	13.8	18.5	17.1	14.4
Total *(2)*	6.87	9.15	10.99	10.68	8.33
Valid responses	8,685	6,118	1,186	1,083	17,072

Notes: (1) Weighted by valid survey responses.
(2) Average annual trips exclude respondents who did not indicate their household income.

Table 9. Average air trips in past 12 months by air passenger survey respondents by annual household income—more recent surveys.

Household Income (2015 $)	Average Annual Trips					
	BOS 2013 Survey	LAX 2015 Survey *(1)*	MWCOG 2013 Survey	OAK 2014/15 Survey	SFO 2014/15 Survey	Weighted Average *(2)*
Under $15,000	3.5	4.3	4.7	4.1	3.9	4.2
$15,000 - $24,999	3.5	4.1	4.0	4.1	3.9	3.9
$25,000 - $49,999	3.4	3.8	4.8	4.6	4.7	4.4
$50,000 - $99,999	4.1	7.1	5.7	6.5	6.7	6.0
$100,000 - $149,999	5.7	7.5	7.3	9.4	9.7	8.0
$150,000 - $199,999	8.0	7.5	9.0	12.4	10.5	9.8
$200,000 and over	12.6	10.3	12.7	17.2	15.7	14.2
Total *(3)*	7.07	6.79	8.30	9.81	9.51	8.69
Valid responses	3,394	480	5,034	3,039	4,852	17,069

Notes: (1) Los Angeles West Side residents.
(2) Weighted by valid survey responses.
(3) Average annual trips include respondents who did not indicate their household income.

income for the previous calendar year, before adjusting the responses to a consistent set of household income ranges.

Although the general pattern is broadly consistent across the nine surveys, the average numbers of annual trips for each income range and in total for each survey differ considerably. In particular, the values for the surveys at the two Bay Area airports (OAK and SFO) are significantly higher than for the other surveys. This is apparent for the two LAX surveys; the first was performed in the same year as the first two Bay Area surveys, and the second was performed less than a year after the second two Bay Area surveys. The reason for the large difference in values between the LAX surveys and the four Bay Area surveys is unclear and deserving of further research.

Although both OAK and SFO serve the same region, it is notable that Bay Area residents using OAK had a slightly higher overall air travel propensity than those using SFO in both the earlier and more recent surveys. Although this was not the case for all income ranges, it was true for higher income respondents with household incomes over $150,000 (in 2015 dollars) in both sets of surveys, who of course made the highest average number of air trips. It is possible that this reflects a greater use of OAK for frequent business travel in West Coast markets, which are particularly well served from OAK. If so, this has interesting implications for use of secondary airports in multi-airport regions such as the Bay Area and is deserving of further research.

Another interesting finding from the results shown in Tables 8 and 9 is that the overall average air trip propensity declined from the earlier to the later surveys in all regions for which surveys were analyzed in both periods. This decline does not appear in the weighted average results across each set of surveys because the surveys for LAX, which had the lowest overall average air trip propensity, had very different sample sizes in the two periods. The 2006 LAX survey had the largest number of valid responses of all the earlier surveys, accounting for almost half the responses, which depressed the weighted average. The 2015 LAX survey had the lowest number of valid responses used to calculate the average number of annual air trips in the more recent surveys and had very little influence on the weighted average. This decline in average air travel propensity appears to have occurred in almost all income ranges for the MWCOG and Bay Area surveys. The situation is less clear in the case of the LAX surveys but, as noted above, the number of valid responses used in the analysis of the 2015 survey was very small so differences for a given income range are less reliable.

The average number of air trips in the past 12 months reported by survey respondents to five recent air passenger surveys by respondent age range is shown in Table 10.

Respondents in the age range 45 to 54 reported the highest average number of air trips in the past year for all surveys except the MWCOG 2013 survey, where respondents in the age range 55 to 64 reported a slightly higher average number of air trips. Respondents in the age range with the highest average number of air trips generally reported about twice as many air trips on average as those in the age range with the lowest average number of air trips. This was generally respondents in the age range 18 to 24, except for the LAX 2015 survey, where respondents 65 or older reported slightly fewer air trips on average than those in the age range 18 to 24. The weighted average number of air trips per year across the five surveys gave respondents in the age range 45 to 54 having over twice as many air trips as those in the age range 18 to 24.

It is clear from the analysis of the various surveys that respondents who were making a business trip when they were surveyed typically report a higher average number of air trips in the previous year than respondents who were making a personal trip. This is not surprising, since most if not all business air travelers will also make personal air trips, while the reverse is not always true. Also, it seems reasonable that some business travelers make a large number of air trips each year for business, while relatively few travelers make a large number of personal air trips each year. However, it is quite likely that the number of annual air trips reported by many of the survey respondents making a personal trip who reported making several air trips included both business and personal trips. The data from each of the surveys consistently show that a fairly small number of air passengers report making a large number of air trips per year (say more than 12, or an average of one a month) and that this small number of passengers accounts for a relatively large proportion of total air trips.

More detailed comparative analysis of each of these surveys that explored how air travel propensity varied with additional respondent characteristics is presented in Appendix C.

Tulsa International Airport. Tulsa International Airport (TUL) has undertaken annual airport customer surveys for the past 5 years. The findings of these surveys provide a useful comparison to those from the surveys at larger airports. Airport staff provided summary data for the surveys from 2012 to 2016 and detailed survey response data for the 2016 survey. The surveys covered both arriving and departing passengers as well as meeters and well-wishers. In addition to collecting statistical data on each type of airport customer, the survey asked questions about the customer experience at the airport and improvements they would like to see, as well as other

Table 10. Average air trips in past 12 months by air passenger survey respondents by age range—recent surveys.

Age Range	Average Annual Trips					
	BOS 2013 Survey	LAX 2015 Survey *(1)*	MWCOG 2013 Survey	OAK 2014/15 Survey	SFO 2014/15 Survey	Weighted Average *(2)*
18 - 24	3.5	5.7	5.1	4.9	5.4	4.9
25 - 34	6.1	7.0	7.9	8.7	9.3	8.2
35 - 44	8.3	7.1	8.9	11.4	11.3	10.0
45 - 54	9.5	7.9	9.2	12.4	11.7	10.6
55 - 64	8.2	6.5	9.5	11.0	10.1	9.7
65 or older	4.7	5.3	6.5	6.9	5.9	6.0
Total *(3)*	7.08	6.79	8.30	9.81	9.51	8.69
Valid responses	3,938	701	6,164	4,558	6,614	21,975

Notes: (1) Los Angeles West Side residents.
(2) Weighted by valid survey responses.
(3) Average annual trips include respondents who did not indicate their age.

airports in the region that they had used. However, the survey did not ask respondents how many air trips they had made in the past year.

The composition of survey respondents and the trip purposes of each type of air passenger are shown in Table 11. The proportion of respondents making business and personal trips varies considerably from year and also differs between departing and arriving passengers in a given year. This could reflect the relatively small size of the sample, as well as the timing of the surveys. Nonetheless, for the three most recent surveys the percentages of respondents making business trips were higher than for those making personal trips, in contrast to the survey results for 2013 and the findings of air passenger surveys at larger airports.

The survey did not ask how many people were in each travel party, so the percentages shown in Table 11 (and the following table) are of air parties, not total air passengers. Since the average air travel party size of those making business trips is usually considerably lower than those making personal trips, the percentages of air passengers making a business trip would be lower than shown in the table.

A more detailed analysis of the 2016 survey response data was undertaken to determine how air passenger characteristics varied by trip purpose. Table 12 shows the profile of the air passenger respondents by trip purpose. A much higher percentage of respondents on a business trip were male, while a higher percentage of those on a personal trip were female. While the higher percentage of male business travelers is not surprising, the higher percentage of those making a personal trip who were female is surprising. Although other air passenger surveys have also found a somewhat higher percentage of respondents making personal trips to be female, the difference has not been as great as suggested by the TUL survey.

The age profile of the survey respondents is significantly different for respondents who were making a business trip and those making a personal trip. Of those making a business trip, 80% were between the ages of 30 and 59, with only 6% below the age of 30 and over a third in the age range from 50 to 59. In contrast, 23% of those making a personal trip were below the age of 30, with 33% aged 60 or more.

As might be expected, survey respondents who were making business trips had significantly higher annual household incomes than those who were making personal trips, with 43% having incomes of $150,000 or more compared to only 12% for those making personal trips. Survey respondents who were making personal trips had household incomes more evenly distributed between $25,000 and $150,000, with the largest percentage (25%) having incomes between $50,000

Table 11. Sample size and composition of TUL customer survey respondents.

Customer Type	2013	2014	2015	2016
Departing passenger	40%	51%	47%	40%
Arriving passenger	41%	49%	47%	40%
Meeter/well-wisher	19%		5%	20%
	100%	100%	100%	100%
Survey sample size	261	204	213	252
Departing passengers				
Business	42%	65%	55%	65%
Personal	58%	35%	45%	35%
	100%	100%	100%	100%
Arriving passengers				
Business	32%	51%	61%	53%
Personal	68%	49%	39%	47%
	100%	100%	100%	100%

Table 12. Distribution of TUL 2016 air passenger respondent characteristics.

Characteristics	Business Trip	Personal Trip
Gender		
Male	79%	29%
Female	21%	71%
	100%	100%
Age		
18 - 19		4%
20 - 29	6%	19%
30 - 39	20%	14%
40 - 49	24%	15%
50 - 59	36%	16%
60 or more	15%	33%
	100%	100%
Household Income		
Less than $25,000		7%
$25,000 - 49,999	5%	18%
$50,000 - 74,999	10%	25%
$75,000 - 99,999	15%	18%
$100,000 - 149,999	28%	21%
$150,000 or more	43%	12%
	100%	100%
Educational attainment		
Some high school		1%
High school graduate	3%	9%
Trade/tech/vocational	4%	6%
Some college credit	15%	12%
Associate's degree	10%	12%
Bachelor's degree	45%	41%
Post-graduate degree	22%	19%
	100%	100%

and $75,000. No survey respondents who were making a business trip reported a household income below $25,000, while only 7% of those making a personal trip reported an income below $25,000.

The 2016 survey was the first one to ask respondents about the highest level of education they had attained, as shown in Table 12. Not surprisingly, survey respondents who were making business trips had a fairly high level of education with two-thirds having a bachelor's or post-graduate or professional degree and over 90% having some college education. However, survey respondents who were making personal trips also had a fairly high level of education, with 60% having a bachelor's, or post-graduate or professional degree and a further 24% having some college education.

In summary, the results of the TUL customer surveys provide a useful indication of the profile of air travelers using a smaller airport, although the small sample size both limits the ability to explore how the respondent characteristics vary with more than one variable and may have introduced a fair amount of error in the results.

ACI Airport Service Quality Surveys. For many years the ACI has maintained a program of customer satisfaction surveys, ASQ survey, in which many of its member airports participate (http://www.aci.aero/Airport-Service-Quality/ASQ-Home). These surveys are generally undertaken four times per year using a standardized survey questionnaire with a minimum of 350 respondents for each survey. As of 2015, 28 U.S. airports participated in this program.

The ASQ survey asks respondents to rate 30 aspects of their airport experience at the airport where they were surveyed. In addition, the ASQ survey includes a number of questions about the current air trip being taken by respondents and traveler characteristics, although these do not include household income. ACI staff provided ASQ survey response data for surveys undertaken at 28 de-identified airports in 2015 for the following questions:

- Trip purpose
- Number of return air trips made in the past 12 months
- Nationality
- Country of residence
- Postal code
- Gender
- Age

The dataset comprised 68,484 survey responses, of which 58,448 were by U.S. residents. Analysis of the data for U.S. residents was undertaken to explore how the number of air trips in the past 12 months varied by trip purpose, age, and gender. The number of air trips was reported by survey respondents in five ranges: 1–2, 3–5, 6–10, 11–20, and 21 or more. The number of respondents by trip purpose and the proportion that reported making air trips in each range is shown in Table 13.

It should be noted that these trip frequency distributions are based on the purpose of the current trip and do not show the number of trips by each purpose in the past 12 months. Survey respondents who were making a business trip would be more likely to have made more air trips in the past 12 months (many of which would most likely have been for business) than survey respondents making a non-business trip and may not have made any business trips in the past 12 months. The average number of air trips for each trip frequency range shown differs from the mid-point of the range, reflecting the curvature of the cumulative distribution curves. They were obtained from an analysis of the frequency distribution of air trips in the past 12 months by San Francisco Bay Area residents in the 2014/15 air passenger survey undertaken at San Francisco International Airport. Respondents reported the actual number of trips they had made.

There does not appear to be a large difference in the trip frequency distribution for those respondents making a leisure trip or other non-business type of trip, although there was a large difference between those respondents and those making a business trip. Therefore subsequent analysis combined respondents who reported making a leisure trip or other non-business type of trip. The overall average number of trips per year is somewhat lower than found in air passenger surveys at large airports performed around the same time, as shown above in Table 9, but not significantly so. This could reflect the inclusion of smaller airports in the survey responses where local residents may have less reason to make air trips and may well have lower average household

Table 13. Distribution of air trips per year by trip purpose—ASQ surveys.

Trip Purpose	Survey Responses	Percent	Air Trips in Past 12 Months					
			1-2	3-5	6-10	11-20	21+	Total
Business	21,105	36.1	17%	26%	21%	17%	20%	100%
Leisure	30,893	52.9	41%	36%	15%	5%	3%	100%
Other	6,450	11.0	44%	35%	14%	4%	3%	100%
Total	58,448	100	33%	32%	17%	9%	9%	100%
Average Trips								
Business			1.6	4.0	7.8	15.0	38	12.9
Leisure			1.6	3.8	7.5	14.3	33	4.8
Other			1.6	3.8	7.5	14.3	33	4.6
Total								7.7

Table 14. Distribution of air trips per year by age and trip purpose—ASQ surveys.

Age Range	Business Trips			Personal Trips		
	Survey Responses	Percent	Avg. Air Trips in Past 12 mo.	Survey Responses	Percent	Avg. Air Trips in Past 12 mo.
16-21	340	1.6	5.5	2,675	7.3	4.0
22-25	1,106	5.3	8.3	2,893	7.9	4.3
26-34	3,540	17.0	11.0	5,279	14.4	5.1
35-44	4,521	21.7	12.9	4,246	11.5	5.0
45-54	5,587	26.8	14.3	6,146	16.7	5.2
55-64	4,491	21.6	14.5	8,431	22.9	5.0
65-74	1,142	5.5	12.5	6,029	16.4	4.4
76 and over	100	0.5	9.7	1,079	2.9	3.4
Total	20,827	100	12.9	36,778	100	4.8

incomes. The difference in average annual air trips between survey respondents making business and non-business trips is similar to that found in the surveys at large airports.

Table 14 shows the number of respondents by age range for those making business and personal trips, as well as the average number of air trips in the past year. The average number of trips per year increases with age until the age range 55 to 64 in the case of those making a business trip and age range 45 to 54 for personal trips. The average number of trips per year then declines with age. For those making personal trips, the average number of trips per year by those in the highest age range of 76 and over is the lowest of any age range, at 3.4 trips per year on average, although only 3% of those making personal trips are in this age range. Even so, this is still a respectable number of trips per year for someone in this age range.

As found in the analysis of other air passenger surveys, the variation in the average number of air trips per year with age for those making a business trip is much wider than for those making a personal trip.

Table 15 shows the number of respondents by gender for those making business and personal trips, as well as the average number of air trips in the past year.

As might be expected, a higher proportion of those making business trips were male and those travelers reported a somewhat higher average number of air trips in the past year than female respondents making a business trip. Perhaps more surprisingly, although consistent with findings from other air passenger surveys, a higher proportion of those making personal trips were female, although of those making a personal trip, male respondents reported a higher average number of air trips in the past year than female respondents. This most likely reflects the fact that male respondents making a personal trip may have made a larger number of business trips in the past year on average than female respondents making a personal trip.

More details of the analysis of the ASQ survey data are provided in Appendix C.

Table 15. Distribution of air trips per year by gender and trip purpose—ASQ surveys.

Gender	Business Trips			Personal Trips		
	Survey Responses	Percent	Avg. Air Trips in Past 12 mo.	Survey Responses	Percent	Avg. Air Trips in Past 12 mo.
Male	13,305	64.4	14.1	14,007	38.5	5.4
Female	7,360	35.6	10.6	22,348	61.5	4.4
Total	20,665	100	12.1	36,355	100	4.8

Survey of International Air Travelers

SIAT is undertaken annually by the National Travel & Tourism Office (NTTO) (formerly the Office of Travel and Tourism Industries) of the U.S. Department of Commerce. This survey provides a large sample of both outbound U.S. residents and inbound foreign visitors traveling between the United States and overseas countries (i.e., excluding Canada and, until recently, Mexico). The survey collects detailed trip purpose information and the number of air trips to/from the United States by the respondent in the prior 12 months (and until 2012 the prior 5 years), as well as a range of socioeconomic data. The major value of this survey lies in the fact that it has been performed using a consistent survey instrument every year since 1983, with some changes from 2012 on. Therefore, it provides a unique resource to study how international air travel propensity and air traveler characteristics have changed over time.

Individual survey response data for U.S. residents was obtained from the NTTO for the surveys performed in 2005, 2010, and 2015. These data were analyzed as described in detail in Appendix C.

A number of changes were made to the SIAT survey instrument for the 2012 and subsequent surveys. The principal change that affects the analysis presented in this report is that prior to 2012 respondents reported their annual household income by selecting from 11 income ranges, the highest of which was $200,000 or more, whereas from 2012 respondents reported their actual household income. This has two implications for the analysis. The first is that for surveys before 2012 it prevents any analysis of how the number of international air trips varies with income for households with an annual income above $200,000. In the 2015 survey, 18.6% of survey respondents reported an annual household income of $200,000 or more, with 2.4% reporting a household income of $500,000 or more.

The second implication is that the analysis of the 2015 survey data could exclude respondents who reported an annual household income below $10,000, since it was felt that these respondents included an unknown number who misreported their household income (it is unclear how someone with an income under $10,000 could afford to make an international air trip). However, in the survey data prior to 2012 the lowest household income range was under $20,000 so it was not possible to exclude respondents who would have reported an annual household income of less than $10,000 had this been an option. Therefore all respondents were included in the analysis. In the 2015 survey data, about 3% of those reporting a household income reported an income below $10,000, while about 2.4% reported an income between $10,000 and $19,999. Thus is appears that a high proportion of survey respondents reporting a household income below $20,000 may have misreported their income.

The surveys for the 3 years over a 10-year period showed broadly similar patterns in the variation of the average number of international air trips per year with household income for each year as shown in Table 16. The overall average number of international air trips per year declined from 2005 to 2010, then recovered by 2015 to a level somewhat below that in 2005. Although the decline from 2005 to 2010 and the recovery from 2010 to 2015 occurred in all household income ranges, the change from 2005 to 2015 differed between the income ranges, with the average number of air trips generally increasing from 2005 to 2015 for survey respondents from households with incomes below $120,000 per year but decreasing significantly for respondents from households with incomes above $120,000 per year.

Of course, the household incomes reported by survey respondents are expressed in current dollars and the same income ranges were used for each of the surveys prior to 2012 and also used for the 2015 data in Table 16 for consistency. Therefore, if expressed in constant dollars, the income ranges would change over time. Nonetheless, the distribution of survey responses by household income does not appear to have changed significantly between the three surveys.

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Table 16. Average international air trips in past 12 months by U.S. residents by annual household income.

Household Income	2005		2010		2015	
	Percent Responses	Average Annual Trips	Percent Responses	Average Annual Trips	Percent Responses	Average Annual Trips
Under $20,000	3.7	1.73	5.8	1.62	2.2	2.04
$20,000 - $39,999	7.4	1.75	8.3	1.74	8.8	2.06
$40,000 - $59,999	11.4	2.02	11.3	1.92	12.3	2.15
$60,000 - $79,999	12.3	2.21	11.9	2.01	12.7	2.37
$80,000 - $99,999	11.8	2.49	11.5	2.16	10.4	2.48
$100,000 - $119,999	11.6	2.70	11.7	2.35	13.7	2.73
$120,000 - $139,999	8.2	3.24	7.7	2.61	7.6	2.83
$140,000 - $159,999	6.4	3.39	6.0	2.82	8.3	3.17
$160,000 - $179,999	4.3	3.80	4.2	2.95	3.1	3.10
$180,000 - $199,999	3.3	3.85	3.4	3.12	2.3	3.25
$200,000 or more	19.6	4.52	18.1	3.85	18.6	3.95
Total	100	2.90 (*1*)	100	2.45 (*1*)	100	2.67 (*1*)
Valid responses	21,584		22,980		18,274	

Note: (1) Average annual trips include respondents who did not indicate their household income.

The percentage of respondents reporting annual household incomes under $20,000 in the 2015 survey excluded those reporting incomes under $10,000, so it is to be expected that this percentage would be lower than for 2005 and 2010 (and the percentages for other income ranges correspondingly higher, although the effect in each income range would be relatively small). The percentage of survey respondents who reported a household income of $160,000 or more declined from about 27% in 2005 to about 24% in 2015. This is somewhat surprising, given the recent trends in household income distribution in the United States and the increase in household incomes in current dollars that occurred from 2005 to 2015, the 2007 recession notwithstanding.

In contrast, the data from the three surveys for the average number of international air trips per year by the age of the survey respondent shows a clear trend, with an increasing percentage of survey respondents in the age ranges below 35 and age 60 or over, and a corresponding decline in the percentage of survey respondents in the age ranges between 35 and 59, as shown in Table 17.

There was also a clear trend in the trip purpose split over the three surveys, as shown in Table 18. The average number of air trips per year declined for both business and personal purposes from 2005 to 2010 and subsequently increased from 2010 to 2015. However, whereas the average number of air trips by respondents making a business trip in 2015 was lower than in 2005, the average number of air trips by respondents making a personal trip was higher in 2015 than in 2005. The percentage of survey respondents that were making a business trip declined steadily from 2005 to 2015. By 2015, the share of international air trips that were made for business was almost half that in 2005.

Perhaps the most striking finding from the analysis of the SIAT data is that although the average number of international air trips in the past year reported by survey respondents increases with increasing household income, as would be expected, the difference between the lowest income ranges and the highest is quite small. In 2015 the average number of international air trips per year by respondents with a household income of $200,000 or more was less than twice that by respondents with a household income under $20,000. Similarly, although survey respondents aged between 40 and 59 reported a somewhat higher average number of international air trips per year than those under 40 or over 59, the difference between the average number of international air trips per year by respondents in the age range with the lowest average

Table 17. Average international air trips in past 12 months by U.S. residents by age range.

Age Range	2005		2010		2015	
	Percent Responses	Average Annual Trips	Percent Responses	Average Annual Trips	Percent Responses	Average Annual Trips
18 - 24	6.7	1.72	9.7	1.66	12.6	1.99
25 - 29	8.1	2.17	9.6	2.03	11.1	2.31
30 - 34	9.6	2.72	9.2	2.42	9.9	2.60
35 - 39	10.8	3.08	9.2	2.69	8.5	2.88
40 - 44	12.5	3.31	10.8	2.73	9.1	3.10
45 - 49	12.5	3.59	10.8	2.89	9.4	3.06
50 - 54	12.2	3.35	11.0	2.95	10.5	3.16
55 - 59	10.6	3.17	9.6	2.77	8.4	3.08
60 - 64	7.4	2.84	8.6	2.36	7.9	2.73
65 - 69	4.9	2.50	5.9	2.35	6.5	2.39
70 - 74	2.8	2.17	3.3	2.23	3.8	2.33
75 - 79	1.4	2.04	1.4	1.87	1.7	2.17
80 - 84	0.4	1.92	0.7	1.75	0.5	2.09
85+	0.1	2.53	0.2	1.89	0.1	2.61
Total	100	2.90 (*1*)	100	2.45 (*1*)	100	2.67 (*1*)
Valid responses	22,972		12,925		27,508	

Note: (1) Average annual trips include respondents who did not indicate their age range.

air travel propensity (those aged 18 to 24) and those in the age range with the highest propensity (those aged 45 to 49 in 2005 and 50 to 54 in 2010 and 2015) declined from a factor of 2.1 in 2005 to 1.6 in 2015. There is a practical limit on how many international air trips any household is likely to make in a year, irrespective of their household income, and every survey respondent will have made at least one such trip, so the relatively small range of the average number of international air trips with household income or respondent age is perhaps not so surprising.

The overall average number of international air trips per year by survey respondents was about 2.7 in 2015. Although this is a decrease from the value in 2005, it was an increase from the value in 2010. It is not clear whether the increase from 2010 to 2015 represents an ongoing trend that will result in higher values in the future.

Additional analysis of the SIAT data exploring differences in the average number of international air trips per year by gender and race/ethnicity of the survey respondent is documented in Appendix C.

Online Surveys of Air Travelers

Online surveys of air travelers are sometimes undertaken in support of research projects or other studies and can provide a complementary perspective to data collected through intercept

Table 18. Average international air trips in past 12 months by U.S. residents by trip purpose.

Trip Purpose	2005		2010		2015	
	Percent Responses	Average Annual Trips	Percent Responses	Average Annual Trips	Percent Responses	Average Annual Trips
Business	29.9	4.87	23.0	4.18	16.9	4.62
Personal	70.1	2.06	77.0	1.94	83.1	2.27
Total	100	2.90 (*1*)	100	2.45 (*1*)	100	2.67 (*1*)
Valid responses	23,963		26,435		28,016	

Note: (1) Average annual trips include respondents who did not indicate their trip purpose.

surveys of air passengers at airports. Although online surveys of air travelers typically collect information on air trips made by respondents, they are really a form of a household survey in that each respondent usually represents one household (or one individual within a household) and the probability of a respondent participating in the survey does not vary with the number of annual air trips made (although this information may be reported in the survey). In contrast, an intercept survey of air passengers conducted at an airport is essentially a survey of air passenger trips, not of individual travelers. The research has identified three such surveys, one undertaken as part of *ACRP WOD 22: Passenger Value of Time, Benefit Cost Analysis, and Airport Capital Investment Decisions*, and two more recent surveys that were performed in late 2015 and early 2017 for Airlines for America (A4A). A detailed analysis of the data from each of these surveys is presented in Appendix C.

ACRP 03-19 Air Traveler Survey. As part of *ACRP WOD 22* a web-based survey was performed in early 2013 of individuals who had made a paid domestic air trip in the prior 6 months. The survey respondents were recruited from a commercial firm that maintains panels of individuals willing to participate in online surveys and provided details about their most recent trip, including the trip purpose and air party size, as well as the number of air trips they had made in the previous 12 months for business and non-business (personal) purposes. The survey also collected information on various socioeconomic characteristics of the respondents, including personal and household income, gender, age, and household composition.

The distribution of the O&D of the most recent domestic air trip reported by survey respondents was compared to the overall pattern of domestic O&D travel and found to be reasonably representative of domestic air travel in general (Resource Systems Group, Inc. 2015). Although the sample size of the survey was fairly small (1,171 respondents) the respondents were distributed throughout the United States. Thus, the survey provides a more representative sample of national air passengers compared to surveys conducted at specific airports. Although the survey respondents were on average older and with higher incomes than the general U.S. population, this may partly reflect the air traveler population, which other surveys have shown to be older and have a higher average income than the population in general. The proportion of the survey respondents who were female (55%) was somewhat higher than the population in general. The extent to which this reflects the domestic air traveler population is unclear. Although many airport air passenger surveys collect data on the respondent gender, they typically only obtain one response from each air party and thus only report the gender of the person completing the survey or answering the survey questions on behalf of the party. In the case of a family or couple traveling together, it is possible that a male member of the party would be more likely to respond to the survey. Also, the comparison is complicated by the fact that men make more air trips per year on average than women, which would reduce the percentage of female respondents in airport air passenger surveys.

A detailed analysis of the gender, age, household income, and household composition profile of the survey respondents compared to the U.S. population is presented in Appendix C.

The purpose of the most recent air trip taken by survey respondents is shown in Table 19 with the six reported purposes reclassified into business and personal trips.

Overall, 26% of the trips were taken for business purposes, of which a little less than a third (8% of all trips) were to attend a conference or similar event. Personal trips were fairly evenly split between vacations and visiting friends or relatives. However, this could be influenced by the time of year when the survey was performed. Air trips taken in the previous six months would have included visits to family at Thanksgiving or Christmas, but would not have included any trips taken the previous summer. The low percentage of trips to attend college or school (less than 1%) reflects the age profile of the survey respondents, with only 4% in the age range from 18 to 24.

Table 19. Purpose of most recent trip taken by ACRP 03-19 survey respondents.

Trip Purpose	Total		Male		Female	
	Responses	Percent	Responses	Percent	Responses	Percent
Business	206	17.6	139	26.1	67	10.5
Attend conference	91	7.8	43	8.1	48	7.5
Vacation	386	33.0	160	30.0	226	35.4
Visit friends/relatives	391	33.4	144	27.0	247	38.7
Attend school/college	9	0.8	3	0.6	6	0.9
Other	88	7.5	44	8.3	44	6.9
Total	1,171	100	533	100	638	100
Business	305	26.0	187	35.1	118	18.5
Personal	866	74.0	346	64.9	520	81.5
Total	1,171	100	533	100	638	100

The proportions of trips by different purposes are significantly different for male and female respondents. Only 19% of female respondents made a trip for business purposes, compared to 35% for male respondents, although both male and female respondents made a similar percentage of trips to attend a conference or similar event. Female respondents made slightly more trips to visit friends or relatives than for vacations, whereas the reverse was true for male respondents.

An analysis of the average air party size reported for the most recent air trip was undertaken, as discussed in Appendix C. Although the average air party sizes for business and personal trips given by the analysis were both higher than those typically found in airport air passenger surveys, the discrepancy was larger for business trips. The difference may be due to the higher proportion of older respondents in the survey respondents, particularly male respondents, who may be more likely to take a spouse on a business trip than younger air travelers, who are more likely to be single, or with a working spouse or children.

The average number of trips in the past year reported by survey respondents is shown in Table 20 by household income, gender, and trip purpose, together with the estimated number of air passengers on these trips based on the analysis of average air party size for the most recent

Table 20. Average air trips in past year by ACRP 03-19 survey respondents by household income and gender.

Household Income	Total	Business Trips			Personal Trips		
		Total	Male	Female	Total	Male	Female
Under $10,000	7.2	3.6	4.5	3.0	3.6	3.5	3.6
$10,000 - 19,999	3.4	1.1	3.5	0.6	2.4	2.5	2.1
$20,000 - 29,999	3.4	0.8		0.6	2.6		2.8
$30,000 - 39,999	4.1	1.6	4.0	0.7	2.5	2.3	2.6
$40,000 - 49,999	4.5	1.7	2.7	1.4	2.7	3.4	2.4
$50,000 - 74,999	4.5	1.7	2.4	1.2	2.8	2.7	2.9
$75,000 - 99,999	5.8	2.7	3.7	1.9	3.1	2.9	3.2
$100,000 - 149,999	6.1	3.0	3.9	1.9	3.2	3.0	3.3
$150,000 - 199,999	7.5	4.1	5.4	2.2	3.4	3.4	3.3
$200,000 - 249,999	8.5	4.5	5.4	3.3	4.1	3.3	5.0
$250,000 or more	10.2	5.7	8.1	2.9	4.5	4.5	4.4
Total	6.0	2.9	4.2	1.7	3.2	3.1	3.2
Average air party size	1.79	1.55	1.48	1.70	2.01	2.02	2.00
Air passengers	12,609	5,201	3,312	1,889	7,408	3,354	4,054
Percent business	41.3%						

trip. It was assumed that the average air party sizes for business and personal trips by male and female survey respondents in the past year were the same as reported for the most recent trip. On this basis, for the trips in the past year reported by the survey respondents the number of air passengers making a business air trip accounted for 41% of all air passengers trips. This percentage is considerably higher than the percentage typically found in air passenger surveys at airports, which may be partly due to the average air party size assumptions for business trips.

The average air trips in the past year generally increase with increasing household income, as would be expected, and are generally larger for personal trips than for business trips. The percentages for both business and personal trips by males with household incomes between $10,000 and $30,000 have been combined due to the small number of male respondents with incomes in this range. Even so, the number of male survey respondents with household incomes below $50,000 and the number of female respondents with household incomes below $30,000 are both fairly small, so the average annual trips for respondents in these income ranges could be distorted by a few respondents who made an atypically large number of trips.

As has been found with other surveys, the average number of reported air trips by survey respondents in the lowest income range (under $10,000) is surprisingly large, and higher than the values found for most income ranges below $200,000 and all income ranges below $150,000 (in the case of personal trips by male respondents all income ranges below $250,000).

The average number of business trips by female respondents is significantly lower than for male respondents, particularly for female respondents with household incomes between $10,000 and $40,000. However there appears to be no systematic difference in the average number of personal trips between male and female respondents. The difference for business trips does not appear to reflect differences in the proportion of female respondents who were employed. In fact almost the same proportion of male and female survey respondents (52%) reported that they were employed full-time or self-employed, so the difference is more likely to reflect the different types of employment. Female respondents who reported that they were self-employed made almost as many business trips on average (5.1 per year) as self-employed male respondents (5.3 per year), while female respondents who were employed full-time made only 2.1 business trips per year on average compared to 6.9 for male respondents employed full–time.

Analysis of the response data from the ACRP 03-19 survey suggests that the survey respondents are neither fully representative of the U.S. population nor of air travelers in general. However, given these limitations, the survey response data do provide several useful findings. The first relates the average number of air trips per year to various household characteristics, including household income and age and gender of the respondent. In particular, female respondents made fewer air trips per year for business than male respondents, although there appears to be little difference between male and female respondents in terms of the number of personal air trips per year that they make. As expected, the average number of air trips per year increased with household income, although the increase was not proportional to income. The second useful contribution of the survey is that survey respondents reported the number of business and personal air trips they had made in the past year. This allows some analysis of air travel propensity by trip purpose. Although the average number of both business trips and personal air trips per year increased with income, the average number of business trips increased much faster than personal trips.

A4A Air Travel Survey. A4A has commissioned two recent online surveys of the U.S. adult population (age 18 or over and resident in the continental U.S., Alaska, and Hawaii) that were performed by the polling firm Ipsos Public Affairs. The first survey was performed from December 14 to 22, 2015, and collected data from 3,019 adults. The second survey was performed from January 6 to 13, 2017, and collected data from 5,047 adults. The survey respondents were drawn from an Ipsos panel, supplemented with panels from partner organizations, and other sources. The sample was selected to reflect the demographics of the U.S. population based on the U.S. Census American Community Survey and post hoc weights were applied to reflect population characteristics on gender, age, region, race/ethnicity, and income.

The surveys addressed a wide range of air travel issues, but collected data on the demographic and socioeconomic characteristics of the respondents, as well as the number of air trips that the respondents had made in the previous year and (for those respondents who had not flown in the previous year) whether they had ever flown on a commercial flight. For the 2015 survey, respondents were asked how many round trips by airline they had already made in 2015 or planned to make in the remaining weeks of 2015. For the 2017 survey, respondents were asked how many round trips by airline they had made in 2016. In both cases respondents were asked to give separate totals for trips that were primarily for business purposes, primarily for personal leisure, and primarily for personal non-leisure purposes (such as traveling to/from college, family event, job interview, or medical reasons). Respondents were also asked how many of their total trips combined business and personal purposes.

Detailed survey response data were not made available. However, A4A staff has shared aggregate results (Heimlich 2016; Heimlich and Jackson 2017) and topline statistics for each question have been published on the Ipsos website (ipsos-na.com/news-polls/pressrelease.aspx?id=7208 and id=7585).

The surveys found that 19% of 2015 respondents and 11% of 2017 respondents indicated that they had never flown on an airline. The percentage of 2015 respondents who had never flown on an airline was similar to the percentage found in a previous survey in 1997 performed by the Gallup Organization for the Air Transport Association (the former name of A4A). The percentage of 2015 respondents who had never flown on an airline seems too high, both relative to the 1997 percentage as well as the much lower percentage a year later. Of those respondents who indicated that they had flown before, 55% of 2015 respondents indicated that they had made no air trips that year, while 51% of 2017 respondents indicated that they had made no air trips in 2016.

The distribution of the number of air trips taken by survey respondents who made at least one air trip in each year is shown in Table 21 together with the percentage of air trips for each trip purpose and the average number of trips per respondent who had made an air trip during the year.

The decline in the percentage of survey respondents who indicated that they made nine or more air trips in the past year from 2015 to 2016 explains the drop in the total average trips per respondent from 4.8 to 4.5. Given the larger sample size in the 2017 survey and the fact that the overall level of air travel increased by about 3.5% from 2015 to 2016, based on U.S. Department of Transportation data, it seems likely that the difference is more an artifact of the sampling than an actual trend and that the 2016 data are probably more accurate.

More detailed analysis of the survey findings that examined differences in the average number of reported air trips per year with respondent race/ethnicity, age, annual household income, and highest level of educational attainment is presented in Appendix C. Differences in the average number of air trips in the past year by respondent race/ethnicity and age is shown in Table 22. The larger sample size of the 2017 survey (2016 air trips) probably makes those results somewhat more reliable.

The survey findings show considerable variation in the average number of air trip per year across respondents of each race/ethnicity, with Asian respondents reporting an average number of air trips per year over three times the average trip rate reported by black respondents and over one and a half times the average trip rate reported by white respondents. The age group with the

Table 21. Distribution of air trips per year by A4A survey respondents who made air trips in each year.

Air Trips	2015	2016
1	31%	27%
2	20%	20%
3	10%	13%
4	9%	13%
5	5%	5%
6	6%	6%
7	2%	3%
8	2%	2%
9 or more	15%	11%
	100%	100%
Trip Purpose		
Business	31%	31%
Personal Leisure	48%	51%
Personal Other	21%	18%
	100%	100%
Average Trips		
Business	1.5	1.4
Personal Leisure	2.3	2.3
Personal Other	1.0	0.8
Total	4.8	4.5

highest average number of air trips, those age 25 to 44, reported an average trip rate three times that reported by respondents age 65 and over.

The A4A surveys provides a useful complement to the other air passenger surveys discussed earlier and to the household travel surveys discussed in the next section, since they are surveys of all American adults, whether or not they made an air trip in the past year. The survey results thus allow a comparison between air travelers (those who made at least one air trip in the past year) and the larger population. The surveys also collected data on the race/ethnicity and educational attainment of the respondents, characteristics that are not typically available from air passenger surveys (although sometimes available from other surveys, such as the CES). However,

Table 22. Average air trips per year by all A4A survey respondents by race/ethnicity and age.

Air Trips	2015	2016
Race/Ethnicity		
White	2.0	2.2
Black	1.4	1.1
Hispanic	3.4	2.6
Asian	3.2	3.4
Other	1.0	1.1
Total	2.1	2.2
Age		
18-24	2.1	1.3
25-44	3.2	3.3
45-64	1.6	1.5
65+	1.1	1.1
Total	2.1	2.2

some of the distributions of respondent characteristics reported in presentations by A4A staff suggest that the survey may have undersampled some population segments or the weighting of the survey data may have distorted the results.

Summary and Conclusions

The analysis of air passenger surveys has shown that air travel propensity, expressed as the average number of air trip per year, varies widely with a broad range of respondent socioeconomic characteristics, including household income, age, race/ethnicity, and educational attainment. It can be expected that changes in the distribution of any of these characteristics across the population will have an effect on air travel demand. It also follows that the common practice in air passenger demand models of using aggregate or average measures of household income will fail to reflect the effect of changes in the distribution of household incomes as a percentage of the average income level.

Although household income shows the widest range of air travel propensity, with survey respondents from households with incomes over $200,000 in 2015 dollars reporting making an average of over three times as many air trips per year as respondents from households with incomes under $25,000 in 2015 dollars, there is also a significant range in air travel propensity for different age ranges and race/ethnicity categories. Survey respondents to recent surveys aged between 45 and 54 generally reported an air travel propensity of about twice as many air trips per year as those aged between 18 and 24 and somewhat under twice as many as those 65 and over. Fewer air passenger surveys have collected data on respondent race/ethnicity, but recent surveys by A4A have found that Asian and Hispanic respondents reported an average number of air trips per year about one and a half times that reported by white respondents and about three times that reported by black respondents.

However, it is quite likely that at least part of the differences in air travel propensity by factors such as age, race/ethnicity, and educational attainment reflect differences in household income. The analysis undertaken in the course of the project has not attempted to separate these effects but this forms an important topic for future research.

Another important dimension of disaggregated measures of air travel propensity is air trip purpose. Survey results show that the distribution of the average number of business air trips per year with various socioeconomic factors is significantly different from the corresponding distributions for personal air trips. Since the relative proportions of business and personal air travel can be expected to vary in different markets, and may well change at different rates over time, developing separate air passenger demand relationships for different trip purposes is likely to lead to more robust air passenger demand models.

Household Travel Surveys

Household travel surveys can provide an alternative perspective on air travel to that provided by intercept surveys of air travelers undertaken at airports or through online surveys of air travelers. These surveys commonly take the form of an interview survey that asks household members to report the details of their travel on a particular day or days as well as the household socioeconomic characteristics. Since most respondents will not have taken a long-distance trip on the particular day they were asked to report, some household travel surveys include a long distance travel component that asks respondents to provide details of long-distance travel undertaken within a longer recent recall period. However, the definition of a long-distance trip and the length of the recall period typically vary between different surveys.

One valuable feature of most household travel surveys that address long-distance trips is that they typically include long-distance trips by all modes, not just air trips. While air trips are the primary focus of the current research, analysis of household travel surveys can contribute to a better understanding of how mode choice decisions in making long-distance trips affect the demand for air travel.

The research team examined four such household travel surveys, two national surveys and two statewide surveys. The following is a summary of the findings from the analysis of the data from these surveys; more detail is presented in Appendix C.

National Household Travel Survey

The 2001–2002 National Household Travel Survey (NHTS) collected data on all trips over 50 miles made by members of responding households during a four-week recall period. Obviously many households would not have made any air trips in a given four-week period and for those that did there is no information on how many air trips they made in the previous year. However, the relationship between household characteristics and the average number of air trips and long-distance trips by other modes made during the four-week recall period can give an indication how air travel propensity and long-distance travel mode split vary with household characteristics.

An analysis of data from the 2001/2002 NHTS is described in more detail in Appendix C. This analysis examined the increase in the number of air trips per year with household income based on the long-distance trips reported by survey respondents. The results of this analysis indicate that in 2001 U.S. households made approximately 191 million air trips, of which about 79% were made by households with incomes of $50,000 or more. These data allow a comparison of the increase in air travel propensity with income based on the survey responses. For respondents in all income ranges the data imply an average of about 1.75 air trips per household, with a 10-fold difference between households with incomes below $25,000 and households with incomes of $50,000 or more.

As discussed in more detail in Appendix C, this overall air travel propensity is well below the values found in more recent surveys, such as the Michigan Travel Counts Survey discussed below. Furthermore, the difference in average air trips per household between the three household income ranges is much wider than found in other surveys. Until these differences are resolved it would appear that the NHTS data on air trips are not only quite dated but should be regarded with considerable caution.

Omnibus Household Travel Survey

The U.S. Department of Transportation Bureau of Transportation Statistics (BTS) undertook a monthly or bi-monthly Omnibus Household Survey of approximately 1,000 randomly selected households from August 2000 to October 2003, with an additional survey in October 2009. The survey included information on air travel as well as respondent and household socioeconomic characteristics and thus provides additional information on air travel to that given by the 2001–2002 NHTS, which was undertaken at approximately the same time. However, unlike the NHTS, the Omnibus Household Travel Survey not only asked about air travel in the previous month, but the surveys from February 2002 asked how long ago the respondents made a commercial flight. This allows some analysis of how air travel in the previous month is related to annual air travel propensity.

Although each survey only included about 1,000 respondents, over the period from August 2000 to October 2003 surveys were performed in 29 months, giving a total of 29,705 responses, allowing fairly detailed analysis of subsets of the survey responses, including seasonal and regional differences. The survey questions relevant to air travel and the socioeconomics of the survey respondents evolved somewhat over the course of the survey period. The first survey, in

August 2000, only asked about the number of days on which a respondent flew in the previous 30 days, without distinguishing between commercial flights and general aviation flights. However, subsequent surveys had separate questions for commercial and general aviation flights. Prior to July 2001, the questions asked about air travel in the previous 30 days. From July 2001, subsequent surveys asked about air travel in the previous month. While the distinction is fairly minor, in calculating air travel propensity some adjustment needs to be made for months with fewer or more days. Also from July 2001, the survey asked how many days in the previous month the respondent made an air trip for business or work.

An analysis of responses to the survey for the one-year period from August 2001 to July 2002 was initially performed. Survey data was collected for 11 months of this period, excluding September 2001, when air travel was disrupted by the terrorist attacks of September 11. During this period survey responses were obtained from 11,325 households, of which 1,293 (11%) reported making at least one air trip on a commercial flight during the previous month. Those survey respondents who reported taking one or more commercial flights during the previous month took flights on an average of 2.64 days in the month. Additional survey data were then analyzed for 9 months from August 2002 to October 2003. During this 15-month period, survey responses were received from 9,502 households, of which 1,070 (11%) reported taking one or more commercial flights during the previous month. Those survey respondents took commercial flights on an average of 2.76 days in the month, a slightly higher use of air travel than reported in the survey for the period from August 2001 to July 2002, which seems reasonable given that the earlier period included the immediate aftermath of the terrorist attacks of September 11, 2001. The results of these analyses are shown in Table 23.

Table 23. Use of commercial air travel in previous month by omnibus travel survey respondents by annual household income.

Household Income	Used Commercial Air Travel	Average Days Used Commercial Air Travel	Percent Made Business Air Trips	Average Days Used Air Travel on Business	Percent of Air Travel Days Making Business Trips
August 2001 to July 2002					
Under $15,000	2.2%	2.14	13.6	1.67	10.6
$15,000 - $29,999	5.0%	2.08	23.6	2.86	32.4
$30,000 - $49,999	6.7%	2.42	35.4	3.12	45.6
$50,000 - $74,999	12.1%	2.36	32.0	2.99	40.6
$75,000 - $99,999	18.5%	2.64	45.1	3.15	53.9
$100,000 or more	31.9%	3.19	56.3	3.73	65.7
Total	11.4% *(1)*	2.64 *(1)*	47.6 *(1)*	3.32	59.2
Valid responses *(2)*	9,717				
Total responses	11,323				
August 2002 to October 2003					
Under $15,000	2.5%	3.10	23.8	2.00	15.4
$15,000 - $29,999	4.3%	2.25	17.5	2.36	18.3
$30,000 - $49,999	7.3%	2.32	22.1	2.88	27.5
$50,000 - $74,999	12.1%	2.70	40.8	2.95	44.6
$75,000 - $99,999	17.3%	2.91	45.2	3.59	55.8
$100,000 or more	31.0%	3.09	49.4	3.59	57.4
Total	11.3% *(1)*	2.76 *(1)*	45.6 *(1)*	3.30	53.9
Valid responses *(2)*	7,959				
Total responses	9,499				

Notes: (1) Includes respondents who did not indicate their household income.

(2) Valid survey responses gave both household income and number of days on which they used commercial air travel in previous month (including none).

Further details of the analysis of these survey responses are presented in Appendix C. The most striking findings of the analysis of the survey results for both periods is that although the percentage of survey respondents who reported taking one or more commercial flights in the previous month increased strongly with income, with only about 2% to 3% of survey respondents with a household income under $15,000 taking at least one flight but over 30% of survey respondents with a household income of $100,000 or more taking at least one flight. The average number of days during the previous month when those who reported taking at least one flight used commercial air travel (which is a surrogate measure for the number of air trips taken) did not vary very much by household income, increasing slightly with income from a little over 2 days for survey respondents with household incomes between $15,000 and $30,000 to a little over 3 days for survey respondents with household incomes of $100,000 or more. This is perhaps not all that surprising, since even people who make many air trips per year may only make one or two in a given month.

In addition to household income, the survey collected data on the respondent age, gender, ethnic group, and education level, as well as the number of household members age 18 or over. These data could be further analyzed to explore how the use of commercial air travel reported in the survey varied with these socioeconomic characteristics, although this was not done as part of the current project.

State Household Travel Surveys

The research team identified three recent statewide household travel surveys that included a long-distance travel component, although the survey for Utah had a much smaller sample size than the other two surveys as well as other limitations. Therefore it was decided to limit the analysis of statewide household travel surveys to the surveys for California and Michigan. Survey response data were obtained for the 2012–2013 California Household Travel Survey and the corresponding data for the long-distance component of the 2015 Michigan Travel Counts survey were provided by the staff at the Michigan Department of Transportation.

California Household Travel Survey. The California Department of Transportation (Caltrans) undertakes the statewide California Household Travel Survey (CHTS) every 10 years (Caltrans 2016). The most recent survey was undertaken from January 2012 following a pre-test in late fall 2011, and ending on January 31, 2013. The survey obtained complete travel data from 42,431 households (NuStats 2013). Travel data were collected from households in all 58 California counties as well as parts of three adjacent Nevada counties. Data was collected by a combination of computer assisted telephone interviewing (CATI), an online survey, and three types of global positioning system (GPS) devices. All participating households were asked to record their travel for a pre-assigned 24-hour period and complete a long-distance travel log covering trips by household members to a location 50 miles or more away in the 8 weeks prior to the assigned travel day.

An initial recruitment survey collected an extensive range of information about each household that agreed to participate in the survey, including the following:

- Household size
- Total household income for the past year
- Name, age, gender, and race of each household member
- Relationship among household members
- Country of birth of each household member and year moved to United States if not born in the United States
- Employment status of each household member, together with details of employment
- Student status and highest education level of each household member

The long-distance travel log provided space for recording up to eight long-distance trips of 50 or more miles made by any household member during the 8 weeks preceding the travel diary day, starting with the most recent trip. Thus if the household members made more than eight such trips, only the most recent eight trips could be recorded on the long-distance travel log that was provided. The information requested for each trip comprised:

- The date of departure
- The place name and address where the trip started
- The place name and address of the final destination
- The main purpose of the trip (using trip purpose codes provided)
- The number of people traveling with the respondent
- The number of household members traveling with the respondent and which ones
- The method of travel that was used for the longest distance (using codes provided for each mode of travel)

Respondents were instructed to treat each direction as a separate trip. This effectively limited the long-distance travel log that was provided to a maximum of four round trips. Since it covered all trips of 50 miles or more, it is quite likely that many households made far more long-distance trips than this during an 8-week period. Respondents who made more than eight long-distance trips during the 8-week period were instructed to record the details of the additional trips on a separate sheet of paper. An additional problem with the long-distance travel log is the wording of the instructions for entering the number of people traveling together. This refers to the number of people traveling with "you" (the person completing the log), i.e., excluding the respondent. However, this implies that the respondent was traveling on all the trips, which may not have been the case.

The long-distance travel file contained records for 68,193 trip legs reported by 18,012 households, four of which did not report their household characteristics. Some records were missing data on the mode used or the number of people on the trip. These trip leg records were dropped from the analysis, which resulted in 67,125 trip legs reported by 17,736 households. The number of reported trips dropped off sharply above eight trip legs, suggesting that many households did not attempt to record more than eight trip legs. Although no household should report only one long-distance trip leg, since any round trip has to involve at least two legs, some 20% of households did so. This suggests that many households may have only reported one direction of a round trip, which is borne out by an examination of the trip data.

The largest number of reported trip legs by a given household in the long-distance travel file was 50, by 10 different households. Although this is a very small fraction of the total households reporting long-distance trips (less than 0.1%) only one or two households in each case reported a number of trip legs between 41 and 49, suggesting that the number of reported trip legs recorded in the retrieval survey may have been limited to 50.

These trip legs were then classified as outbound, intermediate, or return legs, based on the O&D zip code of each leg, where an intermediate leg was one that neither began not ended at the respondents home. This allowed the number of outbound legs of round trips to be counted, which gave a total of 38,115 outbound legs by 17,480 households. The lower number of households than those reporting long-distance trips was because a few households did not report any outbound trips. This could have resulted from the outbound leg of a trip taking place before the 8-week recall period, but more likely was because the respondents failed to report the outbound leg.

Households reporting making long-distance trips during the recall period comprised 42% of all households participating in the survey. Of those households that reported making outbound long-distance trips during the recall period, 49% reported only making one such outbound trip.

Because some respondents reported air trips beginning or ending at an airport rather than their home zip code, those trip legs were classified as outbound or return legs if the airport in questions was within 150 miles of the home zip code. Examination of the data showed that a small number of reported air trips were made by general aviation, military flights, or were not in fact air trips and these were excluded from valid airline trips.

Trips involving valid airline travel were reported by 3,666 households, or 20.4% of all households reporting long-distance trips and 8.6% of the 42,436 households participating in the survey. Nineteen households did not report the air travel party size for all their airline trip legs and these households were excluded from the analysis, since it is not clear how many air passenger trips those households made. The 3,647 households that reported the air travel party size for all their airline trips reported 5,117 air trips, or an average of about 1.40 air trips per household. The great majority of these households (about 70%) only made one air trip in the 8-week recall period. The largest number of air trips reported by a household was nine. Less than 10% of households reporting making air trips made more than two air trips and less than 5% made more than three air trips.

The distribution of the number of households that reported making long-distance trips during the 8-week recall period and the number that reported making air trips during this period by household income is shown in Table 24. About 8% of households that reported making long-distance trips and 10% of households that reported making air trips did not report their household income. Table 24 also shows the average number of air trips reported by households in each income category that reported making air trips.

As expected, it can be seen from Table 24 that a larger proportion of households that reported making air trips are in the higher income categories. The average number of air trips reported per household generally increases with household income, as expected, except for the lowest income category below $10,000. However, this income category had a fairly small number of households that reported making air trips. It is also consistent with the findings of air passenger surveys performed at airports that respondents in the lowest income category often report a higher rate of making air trips than those in the next income categories above them.

Although the average air trips per household shows an increase with increasing household income, the difference between households with annual incomes below $50,000 and those with annual incomes above $250,000 is not particularly large. However, these averages should be treated with some caution, since they only reflect air trips made over an 8-week period, so the

Table 24. Long-distance trips reported by California household travel survey respondents by household income.

Household Income	All Long-Distance Trips		Air Trips		Avg Air Trips per Household *(1)*
	Households	Percent	Households	Percent	
Up to $9,999	348	2.1	31	0.9	0.17
$10,000 - $24,999	1,173	7.1	96	2.9	0.17
$25,000 - $34,999	1,079	6.5	123	3.7	0.33
$35,000 - $49,999	1,688	10.2	214	6.5	0.49
$50,000 - $74,999	3,025	18.2	446	13.5	0.71
$75,000 - $99,999	2,905	17.5	523	15.8	1.09
$100,000 - $149,999	3,466	20.9	799	24.1	1.67
$150,000 - $199,999	1,488	9.0	458	13.8	2.40
$200,000 - $249,999	682	4.1	263	7.9	3.37
$250,000 or more	750	4.5	361	10.9	5.17
	16,604	100	3,314	100	1.13
Total *(2)*	18,012		3,666		1.15

Note: (1) Air passenger trips per year.
(2) Includes respondents who did not indicate their household income.

likelihood of the members of any given household making more than one air trip in this period is quite small, even if the household makes several air trips per year. This is reflected both in the high percentage of households (70%) that reported making air trips that reported only one such trip and the high percentage of households (80%) that reported making long-distance trips in the 8-week period that did not report making any air trips at all.

Although the survey provides a direct measure of the number of air trips reported for the 8-week period prior to the assigned travel day, in order to estimate the average number of annual air trips made by households with given characteristics, it is necessary to convert the number of air trips in an 8-week period to the number in a year. Since the survey was performed over the course of a little over a year from January 2012 to January 2013, the survey responses cover air travel undertaken over the 15-month period from November 2012 to January 2013, although this should not affect the analysis of air travel propensity of households with different characteristics, since each household only reported the number of air trips in an 8-week recall period. Assuming that the number of air trips made in the 8-week recall period is representative of the average rate of air travel over the year for any given subset of households or for the survey respondents in total, the average number of air trips per household given by the survey responses was multiplied by 6.5 (52/8) to give the average number of air trips per year shown in Table 24. The overall average number of annual air passenger trips per household of 1.15 is well below the average number of annual air trips reported by respondents to the air passenger intercept surveys discussed above.

There are several factors that could, at least partially, account for this difference. The first is that it is not known how many of the households that did not report any air trips in the 8-week recall period in fact made no air trips in the previous year. Obviously such households would not show up in an air passenger intercept survey, which would tend to reduce the average number of air trips per household compared to those found in an air passenger survey. The second factor is that air passenger intercept surveys are surveys of air passenger trips, not of households. An air traveler who makes a large number of air trips per year is more likely to be interviewed in an airport intercept survey than an air traveler who only makes one or two air trips per year. This will tend to inflate the average of the reported number of air trips per year. On the other hand, survey respondents are typically reporting the number of air trips that they personally made during the previous year, which will obviously be less than the number of air passenger trips made by their household in total.

We were not able to come up with a definitive explanation for this discrepancy, but this is an important topic for future research in order to better understand these differences in reported air travel propensity between the findings of household travel surveys and airport intercept surveys.

Leaving aside the issue of the actual air travel propensity values, because the CHTS collected a large amount of detailed socioeconomic data about each household that participated in the survey, the survey data can be used to explore relative differences in air travel propensity across different household characteristics. A more detailed analysis of the CHTS data is contained in Appendix C, including an analysis of the differences in air travel propensity by age and race/ethnicity of the survey respondent.

Michigan Travel Counts Survey. Starting in 2004, the Michigan Department of Transportation has undertaken a series of statewide household travel surveys termed MI Travel Counts. The first survey was undertaken in 2004–2005 and updated in 2009. The latest survey was undertaken in 2015, starting in January and continuing throughout the year. Travel data was obtained from 16,276 households across the state. Participating households provided information on household composition and other characteristics and each household member completed a travel log for an assigned day. In addition, each household completed a long-distance travel log that covered all trips over 100 miles made by household members in the 3 months prior to the assigned travel day. Information on household composition and characteristics collected included the age, gender, and employment status of each household member, the vehicles owned by the household members, and the household income.

The long-distance travel log included the following information for each long-distance trip:

- Destination city and state
- Household members traveling on trip
- Dates of departure and return
- Main reason to making the trip
- How the travel party got to the destination and got around at the destination
- The number of times that this trip was made in the previous 3 months

The reason for the trip and means of travel were free-form entry fields on the travel log, although these were coded when the data were reported. If a trip involved multiple destinations, respondents were instructed to report the furthest destination. Of the 16,276 households responding to the survey, 9,961 (61%) reported making long-distance trips. The long-distance travel file contains one record for each long-distance trip reported by survey respondents.

In addition to collecting details in each long-distance trip undertaken in the previous 3 months reported by survey respondents, the survey asked if any of those trips were made multiple times during the 3-month period and if so, how many times. If respondents reported that a particular trip was made multiple times in the previous 3 months, the survey also asked how many times the trip had been made in the previous 12 months.

One potential problem with this approach is that it is unclear whether the same number of household members went on each trip in the case where the same trip was made multiple times. Indeed, it is unclear how the "same" trip was defined. Was a trip considered the same if it was to the same destination, or did other aspects of the trip, such as the main mode used, also have to be the same? Obviously, it does not matter if survey respondents reported multiple trips to the same destination as separate trips, since the information for each of these trips would be included in the long-distance travel file. However, if multiple trips to the same destination were reported as the "same" trip when in fact they involved different numbers of household members or even the use of a different main mode, then the resulting number of air passenger trips could be under- or overestimated.

A second problem with estimating the number of air passenger trips reported by survey respondents results from the fact that survey respondents did not identify which household members went on 23% of all the reported air trips or, in a few cases, how many times a given trip was made in the previous 3 months. The missing travel party size data can be corrected for some analyses by assuming that the average number of household members who went on trips where this was not stated is given by the average number of household members who went on air trips where the travel party size was reported.

Analysis of the survey data on repeated trips suggests that on average survey respondents make somewhat more than four times the number of reported air trips in a 3-month period on an annual basis. The survey respondents reported 738 repeated trips in the previous 3 months and 3,132 repeated trips in the previous 12 months, or about 6% more than four times the number in the previous 3 months.

Taking account of the number of household members traveling on each air trip and the number of times a given trip was repeated in the previous 3-month period, the average number of air passenger trips made in the previous three months and the average number of air trips for each household income range are shown in Table 25.

Table 25. Air passenger trips in previous 3 months reported by Michigan Travel Counts survey respondents by household income.

Household Income	Air Passenger Trips				Air Party Trips		Avg Air
	Households	Percent	Pax Trips	Avg per h/h	Air Trips	Avg per h/h	Party Size
Less than $15,000	14	1.3	24	1.71	19	1.36	1.26
$15,000-$24,999	25	2.3	46	1.84	32	1.28	1.44
$25,000-$34,999	40	3.7	73	1.83	44	1.10	1.66
$35,000-$49,999	68	6.4	153	2.25	79	1.16	1.94
$50,000-$74,999	221	20.7	420	1.90	248	1.12	1.69
$75,000-$99,999	190	17.8	407	2.14	232	1.22	1.75
$100,000-$124,999	205	19.2	434	2.12	252	1.23	1.72
$125,000-$149,999	111	10.4	267	2.41	150	1.35	1.78
$150,000 or more	195	18.2	710	3.64	349	1.79	2.03
Total	1,069	100	2,534	2.40 *(1)*	1,405	1.31 *(1)*	1.83 *(1)*

Note: (1) Average air passenger trips, air trips per household, and average air party size for all households include respondents who did not indicate their household income.

The overall air travel propensity shown in Table 25 is equivalent to 9.6 passenger trips per household on an annual basis, assuming that the numbers of annual trips are four times the numbers reported for the previous 3-month period. This is slightly higher than the weighted average of about 8.7 air trips in the previous 12 months reported in the airport air passenger surveys shown in Table 9. However, it should be noted that the air travel propensity given in Table 25 is the number of air passenger trips per household, while that given in Table 9 is the average number of annual trips reported by each survey respondent. Presumably the survey respondents were reporting the number of trips that they had made personally, not the number made by all members of their household.

The average number of air trips per household shown in Table 25 appears to decline with income for annual household incomes below $35,000 and then generally increase thereafter. However, the increase in the average number of air trips with income is not as great as found in airport air passenger surveys, as shown in Table 9. This most likely reflects the differences between surveys of households and intercept surveys of air passengers discussed earlier. The average air travel party size also tends to increase somewhat with household income, as shown in Table 25. As a result, the average number of air passenger trips per household shows a stronger increase with household income than the number of air party trips and the increase in average air party size largely offsets the drop in the average number of air trips with income below an annual household income of $35,000.

A more detailed analysis of the Michigan Travel Counts data is presented in Appendix C.

Summary and Conclusions

Although the household travel surveys analyzed in the course of the project provide useful information in how air travel propensity varies with household characteristics, limitations in the way that each survey collected data on air trips make it difficult to compare the results with air passenger surveys that ask how many air trips respondents had made in the previous year.

The findings of the Omnibus Travel Survey are particularly interesting because this was a nationwide survey that covered all households, whether or not they had made air trips. Some 11% of all households reported that they had used commercial air travel in the previous month. Of those households that had used commercial air travel in the previous month during the period from August 2002 to October 2003, they had used air travel for an average of about 2.8 days. As could be expected, the use of air travel increased with household income, both in terms of the percentage of households that had used commercial air travel during the previous

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month and the average number of days in which they had used air travel. Also, as could be expected, of those households that had made air trips, the percentage that had made business air trips increased strongly with income, as did the average number of days that those respondents used air travel for business trips. As a result of these two effects, the percentage of the average number of air travel days on which respondents made business trips increased strongly with income, from about 15% for households with incomes under $15,000 to about 57% for households with incomes of $100,000 or more. The average number of air travel days that involved business trips was about 54%. Although this suggests that somewhat over half of air travel was for business, this could be misleading for two reasons. The first is that personal air trips typically have a higher average air party size than business trips, while the second is that a higher proportion of business trips are likely to be same-day trips than personal trips.

The Michigan Travel Counts survey results are broadly consistent with the findings from airport air passenger surveys in terms of the overall average air travel propensity, although the average number of air trips per household reporting air trips in the previous 3 months does not increase with household income as much as typically found in airport air passenger surveys. As noted earlier, this is likely to result from only considering air trips in the previous 3 months.

In order to effectively compare the findings from the various household travel surveys with those from airport air passenger surveys, the use of air travel reported in the household travel surveys needs to be adjusted for the fact that the period reported is much less than a full year. Further research is needed to establish a robust procedure for making these adjustments.

Summary and Implications for Air Passenger Demand Studies

The findings of the analysis of air passenger and household travel surveys described earlier have important implications for air passenger demand studies. Not surprisingly, the survey results show that air travel propensity, expressed as the average number of air trips in the previous year, varies considerably by household socioeconomic characteristics, including income, age of the survey respondent, gender, and race/ethnicity. Naturally, some of the characteristics are correlated, such as household income and age of the head of household (or at least the household member responding to the survey), so some of the differences in air travel propensity with any one of these characteristics may be partly due to correlation with other characteristics. Ideally, it would be desirable to develop a model of air travel propensity that considers all the relevant household characteristics simultaneously.

The survey findings also show, again not surprisingly, that respondents making a business trip tend to have a higher air travel propensity on average than those making a personal trip. Surveys that have asked how many trips respondents have made in the past year by trip purpose clearly show that the average number of air trips for business purposes by those who made at least one business air trip is considerably higher than the average number of personal trips by those who made at least one personal trip (which includes almost all air travelers). However, many surveys only ask how many air trips respondents made in the past year in total (if they ask about previous air travel at all). Even so, because travelers who have made at least one business air trip in the past year make more air trips per year on average than travelers who have only made personal air trips, the average number of total trips per year by travelers making a business trip when they were surveyed is higher than for those making a personal trip.

The analysis of air passenger and household travel survey data also shows that air travel propensity varies with the age of the survey respondent. In the case of multiperson households, it is assumed that the age of the survey respondent is a good proxy for the respondent's spouse or partner, although of course this is not always the case. The situation is a little more complicated in the case of households with more than two adults, since the other adults could be adult children or parents or other relatives of the survey respondent and hence could be significantly younger or older than the survey respondent. Nonetheless, it seems reasonable that air travel propensity would change at different points in a person's life cycle for any given income level. Therefore changes in the age distribution of the population will affect air travel demand, separately for the effects of changes in household income.

Appendix C provides a more detailed discussion of the implications for air passenger demand studies of the findings of the analysis of the different disaggregated socioeconomic data sources summarized in this section. Based on the analysis of air passenger and household travel survey data, the principal household characteristic from the perspective of the influence of these characteristics on air travel propensity is annual household income. The survey results show that although air travel propensity increases progressively with household income, it is not directly proportional to household income (at least as reported by survey respondents). Appendix C presents functional relationships that have been fitted to the data from five airport air passenger surveys for the increase in average annual air trips with household income for respondents making business and personal air trips. These relationships are generally consistent across the five surveys after expressing household incomes in constant dollars to account for the growth in real incomes over the period covered by the surveys, although the relationship for one survey in each case shows a somewhat different pattern from the other four surveys for reasons that are unclear. All five surveys show a decline in the rate of increase of average air trip propensity with increasing income, suggesting that incorporation of disaggregated household income in air passenger demand studies needs to be done in a way that reflects this declining marginal propensity at higher income levels.

These fitted functional relationships for the change in the average number of annual air trips (AAAT) with annual household income (AHI) used an inverse tangent mathematical function:

$$\text{AAAT} = a \times \text{a}\tan\left[\left(\text{AHI} - b\right)/c\right]$$

where a, b, and c are estimated parameters. This function was found to give a good fit to the data while reflecting both a diminishing rate of growth of average annual air trips with increasing income, as shown by the survey data, and a continuously increasing relationship between average annual air trips and income, as required by logic. However, these are purely empirical relationships and not based on any underlying causal explanation, such as a relationship between disposable household income and the percentage of disposable income used for air travel.

The functions for survey respondents making a business trip were significantly higher than for those making a personal trip (approximately twice as high), which seems inherently reasonable. However, it should be noted that these functions are for total annual trips in each case, not for business and personal trips separately.

The varying slope of the air travel propensity functions with household income suggests that simply using an aggregate measure of household income (or similar measure of overall economic activity such as gross regional product) in air travel demand models will fail to fully capture the effect of changes in real income distribution and the associated changes in air travel propensity.

The functional relationships of air travel propensity with household income have two other important implications. The declining slope of the functions with increasing household income means that if real household incomes rise over time, the resulting change in air travel propensity for any given increase in income becomes less. Therefore it can be expected that the relationship between air travel and aggregate household income (or similar measures of overall economic activity) will tend to decline over time as real incomes rise unless offset by reductions in the real cost of air travel. The second implication arises from the significant difference in the average number of annual air trips at any given level of household income by those making a business trip and those making a personal trip. This means that the total amount of air travel at a given airport generated by any particular distribution of annual household incomes in the region served by the airport will depend on the relative proportions of business and personal air trips by the residents of the region, which is likely to vary from region to region, depending on the composition of the local economy.

Given the effect on overall air travel propensity of changes in household income and the age distribution of the population, as well as the potential effect of changes in other household characteristics and the significant impact on overall air travel propensity of the relative proportions of business and personal trips in any given market, it seems unlikely that these complex interactions can be adequately reflected in air travel demand models by including just one or two socioeconomic variables that measure a limited number of dimensions of the underlying distributions. Instead, it may be more effective, and more flexible, to include an estimate of average air travel propensity in the models directly and develop a procedure to calculate the average air travel propensity from the underlying distributions of household income, age of the head of households, and other relevant socioeconomic characteristics, based on relationships estimated from air passenger and household travel surveys. Historical data on the underlying distributions of household income, age of the head of households, and other household characteristics are generally readily available at a national and regional level. Projections for changes in the distributions for future years are also available for some data, or scenarios for future changes in the distributions can be developed from current trends in the distributions and assumptions about potential changes in those trends.

Future Research Needs

It is clear from the analysis undertaken in the current project that existing surveys often do not ask questions that would be helpful to a more comprehensive analysis of air travel propensity. Such limitations include failing to record the gender of the other adult members of the air travel party, only asking about total air trips in the past year by survey respondents, rather than distinguishing between business and personal trips, limiting the ranges of household income, particularly higher incomes, when presenting respondents with ranges of income to select or recording responses using income ranges, and omitting questions about race and ethnicity or household size. One socioeconomic characteristic that is difficult to address in a survey is the sector of the economy in which business travelers are employed. However, this information would be extremely valuable to improve the understanding of how the extent of business air travel differs across different sectors of the economy. Developing appropriate and practical survey questions to collect this information, as well as the necessary analysis techniques to translate survey responses to standard codes, would be a valuable future research activity.

Although there are practical limits on how many questions can be added to an air passenger intercept survey before it becomes too long to expect travelers to answer, there are ways to address this problem through the design of the survey. For example, there could be different versions of the survey questionnaire that address different issues or follow-up questions could be asked depending on the response to given questions. The increasing use of programmable devices to collect survey data makes this fairly straightforward. Guidance on the appropriate design of survey methodology and question wording would be very helpful in ensuring that air passenger surveys generate the necessary data to improve our understanding of air travel propensity and better support future air passenger demand studies.

CHAPTER 4

Case Studies in Modeling Airport Passenger Enplanements Using Disaggregated Socioeconomic Data

This chapter presents quantitative results from econometric models of annual airport passenger enplanements. The analysis compares the results from model specifications that incorporate a specific type of disaggregated socioeconomic data into a set of baseline models of airport passenger demand. These baseline models rely on the sorts of aggregate socioeconomic variables customarily used in airport analyses. The section also presents results from alternative models of air passenger activity that reflect the differences between disaggregated socioeconomic data elements and the aggregate socioeconomic data that these models typically use.

The comparative model analysis uses a case study approach. The case study airports and airport systems are introduced, along with the equation specifications for modeling air passenger activity that are being compared. With this information about the modeling framework in place, we then present the modeling results. For each case study of airport or airport system, both model goodness of fit results, which address how well econometric model estimates fit the observed data on airport passenger enplanements, and the forecasting performance of the models.

A detailed analysis of annual O&D enplanements for the Baltimore-Washington regional airport system is then presented. This analysis explores the effectiveness of more complex models of air passenger demand. The estimated models make use of dummy variables to isolate the influence of unusual events that may have influenced air travel demand and also explore the use of an alternative disaggregated measure for household income from that used in the case study model specifications. This more complex approach was applied to the total regional enplanements for the three-airport Baltimore-Washington system because the analysis of aggregate regional demand is not affected by issues that might influence the modeling of enplanements at a single airport faced with competition from neighboring airports.

Case Study Airport Selection

To examine the potential contribution of disaggregated socioeconomic data to the fit and forecasting accuracy of regression models of airport annual enplanements, a case study analysis of seven individual U.S. airports and one metropolitan airport system was conducted. The case study airports included a range of airport sizes and service types. The roster of case study airports was selected to provide a sample of airports representative of the variety of circumstances and service settings that exist for commercial service airports in the United States. Table 26 shows these seven case study airports and the single regional system together with the airport characteristics that motivated its selection as part of the case study group of airports.

Table 26. Case study airports and airport system and regions served.

Airport	Characteristics	Associated Metropolitan Region
Washington DC–Baltimore Airport System (BWI, DCA, and IAD)	Three large hubs, strong business and federal government market, available air passenger survey data	Baltimore-Washington Combined Statistical Area (CSA)
LAX (Los Angeles International)	Large hub, international gateway, primary airport in multi-airport region, available air passenger survey data, potential use in the new data source case study	Los Angeles-Long Beach-Anaheim Metropolitan Statistical Area (MSA)
PHX (Phoenix Sky Harbor)	Large hub, major vacation market, airline hub, mid-continent location, some air passenger survey data available	Phoenix MSA
TUL (Tulsa International Airport, Tulsa, OK)	Small hub, strong low-cost carrier presence, potential use in the new data source case study, some air passenger survey data available	Tulsa MSA
PVD (T.F. Green Providence)	Small hub, secondary airport in multi-airport region	Providence MSA
EUG (Eugene, Oregon)	Small hub, primarily regional airline service, isolated location	Eugene MSA
MDT (Harrisburg International)	Small hub, presence of nearby major hub	Harrisburg-York-Lebanon CSA
MSO (Missoula International)	Non-hub, mid-continent, isolated location	Missoula MSA

Specifying Simple Models for Airport Enplanements

Regression models of air passenger demand or enplanements typically use historical data on regional economics or demographics as independent variables that underlie the demand for air travel that drives airport passenger enplanements from year to year. Examples of the types of analyses and organizations that make use of models like these are discussed in Chapter 2.

Once estimated, these econometric models can be used with forecasts of the independent variables to create forecasts of future airport passenger enplanements. The accuracy of such forecasts is affected by uncertainty in at least two ways. First, there may be uncertainty about the continued validity of the estimated model that relates changes in the independent variables to annual airport enplanements. Such uncertainty can reflect changes in factors that affect airline decisions to provide service at an airport, or to changes in relevant variables that were not included in the model. Second, the accuracy of the forecasts for the independent variables themselves is uncertain. Forecasts of the model's independent variables that turn out to be inaccurate can result in inaccurate airport activity forecasts even if the parameters estimated from the historical model remain valid over the forecast period.

For the case study analyses, the models were estimated in log linear form. With such a specification, the independent variable coefficients represent elasticities of the airport's annual passenger enplanements with respect to the independent variable in question.

The principal purpose of the case study analysis was to assess the extent to which a simple regression model for an airport's annual passenger enplanements based on aggregate socioeconomic variables (the baseline model) can be improved by using an additional disaggregated socioeconomic variable as well (the alternative model).

For each of the case study airports or airport systems, the analysis was conducted in the following steps:

1. For the MSA served by each of the case study airports, socioeconomic data was collected, using databases from Woods and Poole. Aggregate socioeconomic data variables used for case study modeling include MSA population, employment, total earnings, wage and salary earnings, gross regional product, and average household income. Annual data on Oil Prices were also collected from the Energy Information Administration, and annual case study airport O&D passenger enplanements were collected using the DB1b database from the U.S. DOT. For each case study airport, the correlations between these variables over the years 1990 to 2010 were calculated.
2. For each of the case study airport MSAs, information about the distributions of regional populations by age group and regional households by income is used to create the disaggregated socioeconomic data series, the percentage of regional households with incomes exceeding $100,000.
3. Log linear regressions are run, first for the baseline case using models that rely only on aggregate socioeconomic variables (along with the oil price variable meant to capture the role of an economywide cost factor that affects consumer spending and airline costs) and then for the alternative case in which the disaggregated socioeconomic variable related to household income distributions [the percentage of MSA households with incomes exceeding $100,000 (in 2009 dollars)] is added to the regression specifications. These regressions are estimated using annual data for the years 1990 to 2010.
4. For each of the case study airports, out-of-sample-period forecasts are created using the estimated model parameters for one of the aggregate socioeconomic variables (GRP) and the types of forecasts typically provided for these variables by Woods and Poole. For each of the case study airports, the forecasting performance of the two estimated models over the years 2010 to 2015 is assessed.

For each case study airport, the log linear regression results of Step 3 are those of 13 distinct log-linear regression specifications used to define the baseline regressions and assess the additional explanatory or forecasting power that might be contributed by using the disaggregated household income variable in the alternative regressions along with the baseline aggregate socioeconomic variables.

In the six Baseline Regression Equations, there are two explanatory variables, the annual Oil Price variable and one of the six aggregate socioeconomic variables.

$$\ln(\text{Ann Enp}_t) = \beta_0 + \beta_1 \times \ln(\text{Oil Price}_t) + \beta_2 \times \ln(\text{Aggregate SE Var}_t)$$

Mirroring the baseline regressions there is also a two variable model specification, a Baseline Regression Equation Using the Disaggregated Socioeconomic Variable, in which the aggregate socioeconomic variable is replaced by the disaggregated socioeconomic variable, so the disaggregated variable is used instead of the aggregate one.

$$\ln(\text{Ann Enp}_t) = \beta_0 + \beta_1 \times \ln(\text{Oil Price}_t) + \beta_2 \times \ln(\text{Disagg SE Var}_t)$$

Finally, for each case study airport six Alternative Regression Equations are estimated, in which the disaggregated socioeconomic variable is added as an additional explanatory variable to each of the six baseline equation specifications.

$$\ln(\text{Ann Enp}_t) = \beta_0 + \beta_1 \times \ln(\text{Oil Price}_t) + \beta_2 \times \ln(\text{Aggregate SE Var}_t) + \beta_3 \times \ln(\text{Disagg SE Var}_t)$$

Case Study Model Estimation Results and Model Performance

Results from the case study model regressions using the model specifications outlined earlier are reported in this chapter, following a discussion of variable correlation issues in the socioeconomic data (aggregated and disaggregated). The presence of strong correlation among independent variables has important impacts for model estimation when two or more correlated variables are included as independent regression variables.

Insights into the regression model results for the case study airports can be gained from an analysis of the correlations between the variables used in the estimations of these equations. These correlation results are presented in detail for two of the case study airports, one of them a large hub and the other a small hub airport. These correlation patterns are then presented in less detail for the remaining six case study examples.

Following the discussion of correlation issues, two types of diagnostic results are considered for the case study regressions. First, we report the goodness of fit of the regression models for each of the case study airports. This includes both an overall assessment of model fit, with comparisons across the case study airports, including the statistical significance of the regression coefficient estimates, and also, for each case study airport, a comparison of the model statistics for the baseline regression results with those of the regression equations that include the disaggregated socioeconomic variable, the percentage of households with incomes exceeding $100,000 in the MSA or CSA served by the case study airport. Second, the accuracy of out-of-sample forecasts of annual enplanements is examined for each case study airport.

Correlations Among Case Study Model Variables

Before reporting these modeling results, insights into the regression model results for the case study airports were taken from a preliminary analysis of the correlations among the variables used in the estimations of these equations. These correlation results are presented in detail for two of the case study airports, one of them a large hub and the other a small hub airport. Then, these correlation patterns are presented in less detail for the remaining six case study examples.

We first examine the values taken by the variables used in the regression models over the 1990–2010 sample period for Phoenix, Arizona, which is served by Phoenix Sky Harbor International Airport (PHX), a large hub. Table 27 reports the values taken by the socioeconomic and other variables used in the estimation of annual enplanements at PHX, reported at 5 year intervals between 1990 and 2010. These include both the aggregated socioeconomic variables used in

Table 27. Phoenix socioeconomic trends and O&D enplanements—1990 to 2010.

Variable	1990	1995	2000	2005	2010
Population (,000)	2,249.1	2,744.0	3,273.5	3,774.7	4,209.3
Employment (,000)	1,266.3	1,508.6	1,933.7	2,249.8	2,226.8
Total Earnings (millions)	$45,970.2	$60,514.0	$91,479.6	$110,809.3	$107,593.0
Wages and Salaries (millions)	$35,902.3	$45,496.3	$69,180.9	$81,655.4	$79,057.4
Gross Regional Product (millions)	$74,756.6	$104,205.9	$147,324.2	$180,929.1	$177,019.1
Avg HH Income	$72,399	$77,626	$94,127	$99,809	$94,975
% HH >$100,000 Income	14.7%	17.2%	22.1%	22.0%	20.8%
DB1B O&D Enplanements	2,511,285	4,438,203	5,935,671	6,007,806	5,789,690
Oil Price (Composite Refiner Acquisition Cost)	$40.16	$27.16	$38.86	$60.44	$83.99

the baseline and the case study alternative regression specifications, and the disaggregated socioeconomic variable—the percentage of Phoenix MSA households with annual incomes exceeding $100,000 (in 2009 dollars)—used in the alternative regression specification. This table also shows values in those years for annual O&D enplanements at PHX and for the oil price variable used as an independent regression variable. All dollar values are real values adjusted for inflation, expressed in 2015 dollars.

As can be seen in both Table 27 and Figure 5, while population in the Phoenix MSA has grown steadily throughout the study period, the MSA was negatively affected in the national recession that began in 2007. This is expressed in the declines experienced in employment, earnings (both total earnings and wage and salary earnings), gross regional product, average household income, and the proportion of Phoenix households with incomes exceeding $100,000 (in 2009 dollars).

Figure 5 does not include the indexed series for the real price of oil because the variability of this series is much greater than that of the other variables shown. Figure 6 adds the indexed real oil price series to those depicted in Figure 5 to indicate this difference.

To complete the presentation of the comparative behaviors of the regression data for the PHX case study analysis, Table 28 reports the correlations between the variables in the annual series that are shown in the figures. As seen in the tabulated correlation values, the socioeconomic series (aggregate and disaggregated series) are highly positively correlated, with all displaying a general increasing trend that is reversed somewhat in the latter years of the sample period. (The population variable for Phoenix does not have this falling off in later years.) There is also strong positive correlation between the socioeconomic variables and the series for annual PHX enplanements, and, to a lesser degree, with the oil price variable, which rose and declined dramatically in the later years of the sample period (shown in Figure 6).

These strong positive correlations among the socioeconomic variables have implications for their use in regression models, especially since they are also positively correlated with the annual enplanements series. The strong positive correlation means that each of the socioeconomic variables contains very similar explanatory information with respect to the annual enplanements at PHX that the regression models are meant to explain or represent. In particular, estimating a regression model that uses two or more of these highly correlated socioeconomic variables as independent, or explanatory, variables is likely to result in unusual coefficient estimates while

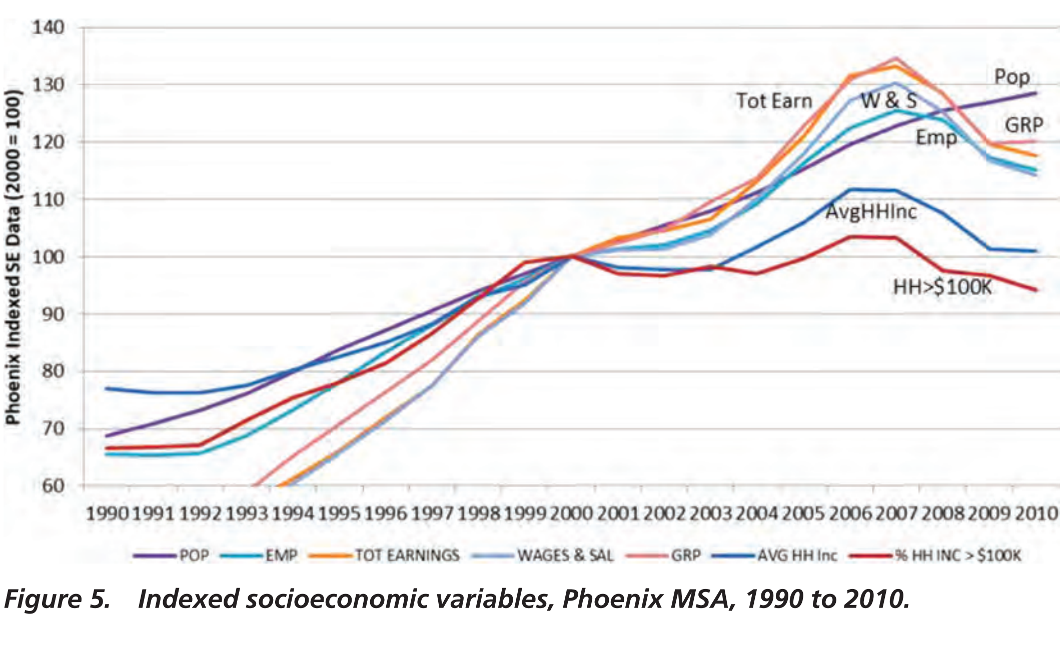

Figure 5. Indexed socioeconomic variables, Phoenix MSA, 1990 to 2010.

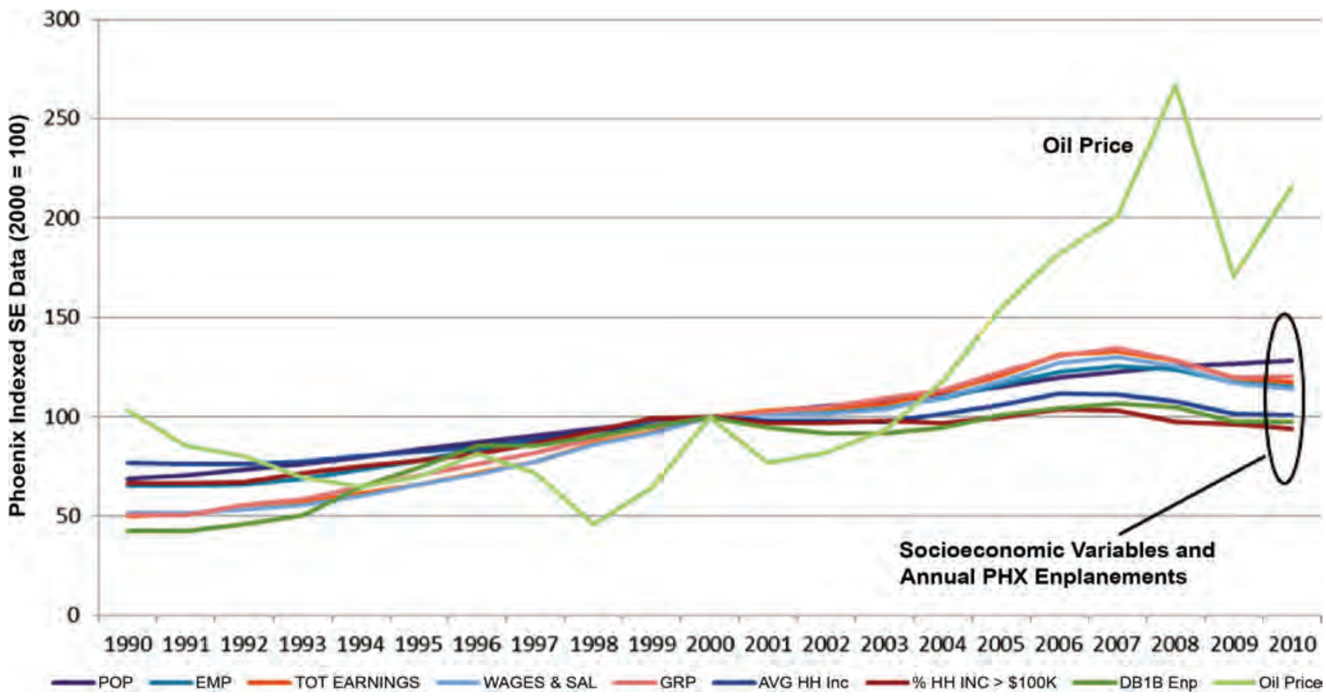

Figure 6. Indexed Phoenix socioeconomic variables with indexed real oil price, 1990 to 2010.

adding very little explanatory power compared to a model estimated with fewer of these independent variables. We will see numerous examples of this in the case study regression model estimates.

As a second example, consider the underlying data for the case study analysis of annual O&D enplanements at Tulsa International Airport (TUL), a small hub airport serving Tulsa, Oklahoma. Table 29 presents the Tulsa MSA socioeconomic data used in the analysis as well as the TUL annual enplanements data at 5 year intervals over the sample period. The Tulsa MSA is smaller than the Phoenix MSA, reporting less than a quarter of the Phoenix population at the beginning of the sample period and growing more slowly than Phoenix over the course of the period.

These comparisons can also be seen in Figure 7, which reports the indexed values of the aggregate socioeconomic variables used in the case study regression analyses for TUL along with the indexed values for TUL annual enplanements and the disaggregated socioeconomic variable

Table 28. Correlations among Phoenix case study model variables 1990 to 2010.

Variable	Population	Emp	Total Earn	Wages & Salaries	GRP	Avg HH Inc	% > $100K	DB1B Enp	Real Oil Price
Population	1								
Employment	0.982	1							
Total Earnings	0.975	0.997	1						
Wages & Salaries	0.973	0.997	1.000	1					
GRP	0.978	0.998	0.998	0.998	1				
Avg HH Inc	0.943	0.987	0.991	0.993	0.988	1			
% > $100K	0.880	0.929	0.933	0.938	0.938	0.952	1		
DB1B Enplanements	0.888	0.925	0.914	0.919	0.927	0.929	0.968	1	
Real Oil Price	0.771	0.740	0.725	0.723	0.717	0.685	0.464	0.504	1

Table 29. Tulsa socioeconomic trends and O&D enplanements 1990 to 2010.

Variable	1990	1995	2000	2005	2010
Population (,000)	505.3	531.1	563.7	568.2	605.1
Employment (,000)	349.3	370.9	425.4	420.1	430.0
Total Earnings (millions)	$14,048.4	$15,129.8	$19,992.1	$23,104.7	$23,262.7
Wages and Salaries (millions)	$10,399.2	$10,757.0	$13,866.1	$14,253.7	$14,935.7
Gross Regional Product (millions)	$21,109.1	$22,791.1	$28,852.4	$32,555.4	$34,424.1
Avg HH Income	$74,275	$77,989	$94,664	$107,035	$109,308
% HH >$100,000 Income	11.4%	12.2%	15.4%	15.3%	15.4%
DB1B O&D Enplanements	1,426,236	1,485,519	1,707,647	1,492,890	1,431,896
Oil Price (Composite Refiner Acquisition Cost)	$40.16	$27.16	$38.86	$60.44	$83.99

used for the analysis, the percentage of Tulsa MSA households with incomes exceeding $100,000 (in 2009 dollars). As in the Phoenix MSA, the population rose steadily throughout the sample period, while other socioeconomic variables experienced growth and then some decline in the aftermath of the 2007 recession. TUL annual enplanements have been volatile while showing no overall growth over the period.

Table 30 reports the correlations among these variables for the Tulsa MSA over the sample period. As with Phoenix, these socioeconomic variables are highly correlated, although these correlations are not as strong between the socioeconomic variables and TUL annual enplanements. Over the sample period there is also a modest negative correlation between annual enplanements at TUL and the oil price series.

The data series used in the case study analysis for the other six case study airports or airport systems show similar patterns of change and correlation over the sample period. These are reported in greater detail in Appendix D but the historical values for the enplanement and socioeconomic variables used in the case study analysis for the other six case study airports are reported in Tables 31 and 32. These socioeconomic and enplanement data are reported in five

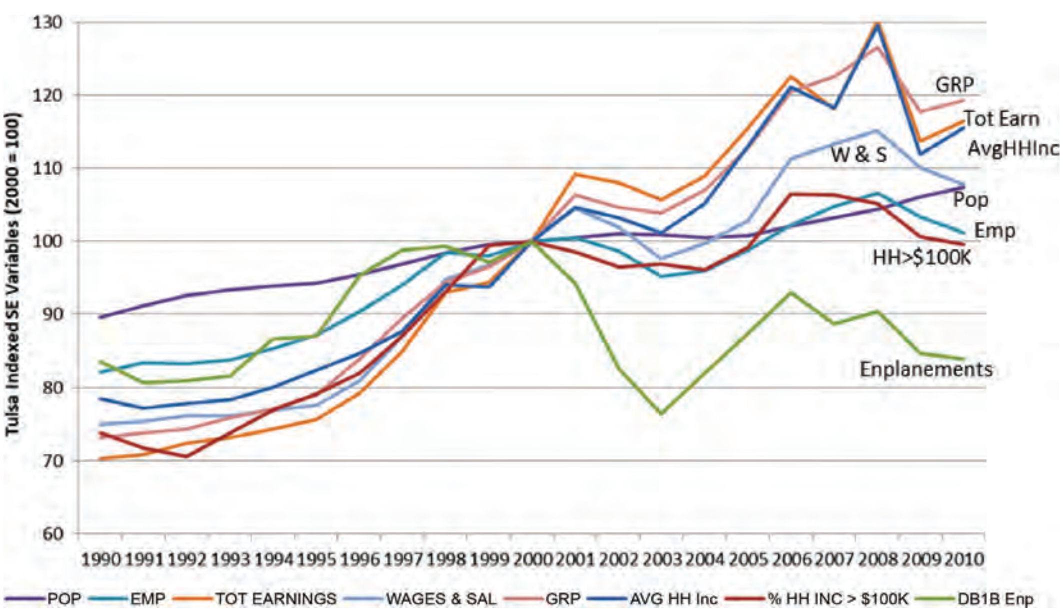

Figure 7. Indexed socioeconomic variables, Tulsa MSA, 1990 to 2010.

Table 30. Correlations among Tulsa case study model variables 1990 to 2010.

Variable	Population	Emp	Total Earn	Wages & Salaries	GRP	Avg HH Inc	% > $100K	DB1B Enp	Real Oil Price
Population	1								
Employment	0.936	1							
Total Earnings	0.932	0.940	1						
Wages & Salaries	0.947	0.975	0.983	1					
GRP	0.954	0.951	0.992	0.988	1				
Avg HH Income	0.916	0.928	0.991	0.972	0.990	1			
% > $100K	0.919	0.976	0.949	0.973	0.951	0.928	1		
DB1B Enplanements	0.141	0.383	0.115	0.208	0.137	0.127	0.330	1	
Real Oil Price	0.687	0.630	0.755	0.714	0.783	0.826	0.605	−0.107	1

Table 31. Other case study airport socioeconomic trends and O&D enplanements—1990 to 2010 (Baltimore-Washington, Eugene, and Harrisburg).

Baltimore-Washington (BWI//DCA//IAD)	1990	1995	2000	2005	2010
Population (,000)	7,089.4	7,525.9	8,014.1	8,573.5	9,088.9
Employment (,000)	4,613.6	4,675.0	5,271.0	5,718.1	5,879.3
Total Earnings (millions)	$206,643.1	$225,701.4	$298,961.0	$359,596.0	$389,567.9
Wages and Salaries (millions)	$160,076.5	$171,242.8	$226,206.6	$264,885.0	$285,829.1
Gross Regional Product (millions)	$314,863.6	$348,991.4	$445,151.1	$549,959.9	$604,278.6
Avg HH Income	$96,246	$100,271	$120,610	$130,421	$138,616
% HH >$100,000 Income	25.4%	27.1%	32.3%	34.0%	35.9%
DB1B O&D Enplanements	12,476,709	14,570,808	20,548,395	23,277,051	22,140,825
Eugene Airport (EUG)	**1990**	**1995**	**2000**	**2005**	**2010**
Population (,000)	284.3	306.7	323.5	335.8	351.9
Employment (,000)	154.5	167.6	186.6	197.1	183.7
Total Earnings (millions)	$5,043.6	$5,901.8	$7,272.4	$7,805.9	$7,285.3
Wages and Salaries (millions)	$3,524.0	$4,058.2	$5,015.4	$5,526.1	$5,179.6
Gross Regional Product (millions)	$7,367.5	$8,963.2	$11,111.7	$12,727.6	$14,170.1
Avg HH Income	$61,422	$68,029	$76,687	$76,991	$76,272
% HH >$100,000 Income	9.1%	10.7%	14.3%	13.2%	12.5%
DB1B O&D Enplanements	231,011	300,909	338,636	283,763	354,543
Harrisburg Airport (MDT)	**1990**	**1995**	**2000**	**2005**	**2010**
Population (,000)	475.9	498.8	509.5	525.8	550.3
Employment (,000)	327.4	353.8	377.2	386.1	383.8
Total Earnings (millions)	$13,033.7	$14,841.4	$17,563.1	$19,565.0	$19,710.8
Wages and Salaries (millions)	$9,649.0	$10,905.9	$12,983.9	$14,074.0	$14,171.7
Gross Regional Product (millions)	$19,524.2	$23,136.0	$26,296.2	$29,819.8	$30,729.5
Avg HH Income	$77,339	$81,163	$90,572	$92,515	$96,073
% HH >$100,000 Income	12.5%	14.1%	18.1%	18.5%	19.2%
DB1B O&D Enplanements	514,185	554,327	629,003	617,432	650,801

Table 32. Other case study airport socioeconomic trends and O&D enplanements—1990 to 2010 (Los Angeles, Missoula, and Providence).

Los Angeles Int'l (LAX)	1990	1995	2000	2005	2010
Population (,000)	11,297.1	11,692.7	12,392.7	12,726.4	12,845.3
Employment (,000)	6,881.7	6,550.1	7,236.8	7,542.9	7,310.5
Total Earnings (millions)	$348,773.9	$339,349.0	$430,361.1	$481,291.6	$457,515.0
Wages and Salaries (millions)	$262,676.1	$241,952.5	$305,626.4	$331,955.8	$322,306.0
Gross Regional Product (millions)	$567,496.6	$549,222.4	$663,513.7	$784,224.7	$781,679.2
Avg HH Income	$105,118	$105,482	$126,253	$136,670	$141,191
% HH >$100,000 Income	25.5%	24.9%	28.2%	27.5%	26.4%
DB1B O&D Enplanements	14,530,215	16,411,458	19,714,223	18,462,728	18,453,834
Missoula Int'l Airport (MSO)	**1990**	**1995**	**2000**	**2005**	**2010**
Population (,000)	79.1	90.4	96.2	102.3	109.4
Employment (,000)	47.6	58.1	66.2	73.4	73.9
Total Earnings (millions)	$1,455.0	$1,833.6	$2,324.4	$2,755.4	$2,761.2
Wages and Salaries (millions)	$1,017.2	$1,245.0	$1,597.1	$1,853.3	$1,943.1
Gross Regional Product (millions)	$2,259.6	$2,821.1	$3,436.7	$4,226.8	$4,390.5
Avg HH Income	$58,650	$64,351	$74,201	$78,042	$76,847
% HH >$100,000 Income	8.4%	9.1%	11.5%	12.9%	13.9%
DB1B O&D Enplanements	130,830	168,200	219,030	230,916	285,537
Providence T.C. Green (PVD)	**1990**	**1995**	**2000**	**2005**	**2010**
Population (,000)	1,513.2	1,535.8	1,586.1	1,613.4	1,602.2
Employment (,000)	786.5	784.8	852.1	878.5	846.2
Total Earnings (millions)	$29,380.0	$30,928.0	$37,851.5	$42,470.1	$42,262.2
Wages and Salaries (millions)	$22,067.2	$22,810.9	$27,961.0	$30,496.2	$29,987.0
Gross Regional Product (millions)	$45,428.6	$48,171.8	$58,077.4	$68,226.1	$67,387.2
Avg HH Income	$75,569	$77,861	$89,608	$95,285	$101,564
% HH >$100,000 Income	15.0%	15.9%	19.6%	21.1%	21.8%
DB1B O&D Enplanements	1,148,711	1,022,280	2,780,558	2,943,633	2,079,410

year intervals over the 1990 to 2010 sample period. All dollar values are inflation adjusted to 2015 dollars. All of the case study regions experienced growing populations and increasing economic activity over the sample period, although all six case study airports experienced a reduction (or slowdown in the rate of growth, in the cases of the Baltimore-Washington airport system and the Missoula International Airport), a reflection of the Great Recession that began in 2007.

Tables 33 and 34 report the correlations among the regression analysis variables for the six other case study airports. As can be seen for each of the six airports, there are very strong positive correlations among all the socioeconomic variables that were selected for use in the case study regression analyses, including the disaggregated socioeconomic variable, the percentage of regional households with incomes exceeding $100,000 (in 2009 dollars). The weakest correlations are those between the real oil price and annual O&D enplanements at each of the case study airports, although these correlations are still positive for each of the six airports.

Table 33. Correlations among other case study region model variables 1990 to 2010 (Baltimore-Washington, Eugene, and Harrisburg).

Baltimore-Washington (BWI//DCA//IAD)	Population	Emp	Total Earnings	Wages & Salaries	GRP	Avg HH Inc	% > $100K	DB1B Enp	Real Oil Price
Population	1								
Employment	0.981	1							
Total Earnings	0.990	0.995	1						
Wages & Salaries	0.988	0.997	1.000	1					
GRP	0.994	0.994	0.999	0.998	1				
Avg HH Income	0.984	0.996	0.995	0.997	0.994	1			
% > $100K	0.973	0.982	0.978	0.982	0.977	0.984	1		
DB1B Enplanements	0.938	0.958	0.951	0.956	0.949	0.961	0.979	1	
Real Oil Price	0.780	0.805	0.787	0.786	0.797	0.804	0.716	0.685	1
Eugene Airport (EUG)	**Population**	**Emp**	**Total Earnings**	**Wages & Salaries**	**GRP**	**Avg HH Inc**	**% > $100K**	**DB1B Enp**	**Real Oil Price**
Population	1								
Employment	0.923	1							
Total Earnings	0.941	0.987	1						
Wages & Salaries	0.949	0.989	0.997	1					
GRP	0.990	0.938	0.944	0.956	1				
Avg HH Income	0.938	0.974	0.984	0.979	0.939	1			
% > $100K	0.801	0.879	0.911	0.888	0.778	0.928	1		
DB1B Enplanements	0.733	0.745	0.713	0.714	0.733	0.807	0.704	1	
Real Oil Price	0.723	0.642	0.612	0.659	0.772	0.580	0.293	0.448	1
Harrisburg Airport (MDT)	**Population**	**Emp**	**Total Earnings**	**Wages & Salaries**	**GRP**	**Avg HH Inc**	**% > $100K**	**DB1B Enp**	**Real Oil Price**
Population	1								
Employment	0.918	1							
Total Earnings	0.936	0.972	1						
Wages & Salaries	0.928	0.981	0.997	1					
GRP	0.956	0.976	0.996	0.994	1				
Avg HH Income	0.939	0.972	0.989	0.994	0.987	1			
% > $100K	0.906	0.974	0.980	0.990	0.977	0.991	1		
DB1B Enplanements	0.427	0.539	0.483	0.518	0.499	0.531	0.546	1	
Real Oil Price	0.792	0.635	0.665	0.642	0.675	0.659	0.596	0.030	1

The strong correlations, or collinearity, between the socioeconomic variables reported for each of the regions served by the case study airports raise the same statistical challenges for modeling approaches that would use more than one socioeconomic variable as explanatory factors. This is because the close similarity in behavior over time by the socioeconomic variables in each region (a similarity expressed in the high positive correlation between the variables) means that adding a second independent socioeconomic variable from these candidate variables adds little or no new information to the regression. The use of two highly correlated explanatory variables leads to statistical estimation problems and difficulties in interpreting model estimates, sometimes referred to as "variance inflation" (Kennedy 1985), described as a consequence of collinearity or "ill-conditioned data" (Belsley, et. al 1980).

Table 34. Correlations among other case study region model variables 1990 to 2010 (Los Angeles, Missoula, and Providence).

Los Angeles Int'l (LAX)	Population	Emp	Total Earnings	Wages & Salaries	GRP	Avg HH Inc	% > $100K	DB1B Enp	Real Oil Price
Population	1								
Employment	0.880	1							
Total Earnings	0.956	0.971	1						
Wages & Salaries	0.926	0.989	0.992	1					
GRP	0.934	0.964	0.978	0.983	1				
Avg HH Income	0.944	0.961	0.975	0.981	0.992	1			
% > $100K	0.729	0.835	0.793	0.799	0.716	0.744	1		
DB1B Enplanements	0.739	0.731	0.709	0.711	0.694	0.751	0.788	1	
Real Oil Price	0.615	0.724	0.692	0.741	0.806	0.795	0.307	0.436	1
Missoula Int'l Airport (MSO)	**Population**	**Emp**	**Total Earnings**	**Wages & Salaries**	**GRP**	**Avg HH Inc**	**% > $100K**	**DB1B Enp**	**Real Oil Price**
Population	1								
Employment	0.984	1							
Total Earnings	0.968	0.990	1						
Wages & Salaries	0.980	0.991	0.996	1					
GRP	0.979	0.990	0.995	0.997	1				
Avg HH Income	0.962	0.987	0.991	0.991	0.985	1			
% > $100K	0.969	0.979	0.983	0.990	0.986	0.981	1		
DB1B Enplanements	0.972	0.966	0.968	0.980	0.974	0.970	0.975	1	
Real Oil Price	0.732	0.693	0.696	0.734	0.749	0.696	0.732	0.770	1
Providence T.C. Green (PVD)	**Population**	**Emp**	**Total Earnings**	**Wages & Salaries**	**GRP**	**Avg HH Inc**	**% > $100K**	**DB1B Enp**	**Real Oil Price**
Population	1								
Employment	0.950	1							
Total Earnings	0.979	0.976	1						
Wages & Salaries	0.978	0.984	0.998	1					
GRP	0.970	0.966	0.996	0.992	1				
Avg HH Income	0.942	0.947	0.985	0.981	0.984	1			
% > $100K	0.940	0.956	0.978	0.981	0.978	0.989	1		
DB1B Enplanements	0.912	0.913	0.881	0.903	0.863	0.828	0.861	1	
Real Oil Price	0.559	0.650	0.692	0.675	0.705	0.763	0.712	0.364	1

Case Study Model Estimation Results

Tables 35 and 36 present the regression results for all the equation specifications used for the eight case study airports. Table 35 shows the regression results for seven baseline regression specifications (including the specification that includes only the disaggregated socioeconomic variable). Table 36 contains the results from the alternative regression specifications. Table columns report regression results for individual case study airports, and table rows report results for each regression specification, using each of the candidate aggregate socioeconomic independent variables. Cells containing estimated coefficients are color coded to indicate each estimate's degree of statistical significance.

Table 35. Case study airport baseline regression results.

Aggregate Socioeconomic Variable	Regression Variable		Baltimore-Washington	EUG	LAX	MDT	MSO	PHX	PVD	TUL
Population	Constant	coefficient	-12.45	-1.45	-4.99	-4.50	0.49	0.93	-123.16	10.28
		t-statistic	*-3.766*	*-0.476*	*-0.794*	*-1.170*	*0.611*	*0.781*	*-8.188*	*3.863*
	Oil Price	coefficient	-0.087	-0.106	-0.016	-0.189	0.026	-0.297	-0.184	-0.080
		t-statistic	*-1.460*	*-1.455*	*-0.328*	*-3.572*	*0.676*	*-4.346*	*-1.842*	*-1.568*
	Population	coefficient	3.28	2.50	2.37	2.96	2.55	1.93	18.79	0.63
		t-statistic	*8.474*	*4.485*	*3.391*	*4.626*	*12.901*	*11.444*	*9.058*	*1.515*
		Adj R squared	0.847	0.707	0.424	0.465	0.948	0.836	0.797	0.043
Employment	Constant	coefficient	-6.20	4.68	1.00	4.39	5.61	1.93	-46.21	10.83
		t-statistic	*-3.624*	*2.782*	*0.213*	*2.264*	*13.856*	*1.695*	*-9.434*	*9.025*
	Oil Price	coefficient	-0.160	-0.062	-0.044	-0.121	0.062	-0.313	-0.320	-0.100
		t-statistic	*-3.521*	*-0.931*	*-0.773*	*-2.848*	*1.754*	*-4.356*	*-3.811*	*-2.482*
	Employment	coefficient	2.74	1.57	1.84	1.58	1.54	1.98	9.20	0.60
		t-statistic	*12.718*	*4.467*	*3.252*	*4.603*	*13.313*	*11.051*	*12.113*	*2.909*
		Adj R squared	0.922	0.705	0.437	0.464	0.945	0.824	0.905	0.254
Total Earnings	Constant	coefficient	3.21	5.22	7.40	7.21	4.03	3.94	-18.71	12.41
		t-statistic	*2.749*	*2.976*	*2.888*	*5.150*	*8.174*	*4.590*	*-6.533*	*11.507*
	Oil Price	coefficient	-0.095	-0.037	-0.044	-0.131	0.050	-0.216	-0.371	-0.091
		t-statistic	*-1.942*	*-0.543*	*-0.801*	*-2.866*	*1.480*	*-3.658*	*-3.939*	*-1.783*
	Total Earnings	coefficient	1.10	0.86	0.74	0.67	1.03	1.08	3.26	0.21
		t-statistic	*10.609*	*3.983*	*3.478*	*4.362*	*14.077*	*12.313*	*11.133*	*1.775*
		Adj R squared	0.905	0.672	0.448	0.416	0.943	0.878	0.873	0.074
Wages & Salaries	Constant	coefficient	2.52	5.71	5.85	7.21	4.12	3.81	-20.49	11.47
		t-statistic	*2.202*	*3.579*	*1.895*	*5.406*	*9.745*	*4.490*	*-8.284*	*9.058*
	Oil Price	coefficient	-0.099	-0.058	-0.059	-0.125	0.019	-0.218	-0.352	-0.099
		t-statistic	*-2.146*	*-0.824*	*-0.998*	*-2.889*	*0.605*	*-3.770*	*-4.583*	*-2.118*
	Wages & Salaries	coefficient	1.18	0.84	0.90	0.69	1.08	1.12	3.53	0.32
		t-statistic	*11.433*	*4.067*	*3.391*	*4.579*	*16.225*	*12.610*	*13.610*	*2.254*
		Adj R squared	0.915	0.679	0.454	0.448	0.960	0.886	0.909	0.148
GRP	Constant	coefficient	2.47	5.81	5.25	6.88	3.35	3.01	-18.95	11.78
		t-statistic	*2.066*	*4.442*	*1.818*	*4.939*	*6.223*	*3.888*	*-6.201*	*9.465*
	Oil Price	coefficient	-0.106	-0.123	-0.114	-0.134	0.009	-0.201	-0.397	-0.109
		t-statistic	*-2.202*	*-1.748*	*-1.747*	*-3.035*	*0.254*	*-4.132*	*-3.928*	*-2.037*
	GRP	coefficient	1.12	0.78	0.90	0.67	1.08	1.11	3.16	0.27
		t-statistic	*10.998*	*4.892*	*3.832*	*4.626*	*14.172*	*14.867*	*10.512*	*2.043*
		Adj R squared	0.905	0.732	0.478	0.455	0.945	0.906	0.843	0.112
Avg HH Income	Constant	coefficient	-6.08	-6.45	4.81	-2.03	-11.75	-15.24	-39.18	10.15
		t-statistic	*-3.602*	*-1.894*	*2.045*	*-0.648*	*-7.312*	*-5.373*	*-7.236*	*5.400*
	Oil Price	coefficient	-0.134	-0.047	-0.125	-0.138	0.032	-0.213	-0.491	-0.123
		t-statistic	*-3.094*	*-0.856*	*-2.280*	*-3.216*	*0.923*	*-3.099*	*-4.201*	*-2.214*
	Avg HH Income	coefficient	1.99	1.72	1.05	1.38	2.12	2.76	4.83	0.40
		t-statistic	*12.823*	*5.467*	*4.893*	*4.900*	*14.091*	*10.452*	*9.660*	*2.217*
		Adj R squared	0.932	0.769	0.584	0.484	0.943	0.844	0.809	0.133
Pct HH Inc>100k (Disaggregated Socioeconomic Variable)	Constant	coefficient	18.91	13.97	18.67	14.72	14.95	18.62	21.15	15.31
		t-statistic	*87.867*	*28.728*	*37.169*	*44.059*	*43.103*	*53.301*	*26.287*	*41.074*
	Oil Price	coefficient	-0.029	0.049	0.040	-0.111	0.015	-0.009	-0.354	-0.090
		t-statistic	*-1.004*	*0.875*	*1.194*	*-2.692*	*0.380*	*-0.200*	*-3.625*	*-2.312*
	Pct HH Inc>100k	coefficient	1.80	0.72	1.52	0.56	1.26	1.95	3.21	0.39
		t-statistic	*16.678*	*4.085*	*4.841*	*4.595*	*12.332*	*13.443*	*10.572*	*2.815*
		Adj R squared	0.949	0.687	0.608	0.453	0.951	0.906	0.830	0.243

Statistical significance of coefficient estimates:

- Not significantly different from 0
- 20% level or better (t-statistic > 1.282)
- 10% level or better (t-statistic > 1.645)
- 5% level or better (t-statistic > 1.96)
- 1% level or better (t-statistic > 2.576)
- Counterintuitive sign

Table 36. Case study airport alternative regression (with disaggregated SE variables) results.

Aggregate Socioeconomic Variable	Regression Variable		Baltimore-Washington	EUG	LAX	MDT	MSO	PHX	PVD	TUL
Population	Constant	coefficient	27.40	2.75	11.51	4.33	7.16	12.16	-33.10	26.10
		t-statistic	*4.431*	*0.351*	*1.460*	*0.525*	*2.798*	*3.254*	*-0.990*	*4.679*
	Oil Price	coefficient	-0.001	-0.068	0.014	-0.161	0.008	-0.124	-0.319	-0.041
		t-statistic	*-0.030*	*-0.689*	*0.328*	*-2.833*	*0.227*	*-1.573*	*-3.324*	*-0.946*
	Population	coefficient	-0.90	1.84	0.75	1.62	1.40	0.72	7.10	-1.48
		t-statistic	*-1.373*	*1.434*	*0.910*	*1.263*	*3.063*	*1.736*	*1.622*	*-1.938*
	Pct HH Inc>100k	coefficient	2.24	0.23	1.25	0.29	0.61	1.28	2.13	0.88
		t-statistic	*6.729*	*0.583*	*2.836*	*1.207*	*2.707*	*3.114*	*2.909*	*3.084*
		Adj R squared	0.952	0.698	0.599	0.467	0.962	0.909	0.866	0.362
Employment	Constant	coefficient	23.53	5.41	35.71	9.36	9.51	12.88	-20.62	11.31
		t-statistic	*2.646*	*0.801*	*3.221*	*1.090*	*4.309*	*3.791*	*-1.552*	*1.694*
	Oil Price	coefficient	-0.002	-0.054	0.138	-0.118	0.035	-0.124	-0.361	-0.099
		t-statistic	*-0.041*	*-0.546*	*1.930*	*-2.716*	*0.949*	*-1.546*	*-4.516*	*-2.329*
	Employment	coefficient	-0.51	1.45	-1.84	0.83	0.91	0.69	5.75	0.54
		t-statistic	*-0.519*	*1.271*	*-1.538*	*0.625*	*2.491*	*1.697*	*3.148*	*0.600*
	Pct HH Inc>100k	coefficient	2.12	0.06	2.66	0.28	0.54	1.32	1.33	0.04
		t-statistic	*3.384*	*0.111*	*3.329*	*0.595*	*1.792*	*3.346*	*2.049*	*0.073*
		Adj R squared	0.946	0.688	0.621	0.438	0.954	0.909	0.917	0.210
Total Earnings	Constant	coefficient	22.43	11.75	19.80	14.83	7.67	16.26	-2.58	25.57
		t-statistic	*5.525*	*1.205*	*3.689*	*1.872*	*2.738*	*2.290*	*-0.200*	*6.917*
	Oil Price	coefficient	-0.008	0.027	0.050	-0.110	0.033	-0.044	-0.378	0.006
		t-statistic	*-0.222*	*0.229*	*0.831*	*-2.199*	*0.912*	*-0.383*	*-4.076*	*0.119*
	Total Earnings	coefficient	-0.25	0.22	-0.08	-0.01	0.69	0.17	1.95	-0.86
		t-statistic	*-0.868*	*0.229*	*-0.210*	*-0.014*	*2.611*	*0.332*	*1.841*	*-2.786*
	Pct HH Inc>100k	coefficient	2.18	0.55	1.64	0.57	0.43	1.65	1.35	1.41
		t-statistic	*4.824*	*0.681*	*2.543*	*0.977*	*1.319*	*1.746*	*1.280*	*3.654*
		Adj R squared	0.946	0.668	0.585	0.421	0.949	0.901	0.876	0.466
Wages & Salaries	Constant	coefficient	22.76	10.18	25.53	11.43	4.94	16.55	-19.11	24.50
		t-statistic	*4.717*	*1.100*	*3.452*	*1.069*	*1.645*	*1.896*	*-1.473*	*3.947*
	Oil Price	coefficient	-0.008	-0.001	0.103	-0.118	0.017	-0.039	-0.354	-0.036
		t-statistic	*-0.202*	*-0.008*	*1.359*	*-2.468*	*0.529*	*-0.290*	*-4.405*	*-0.690*
	Wages & Salaries	coefficient	-0.28	0.39	-0.50	0.30	1.00	0.16	3.41	-0.81
		t-statistic	*-0.798*	*0.410*	*-0.929*	*0.308*	*3.352*	*0.237*	*3.106*	*-1.483*
	Pct HH Inc>100k	coefficient	2.21	0.40	2.17	0.32	0.10	1.68	0.11	1.18
		t-statistic	*4.257*	*0.491*	*2.845*	*0.398*	*0.275*	*1.465*	*0.108*	*2.136*
		Adj R squared	0.946	0.669	0.593	0.422	0.958	0.901	0.905	0.308
GRP	Constant	coefficient	23.02	5.69	16.54	10.35	7.11	6.78	1.31	25.67
		t-statistic	*5.043*	*1.289*	*2.841*	*1.434*	*2.388*	*1.134*	*0.095*	*5.007*
	Oil Price	coefficient	-0.004	-0.125	0.012	-0.126	0.005	-0.157	-0.389	0.022
		t-statistic	*-0.100*	*-1.175*	*0.143*	*-2.593*	*0.143*	*-1.835*	*-3.973*	*0.332*
	GRP	coefficient	-0.28	0.79	0.15	0.38	0.73	0.84	1.57	-0.86
		t-statistic	*-0.900*	*1.885*	*0.367*	*0.606*	*2.646*	*1.984*	*1.441*	*-2.026*
	Pct HH Inc>100k	coefficient	2.23	-0.01	1.33	0.26	0.42	0.48	1.67	1.30
		t-statistic	*4.578*	*-0.028*	*2.173*	*0.491*	*1.285*	*0.636*	*1.505*	*2.770*
		Adj R squared	0.947	0.716	0.587	0.430	0.950	0.907	0.856	0.374
Avg HH Income	Constant	coefficient	23.87	-42.55	11.16	-16.02	-2.99	38.33	16.02	24.59
		t-statistic	*2.623*	*-2.984*	*2.287*	*-0.665*	*-0.436*	*2.458*	*0.483*	*3.313*
	Oil Price	coefficient	-0.006	-0.193	-0.058	-0.156	0.020	0.117	-0.368	-0.003
		t-statistic	*-0.107*	*-2.602*	*-0.816*	*-2.900*	*0.583*	*1.072*	*-2.764*	*-0.036*
	Avg HH Income	coefficient	-0.40	4.72	0.59	2.53	1.43	-1.61	0.41	-0.75
		t-statistic	*-0.545*	*3.965*	*1.549*	*1.276*	*2.613*	*-1.264*	*0.155*	*-1.252*
	Pct HH Inc>100k	coefficient	2.15	-1.48	0.81	-0.49	0.43	3.05	2.95	0.97
		t-statistic	*3.329*	*-2.588*	*1.471*	*-0.586*	*1.308*	*3.471*	*1.686*	*2.001*
		Adj R squared	0.946	0.814	0.624	0.461	0.951	0.905	0.822	0.290

Statistical significance of coefficient estimates:

- (no shading) Not significantly different from 0
- (pink) 20% level or better (t-statistic > 1.282)
- (yellow) 10% level or better (t-statistic > 1.645)
- (light green) 5% level or better (t-statistic > 1.96)
- (green) 1% level or better (t-statistic > 2.576)
- (red outline) Counterintuitive sign

These two tables are somewhat complex, but they present all the estimation results in an organized fashion, making it possible to read both how well the range of independent variables performed for each of the case study airports and regions and to see how coefficient estimates for a given independent variable compared across the eight airports and regions. In the remainder of this subsection we present observations on the parameter estimates reported in the tables.

The regression constant term can be seen as a scaling term that takes values that vary with the magnitudes taken on by the independent variables and the dependent variable. Because of this, the estimated constant term can vary widely from equation to equation for an individual airport or airport system.

The oil price annual variable is included in the regressions as a factor reflecting a basic input cost for airlines and for passengers (as consumers of a full range of goods and services affected by the level of oil prices). The expectation is that the coefficient estimate for the Oil Price variable will be negative, since rising oil prices negatively affect both airline costs (and through those costs, airline service decisions) and consumer expenditures since petroleum is an input to a variety of household consumption, especially auto travel.

Because the regressions are estimated as log linear regressions, the coefficients can be treated as elasticities of airport enplanements with respect to the independent variable. Across the baseline regressions, the elasticity estimates for the Oil Price variable are clustered around –0.1 for the Baltimore-Washington region, EUG, LAX, MDT, and TUL, and have negative values of a slightly greater magnitude (around –0.3) for PHX and PVD. However, the Oil Price elasticity estimates for annual enplanements at MSO take on small but positive values, which is not completely surprising since oil extraction has become an important contributor to the economy of the Missoula area. For the other seven airports, these inelastic estimates indicate that a 1% increase (decrease) in oil prices leads to a decline (increase) in annual enplanements of 0.1 to 0.3% for the airports other than MSO. This may seem to be a negligible impact, but over the sample period oil prices were often volatile and changed much more than a few percentage points from year to year, sometimes doubling or halving themselves in a year's time. Arguably, it is the passenger demand (and airline industry) response to these large shifts in oil prices that is of greatest interest for airport decision-makers. The baseline regression coefficient estimates on the oil price variable are usually but not always statistically significant.

The elasticities estimated for the oil price in the alternative regressions using the disaggregated socioeconomic variable were also almost always negative (again with the exception of MSO), but at smaller magnitudes with more frequent instances of estimates that are statistically insignificant.

In the baseline regressions, the coefficients estimated for the aggregate socioeconomic variables were positive as expected, and nearly always statistically significant at levels of significance of 10% or greater. These estimates represent the influence of the regional economy on annual airport enplanements. For six of the case study airports and region (Baltimore-Washington, EUG, LAX, MDT, MSO, and PHX) there is broad consistency among the parameter estimates for each of the aggregate socioeconomic variables. This is true for those that have a more demographic interpretation; for those airports, the coefficients for the population variable range from 1.93 to 3.28 and the coefficients for the employment variable range from 1.54 to 2.74, with all of the estimates significant at the 0.01 level of statistical significance in each case. It is also true for those that have a more economic interpretation, ranging between 0.67 and 1.10; between 0.69 and 1.18; between 0.67 and 1.12; between 1.38 and 2.76; and between 0.56 and 1.95 for, respectively, the total earnings, wages and salaries, GRP, average household income, and the disaggregated socioeconomic variable percentage of households with incomes exceeding $100,000 (2009 dollars)—considered here as the only independent socioeconomic economic variable in the equation. All of the parameter estimates for these variables are also statistically significant at the 0.01 level of statistical significance.

The remaining case study airports, PVD and TUL, have somewhat anomalous patterns in the parameter estimates for the independent socioeconomic variables included in the baseline regressions. For PVD, the estimates are consistently higher than those for the same variables in the regression for the six case study locations. For example, the parameter estimate for the population socioeconomic variable is 18.79, and the estimate for the Providence MSA GRP socioeconomic variable is 3.16, about three times the magnitude of the parameter estimates for the six airports. Like the others, the parameter estimates for the Providence socioeconomic variables are all statistically significant at the 0.01 level of statistical significance. In contrast, the parameter estimates for the independent socioeconomic variables at TUL are all smaller in magnitude than the estimates at the other case study airports, and these estimates often have lower levels of statistical significance.

For each of the case study airports, conditional on the annual oil price series that is an independent variable in all equations, each of the six socioeconomic variables appears to bring similar information to the estimations (and the disaggregated household income variable that is used on its own and shown in the last rows of Table 35), in the sense that for each of the airports, the adjusted R-squared value is roughly the same for each of the baseline regressions using aggregate socioeconomic variables. For some of the case study airports (MSO, PHX, PVD, and the Baltimore-Washington airport system), the explanatory power of the regressions—expressed as the adjusted R-squared statistic—is relatively high, with values exceeding 0.800 for each of the socioeconomic variables used for that airport. For three of the case study airports (EUG, LAX, and MDT), the adjusted R-squared results are lower, ranging roughly between 0.400 and 0.750. Finally, for TUL, the adjusted R-squared value is consistently below 0.500, and sometimes well below 0.500, regardless of the socioeconomic variable used in the regression.

The model goodness of fit in the alternative specifications (using the disaggregated regional share of households with incomes exceeding $100,000 in 2009 dollars along with the individual aggregate socioeconomic variables from the baseline models) tends to increase slightly compared to the baseline regressions, but only modestly. However, because the disaggregated household income socioeconomic variable is so strongly correlated with each of the aggregate socioeconomic variables, the variance inflation discussed earlier results in many of the parameter estimates for socioeconomic variables (aggregate and disaggregated) having much lower levels of statistical significance in the alternative regression results. In these cases, because of the correlation, the aggregate and disaggregated socioeconomic variables are bringing similar information to the regression, which reduces the precision with which their coefficients are estimated. This outcome has to be balanced against the relatively modest improvement in the overall model fit, as reflected in the estimated R-squared statistic, in deciding whether the alternative regressions provide an improved explanation of the enplaned passenger traffic. The lower statistical significance of the estimated coefficients of the independent variables in the alternative models compared to the baseline models, which is true across all eight case study models, indicates that including the disaggregated household income variable is providing very little new information to the regressions from a statistical perspective.

The regression results for the eight individual case study airports are discussed in greater detail in Appendix D.

Forecasting Results from the Case Study Regression Analysis

For each of the case study airports, ex-post "forecasts" of annual passenger enplanements were calculated for the out-of-sample years 2011 to 2015 using the regression models estimated for each case study airport. For simplicity, out-of-sample forecasts are reported only for the baseline and alternative regression equations that used GRP as the aggregate socioeconomic independent variable for the case study airport's annual enplanements. For each case study airport, model performance can be assessed by comparing the "forecast" values to the actual annual enplanement totals for the years 2011 to 2015.

To make such forecasts of case study airport annual O&D enplanements, it is necessary to define assumed values of the independent variables for those "future" years. Simulating the forecasting situations that would have confronted analysts in 2011 or 2012 (when actual values for the regional MSA variables would have been available through 2010) requires that we use the forecasts for the independent variables that would have been provided to analysts in 2012. This approach differs from the more usual approach to ex-post forecasts that are based on the actual values of the independent variables. Simulating forecasts that might have been made in 2011 introduces two different sources of error in the forecasts: errors due to the model itself and errors due to differences between the forecast and actual values of the independent variable.

A forecast for the oil price variable starting in 2011 that could have been used that year is available from an FAA forecasting database, but Woods and Poole do not archive their past forecasts for socioeconomic variables. Discussions with Woods and Poole staff indicated that, because the Woods and Poole forecasting methodologies do not rely on business cycle fluctuations, the independent variable forecasts that would have been provided in 2012 would be similar in percentage terms to those provided at the present. We used this assumption to create out-of-sample forecasts for the independent socioeconomic variables. For example, if for a particular MSA the 2016 Woods and Poole data release projects a 2% growth rate for GRP between 2015 and 2016, then for our out-of-sample forecasting exercise we assume that for that MSA GRP will grow at a 2% rate between 2010 and 2011. This procedure for translating the most recent Woods and Poole data projections was used to generate the out-of-sample forecasts in our case study analyses.

For each case study airport, four forecast scenarios for the independent variables were created. The first three provided a "high, medium, and low" forecasting range by setting the medium scenario for each variable at the value estimated from the 2016 Woods and Poole projections. The high scenario for each variable is set at 1.5 times the growth rate for the medium scenario, and the low scenario at half that growth rate. For example, if for a given MA the Woods and Poole projection for growth in GRP was 2% growth between 2015 and 2016, and 2.2% growth between 2016 and 2017, then we would use those values for our medium scenario for GRP growth between 2010 and 2011, and between 2011 and 2012. For the high growth scenario we would use 3% growth between 2010 and 2011, and a 3.3% growth rate between 2011 and 2012. The low growth scenario calls for halving the growth rate in the medium scenario to 1% between 2010 and 2011, and 1.1% between 2011 and 2012.

For the independent variable forecasts for the fourth forecast scenario, we use the observed or actual historical values from 2011 to 2015 as the regression model inputs for the 2011 to 2015 enplanement forecasts. Doing this provides an assessment of the estimated model's performance as a forecasting tool, assuming that it had been possible to forecast in 2010 the future values of the model's independent variables (in this example the oil price variable, the regional product, and, in the case of the alternative case study model, the proportion of regional households with incomes exceeding $100,000 in 2009 dollars) with perfect foresight. This provides an assessment of the accuracy of the estimated model as representative of the interactions between the regional economic environment and the case study airport's annual enplanements over the forecast years, unaffected by any errors involved in forecasting the independent variables.

With the values for the independent variables defined for each of the four forecast scenarios, forecasts for annual enplanements from 2011 to 2015 can be calculated for the baseline and alternative GRP regression equations for each case study airport. The assessment of these forecasts considers the accuracy of the forecasts and more importantly considers the extent to which the addition of the disaggregated household income variable improves the accuracy of the alternative regression forecast (which uses the disaggregated income variable) compared to the baseline regression forecast.

Detailed forecast results are shown for two of the case study airports, Phoenix Sky Harbor International Airport and Tulsa International Airport. Figure 8 shows the actual PHX annual O&D enplanements from 1990 to 2015 (a period that includes the out-of-sample forecast), the annual enplanements estimated by the baseline model that uses Phoenix MSA GRP as the independent aggregate socioeconomic variable, and the four forecasts based on the independent variable forecast scenarios described above.

For PHX, there is considerable overlap between actual enplanements in the years 2011 to 2015 and the enplanements projected by each of the four forecast scenarios. The forecast performance of the model is especially striking for the forecasting exercise using the actual values for the oil price and Phoenix MSA GRP ("Forecast Using Actual"). The actual enplanements path ends up within the range of enplanement numbers defined by the high and low forecasts, although this is a consequence of the fact that the forecast growth under each scenario was applied to the modeled enplaned passengers in 2010, which overstated the actual passenger traffic. Had the forecast growth been applied to the actual enplaned passenger traffic in 2010, the projected enplaned passengers under the high growth scenario would have been fairly close to the actual traffic until 2015 when the actual traffic would have exceeded even the high growth scenario at a value between the high growth and "Forecast Using Actual" scenario.

Figure 9 is a similar chart, but the model and forecast paths shown use the Alternative model specification for PHX, for which the independent variables comprise the oil price variable, the Phoenix MSA GRP, and the disaggregated socioeconomic variable used in the case study analysis, the percentage of Phoenix households with household income exceeding $100,000 (in 2009 dollars).

The within-sample (1990 to 2010) model estimates and the out-of-sample forecasts for the PHX Alternative model are similar to those from the Phoenix Baseline model, except that the "Forecast Using Actual" projections are lower than those given by the Baseline model. This can be seen in Table 37, which reports the root mean squared error (RMSE) calculation for each of the four forecasts, the Phoenix Baseline model, and the Phoenix Alternative model.

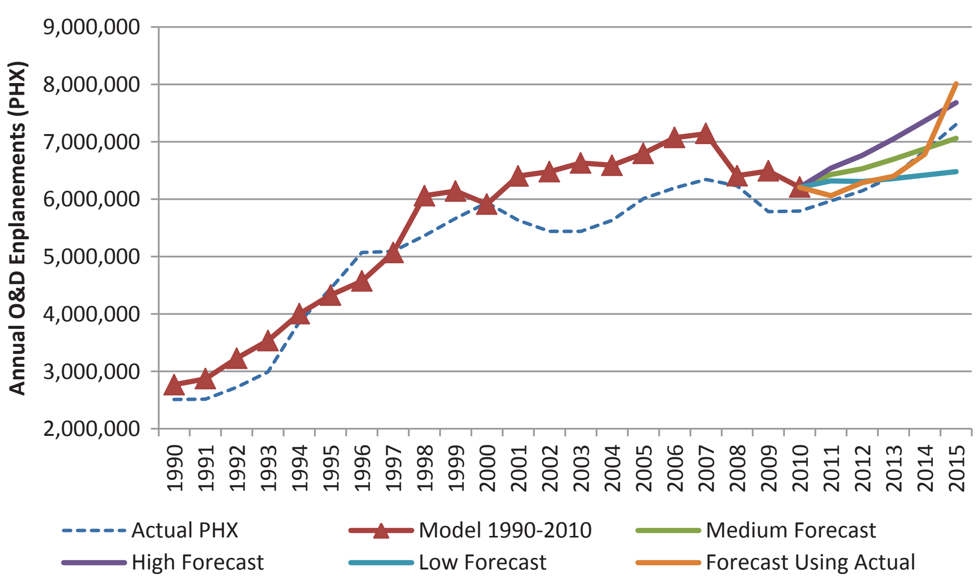

Figure 8. Case study baseline out-of-sample forecasts, Phoenix Sky Harbor.

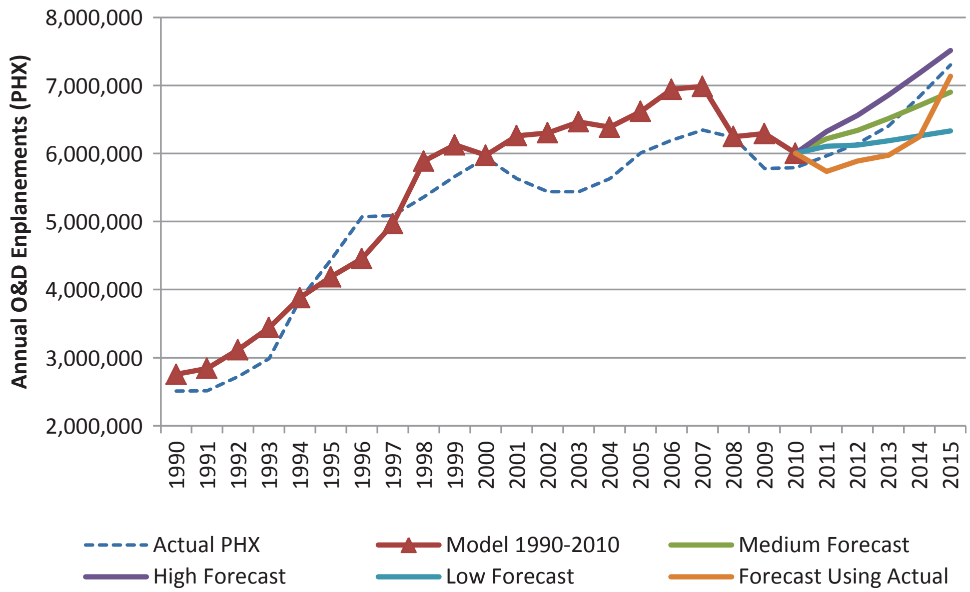

Figure 9. Alternative model out-of-sample forecasts, Phoenix Sky Harbor.

For each of the four forecasting scenarios for Phoenix Sky Harbor, the RMSE of the baseline and alternative forecasts measures the average distance (over the five out-of-sample forecast years) between the model forecasts and the actual PHX enplanements in those years. A forecast with a lower RMSE is "more accurate" than another in the sense that on average it lies closer to the actual values of the PHX enplanements in those years. In this case for PHX, the medium and high forecasts from the alternative model have lower RMSE values than the same forecasts for the baseline model, while the low and actual value forecasts from the PHX baseline model have lower RMSE values than the same forecasts from the alternative model. Comparing the baseline model "forecasts" for PHX with one another, the forecast using the medium and actual value scenarios for the independent variable out-of-sample values for 2011 to 2015 have better forecasting performance—lower RMSE values—than those using the high and low forecast scenarios for the independent model variables. Comparing the alternative model forecasts with one another, the forecasts using the medium and high scenarios for the independent variable out-of-sample values have better forecasting performance (lower RMSE values) than those using the low and actual value scenarios for the independent model variable, although the difference between the performance using the high and actual value scenarios for the independent model variable is fairly small.

Figure 10 shows the actual TUL annual O&D enplanements from 1990 to 2015 (a period that includes the out-of-sample forecast), the annual enplanements estimated by the baseline model that uses Tulsa MSA GRP as the independent aggregate socioeconomic variable, and the four forecasts based on the independent variable forecast scenarios described earlier.

Table 37. RMSE comparisons for PHX baseline and alternative case study model forecasts.

PHX (using GRP)	Root Mean Squared Error		% Difference BL v Alt
	Baseline	Alternative	
Medium Forecast	318,590	241,766	24%
High Forecast	554,205	367,045	34%
Low Forecast	447,829	518,924	-16%
Actual Values	326,203	369,242	-13%

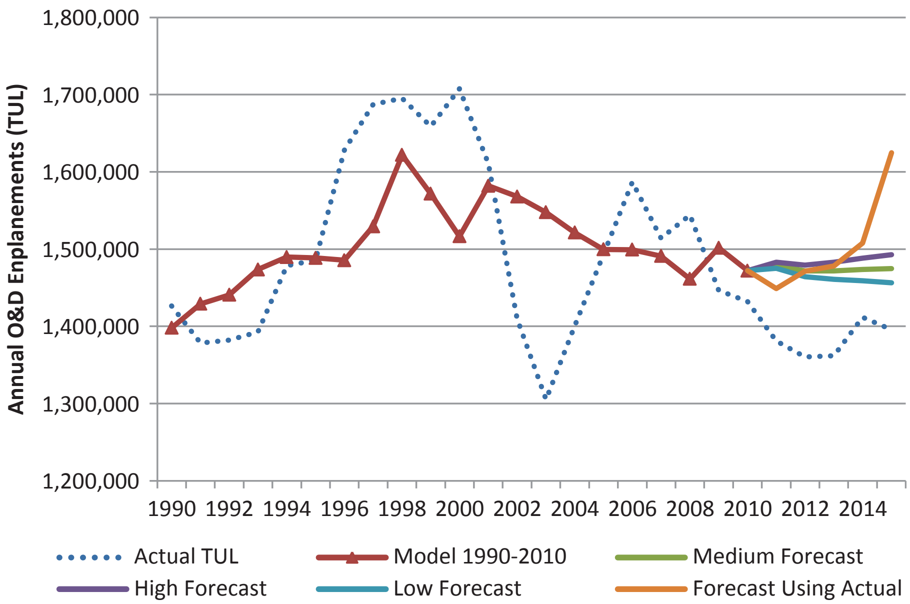

Figure 10. Case study baseline out-of-sample forecasts for Tulsa International.

For TUL, the actual enplanement series is much more volatile than the baseline model estimates, which is reflected in the low adjusted R-squared scores for the TUL models. The forecasting performance of the baseline model is also quite inaccurate. For all four independent variable forecast scenarios, the model severely overforecasts compared to the actual enplanement results at TUL for 2011 to 2015, although this overprojection would be less if the projected growth had been applied to the actual enplaned passenger traffic in 2010 rather than the modeled traffic.

Figure 11 shows the model and forecast values using the alternative model specification for TUL, for which the independent variables comprised the oil price variable, the Tulsa MSA GRP, and the disaggregated socioeconomic variable used in the case study analysis, the percentage of Tulsa households with household income exceeding $100,000 (in 2009 dollars).

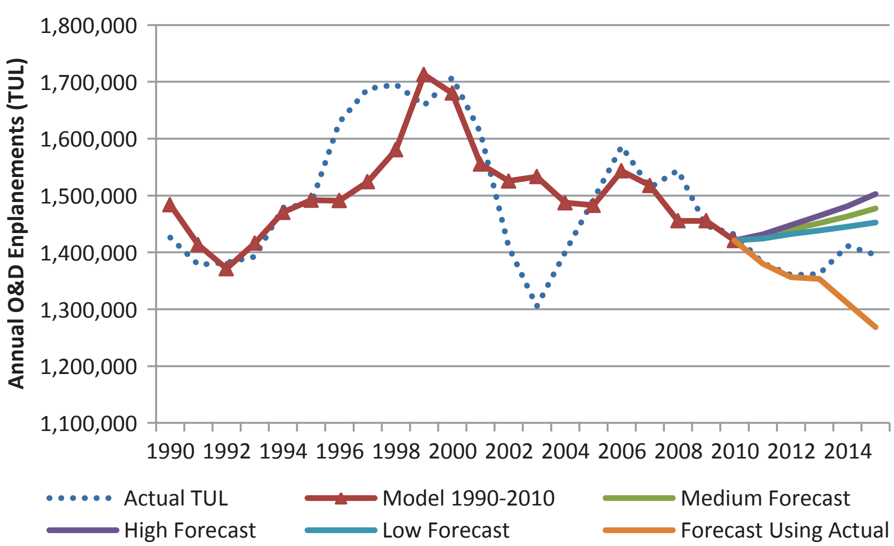

Figure 11. Case study alternative model out-of-sample forecasts for Tulsa International.

The within-sample (1990 to 2010) model estimates and the out-of-sample forecasts for the TUL alternative model differ in some ways from those shown above in the TUL baseline model estimates. Although like the baseline model, the alternative model does not match the volatility of the historical TUL enplanements series, but it does track the actual series more accurately at some points over the sample period. The medium, high, and low forecast scenarios also over-forecast compared to the actual TUL enplanement values for 2011 to 2015, but the forecast scenario based on the actual values of the independent variables over the forecast period is quite accurate for the first 2 years of the out-of-sample forecast period before sharply underforecasting TUL enplanements. The impacts of these characteristics in the forecasts on the average forecast accuracies can be seen in Table 38, which reports the RMSE calculation for each of the four forecasts, the TUL baseline model, the TUL alternative model.

In the RMSE comparison for TUL, for each forecast scenario the alternative model has lower RMSE values than the same forecasts for the Baseline model, although the figures make it clear that none of the forecasts are very accurate predictions of the actual course of enplanements at TUL over the entire out-of-sample period. Comparing the TUL forecasts with one another, the forecasts using the Low scenario for the independent variable out-of-sample values have better forecasting performance (lower RMSE values) than the other forecast scenarios for the independent model variables.

The purpose of the case study analysis is to determine whether the use of disaggregated socioeconomic variables improves the performance of these relatively simple regression models. It was noted above that, for all of the case study airports, the addition of the disaggregated variable did not add much to the in-sample model goodness of fit, as measured by the model R-squared estimates. The same is true in many cases for the assessment of model out-of-sample forecast performance, as measured by comparing the RMSE of the baseline and alternative forecasts for each of the case study airports. Table 39 summarizes these forecast performances.

Table 39 provides a description of the behavior of the forecasts from the baseline model (which uses the oil price variable and the aggregate socioeconomic variable GRP) and the alternative model (which uses the disaggregated socioeconomic variable, the percentage of regional households with incomes exceeding $100,000), and the percentage change in the RMSE when comparing the baseline model RMSE to the alternative model RMSE. A negative value for this measure indicates that the baseline forecast had a lower RMSE than the alternative model did (due to the baseline forecasts being closer to the actual airport enplanement values), and a positive value indicates that the alternative model had the lower RMSE. The smaller the magnitude of the percentage number, the smaller the difference between the baseline and alternative RMSE scores, and therefore the smaller the difference between the two forecasts.

In Table 39 the regression adjusted R-squared statistics are also reported, making it possible to consider the relationship, if any, between the model's goodness of fit at a case study

Table 38. RMSE comparisons for TUL baseline and alternative case study model forecasts.

TUL (using GRP)	Root Mean Squared Error		% Difference BL v Alt
	Baseline	Alternative	
Medium Forecast	94,079	72,038	23%
High Forecast	104,440	86,068	18%
Low Forecast	84,182	58,826	30%
Actual Values	135,787	72,748	46%

Table 39. Model performance diagnostics for case study airport regressions.

Case Study Airport or System	Adj R-squared when GRP is SE variable (BL/Alt)	Characteristics of Out-of-Sample Forecasts	Avg % RMSE Change across the 4 Forecasts (Alt vs BL)
Washington DC–Baltimore Airport System (BWI, DCA, and IAD)	0.905/0.947	Slightly overforecasts, Forecasts exceed actual values, by 10 to 20% (baseline) and by 5 to 15% (alternative)	30% (26% to 36%)
LAX (Los Angeles International Airport)	0.478/0.587	Underforecasts, Forecasts less than actual values, by 5 to 20% (baseline) and by 5 to 20% (alternative)	20% (-40% to +10%)
PHX (Phoenix Sky Harbor International Airport)	0.906/0.907	Forecasts around actuals, Forecasts differ from actual values, by -11 to 10% (baseline) and by -13 to 7% (alternative)	20% (-16% to +34%)
TUL (Tulsa International Airport)	0.112/0.374	Overforecasts, Forecasts exceed actual values, by 3 to 16% (baseline) and by -9 to 8% (alternative)	30% (18% to 46%)
PVD (T.F. Green Airport)	0.843/0.856	Overforecasts, Alternative closer than Baseline, Forecasts exceed actual values, by 8 to 96% (baseline) and by -9 to 70% (alternative)	35% (23% to 52%)
EUG (Eugene Airport)	0.732/0.716	Underforecasts, Forecast values less than actual values, by 9 to 22% (baseline) and by 9 to 22% (alternative)	1% (BL and Alt similar)
MDT (Harrisburg International Airport)	0.455/0.430	Generally underforecasts, Forecasts less than actual values (except in 2015), by 6% or less (baseline) and by 7% or less (alternative)	2% (-9% to +14%)
MSO (Missoula International Airport)	0.945/0.950	Underforecasts, Forecast values less than actual values, by 3 to 20% (baseline) and by 2 to 20% (alternative)	3% (-1% to 6%)

airport and the accuracy of the forecasts produced by the model (using the scenario assumptions about the future values of the independent variables). There appears to be no clear relationship between these model evaluation measures, since some case study models had very high adjusted R-squared values and relatively poor forecasting results. The forecasts and their performance relative to the actual annual enplanements for the case study airports are addressed in greater detail in Appendix D.

In most cases, neither the baseline model nor the alternative model provides an accurate forecast for a case study airport's passenger enplanements over the 2011 to 2015 period, even when the actual data for the independent variables over those years are used to calculate the enplanement forecasts. This may be so because the models are structured as models of passenger demand, and do not take sufficient account of the role of supply side decisions by airlines on the availability of seats and travel opportunities for prospective passengers. This may be especially significant for models of passenger enplanements at smaller airports.

The case study analysis thus provides a comparison of the statistical and forecasting performance of the baseline or traditional modeling approach relying on aggregate regional socioeconomic variables and an alternative modeling approach that also includes a type of disaggregated socioeconomic variable that reflects changes in the share of relatively higher income among regional households. Based on this comparison for the case study airports, is it worthwhile for airport analysts to experiment with the alternative modeling approach? There are several factors to consider.

Relative to the goodness of fit of the baseline models (adjusted R-squared), the alternative model specifications that include the regional disaggregated socioeconomic variable provided very little improvement in this area. This was true for case study airport baseline regressions with relatively high adjusted R-squared results and for case study examples of relatively low baseline regression goodness of fit.

Another factor to consider when comparing the baseline and alternative model specification results is precision or statistical significance of the coefficient estimates. As shown in Table 35, baseline regression estimates frequently resulted in coefficient estimates that are statistically significant, but this frequency of statistically significant parameter estimates was in general reduced when the disaggregated regional socioeconomic variable was added to the equation specification. This general outcome can be seen in Table 36. This result is closely related to the strong correlation between the values taken by the disaggregated socioeconomic variable for each case study airport and the baseline aggregate socioeconomic variables.

A third factor to consider is forecast accuracy. Does including the disaggregated socioeconomic variable related to regional household income distributions result in models that forecast more accurately? Again, the results from the case study analysis are mixed. In most cases, the 5 year out-of-sample forecasts for the case study airports are not very accurate. In some forecast scenarios for some case study airports, the alternative model specification using the disaggregated regional variable provides a more accurate 5 year forecast, as measured by the RSME for the forecasts, since a decline in the RSME for a given forecast scenario indicates that the forecast is on average closer to the actual 2011 to 2015 values. However, improvement on the baseline forecast is not always the case.

In terms of these three criteria (model goodness of fit, precision or statistical significance of model parameter estimates, and out-of-sample forecast accuracy) the alternative case study models provided only modest or mixed improvements to the baseline regression outcomes, indicating that the benefits of applying the approach used to prepare the case study model comparisons are limited.

On the cost side, if the analyst would be using data such as that available from Woods & Poole, there is no additional cost for obtaining the disaggregated household income or other distributional data, since it is included along with the aggregate regional data provided, and only modest computational time and effort would be needed to make use of that data. Because of this second aspect—the relative ease of including the disaggregated regional data in an analysis—the airport may learn new nuances about the demographics and economy of the region it serves when it includes this additional analysis, even if the use of the disaggregated variable provides only modest improvement to the performance of models of air passenger demand that rely on aggregate regional characteristics. In the remainder of this chapter, a more detailed analysis of other methods of including disaggregated socioeconomic variables in air passenger demand models for the Baltimore–Washington airport system provides different approaches that can extend beyond the simple case study comparisons described earlier.

More Detailed Analysis of the Baltimore—Washington Region

The case study regression models used a fairly simple functional form with a limited number of variables in each model. To explore the potential application of more complex models with additional variables, including dummy variables to account for year-specific effects, a more detailed analysis was undertaken of air passenger demand in the Baltimore–Washington metropolitan region. This region was chosen because it is served by three major commercial service airports and air traffic data has been assembled for all three airports, allowing an analysis of regional demand that avoids distortions from changes in the regional share of specific airports. In addition to exploring more complex models, the analysis also explored the use of an alternative disaggregated measure of household income to that used in the initial case study models. This alternative measure was chosen to avoid the problem of correlation between the aggregate and disaggregate measures of household income used in the prior analysis.

Alternative Disaggregated Income Measure

The initial model estimation regressions used the percent of households with personal incomes of $100,000 or more (in constant 2009 dollars) as the disaggregated measure of income. One potential difficulty with this measure is that it is not independent of the average household income; as the average household income has increased over time, the percent of households with incomes above any given threshold (e.g., $100,000) will also have increased as a growing percentage of households move into that income range, even if the relative distribution of incomes does not change. This is reflected in a strong correlation between average household income and the percent of households with incomes of $100,000 or more (0.984 for the Baltimore–Washington region for 1990 to 2010). As a result of this correlation, adding the disaggregated income variable to the model specification typically results in the average household income variable (or other aggregate economic variables that are strongly correlated with household income) becoming statistically insignificant, leaving the disaggregated income variable as the only statistically significant economic variable in the model.

To explore alternative disaggregated measures of household income that are independent of the average household income, an analysis was undertaken of the household income distributions for the Baltimore–Washington region, using data from Woods & Poole Economics. The highest income category is $200,000 or more (in constant 2009 dollars), so the data provide no information about the shape of the distribution above $200,000. To estimate the shape of the distribution for households with incomes above $200,000, an analysis was performed of the household income distribution reported by respondents to the 2010 CES, who reported their actual household income in various categories. The result of this analysis is presented in Appendix D and the resulting distribution was used to estimate the cumulative distribution for household incomes above $200,000.

As an alternative to the percent of households with a personal income of $100,000 or more, the percent of total personal income for all households that was received by the top 10% of households by income is a measure that is independent of changes in the average household income. This measure only reflects changes in the relative distribution of household income after adjusting for changes in average household income.

To calculate this measure from the Woods & Poole data, it is necessary to make two calculations:

- Determine the household income that corresponds to the 90th percentile of the cumulative distribution
- Estimate the average household income for all households below the 90th percentile of the income distribution

Calculating the average household income for households below the 90th percentile, rather than directly calculating the total income for the 10% of households above the 90th percentile, was necessary due to the uncertainty about the shape of the income distribution above $200,000. The percent of total personal income received by households in the top 10% by income can then be easily calculated from the average income for all households and the average income for households below the 90th percentile.

The household income corresponding to the 90th percentile was calculated by assuming that the distribution curve between the two data points on the cumulative income distribution on either side of the 90th percentile was approximated by the logistic function:

$$P = 1/\left(1 + e^{aY^n}\right)$$

where P is the cumulative percentage, Y is the household income, and a and n are parameters that are fitted to the data.

The average income for households below the 90th percentile was calculated by integrating the cumulative income distribution curve below the 90th percentile, assuming that the curve between each pair of data points was approximated by a quadratic function. The parameters of the quadratic function between each pair of data points were determined from the two data points and the subsequent data point in the distribution.

The resulting changes in the values of the percent of total personal income received by households in the top 10% by income from 1990 to 2010, together with the corresponding percent of households with a personal income of $100,000 or more and the average household income, is shown in Figure 12.

The percent of total personal income received by households in the top 10% by income increased at a slower rate than percent of households with a personal income of $100,000 or more from 1990 to 2010, as would be expected given the increase in average household income over the period. The difference in the rate of increase became less after 2000. In fact, from 1999 to 2010 the increase in the two measures was essentially identical. The increase in the two measures differed considerably from year to year, with the changes in the percent of total personal income received by households in the top 10% by income from year to year corresponding more closely to the changes in the average household income (the correlation coefficient for the two measures was 0.99).

Since the percent of total personal income received by the top 10% of households is independent of the average household income, the combination of an increasing average household income and an increasing share of total income received by households in the top 10% means that the average household income of the top 10% of households increased significantly from 1990 to 2010, in fact by 75%. In contrast, the average household income of other households only increased by 21%. During the same period, the regional enplaned O&D passengers increased by a little over 77%.

A trial regression adding a variable for the percent of total personal income received by the top 10% of households to a log-linear model of O&D enplanements per capita for the Baltimore–Washington region for the period 1990 to 2010 with variables for the average household income

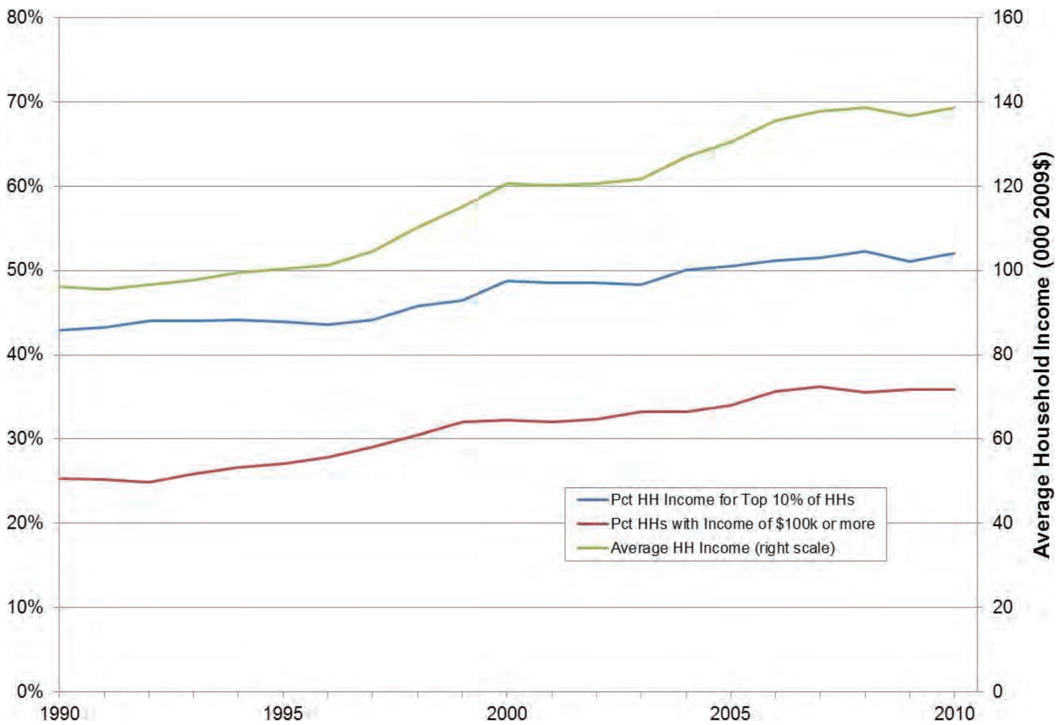

Figure 12. Changes in disaggregated household income metrics over time.

and oil price gave statistically significant coefficients for all variables. In contrast, the same model with the percent of households with incomes of $100,000 in place of the percent of total personal income received by the top 10% of households resulted in a statistically significant coefficient for the percent of households with incomes of $100,000 but the coefficients for the average household income and oil price became statistically insignificant and the coefficient for average household income had a counterintuitive sign.

Modeling Approach and Model Development

The change in the enplaned O&D passengers per person and selected socioeconomic variables, as well as the U.S. average airline yield and the oil price measure adopted, from 1990 to 2010 is shown in Figure 13, expressed as an index relative to the value of each data series in 1990. This allows data expressed in very different units to be shown on the same chart and provides a direct comparison of the relative change in each data series over time. The enplaned O&D passenger and employment data were expressed on a per person basis to account for the effect of population growth on demand while avoiding problems from the correlation that exists between growth in population and growth in other socioeconomic factors.

It seems clear form the data shown in Figure 13 that the level of enplaned passengers per capita after 2000 was influenced by factors other than the ongoing trends in socioeconomic factors and airfares as represented by average airline yield, most notably changes in the airline industry following 9/11. To avoid the effect of these factors distorting the estimates of the effect of the socioeconomic, airline yield, and oil price variables on the level of enplaned passengers and to provide a way to quantify the magnitude of the effect of any additional factors that occurred after 2000, demand models were first estimated using data for the period 1990 to 2000. These models were then used to project enplaned passengers per capita for the period 2001 to 2010 and the resulting projected traffic compared to the actual traffic. This gave the ratio by which

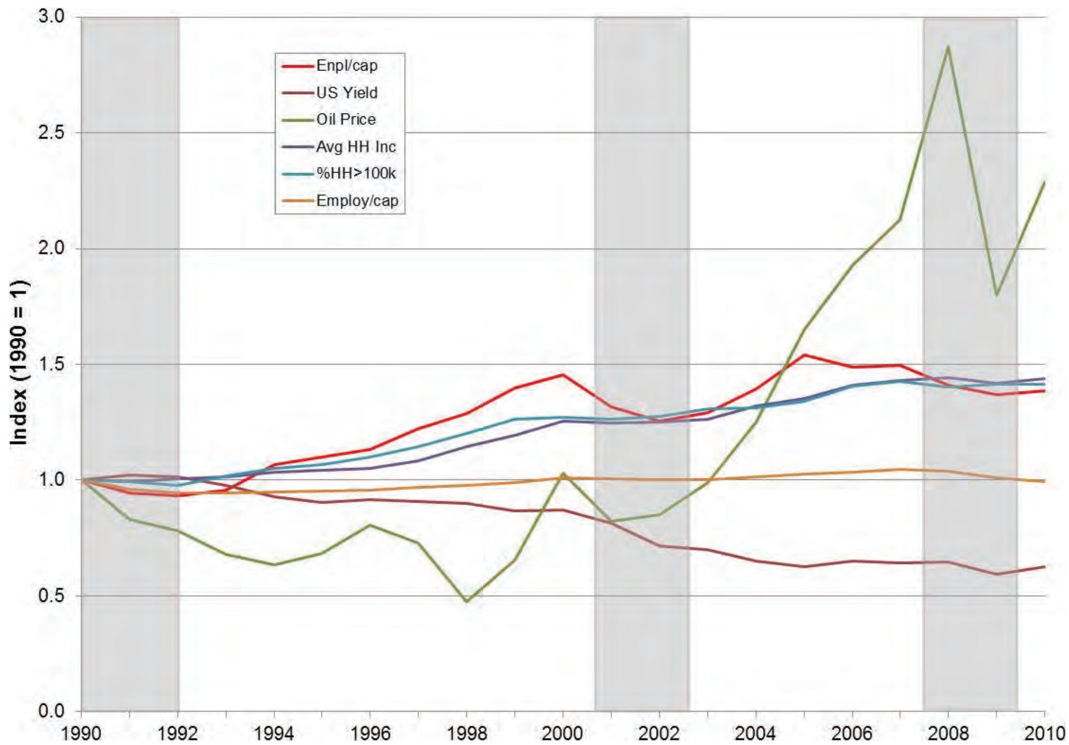

Figure 13. Changes in enplaned O&D passengers and socioeconomic and other data: Baltimore–Washington Region, 1990 to 2010.

the projected traffic exceeded the actual traffic. Based on the resulting pattern of this ratio, year-specific dummy variables were defined to account for the level of overprediction in each year. The models were then re-estimated for the full period including the dummy variables.

The inclusion of year-specific dummy variables forces the model to fit the data for those years. Their inclusion in the model provides two important benefits:

- It allows the estimation of the coefficients of the continuous variables to be based on the full 21 years of data without being distorted by year-specific effects (such as the effect of 9/11 in 2001 and 2002).
- It provides an estimate of the magnitude of any year-specific effects during the period from 2001 to 2010 that reduce the projected enplaned passengers per capita below the level attributable to the effects of the continuous variables.

Naturally, the inclusion of the dummy variables provides no information on what factors may have caused the effect measured by each dummy variable. It merely measures the magnitude of the effect in each year. Interpreting the likely or potential cause of these effects requires additional analysis or thought. However, knowing how the magnitude of the effect changes from year to year may lead to the addition of new continuous variables or changes in the definition of the continuous variables (e.g., using the average fare for the airports in question from the U.S. DOT 10% O&D survey in place of the national average yield) that account for these effects without the need for dummy variables.

Even without such additional analysis, separating out the year-specific effects from the effects of the continuous variables included in the model has value from the perspective of the use of the models for forecasting. If the year-specific effects are considered unlikely to occur in the future or to recur under assumed conditions (e.g., future recessions), the effects measured by the dummy variables can be omitted from the forecasts or used to define future scenarios in which these effects continue but at a different level of frequency. In contrast, developing models that rely on a limited set of continuous variables without considering any year-specific effects runs the risk of the resulting models accounting for these effects by distorting the estimated coefficients of the continuous variables. Use of such models to prepare forecasts can result in a situation where it is unclear whether and to what extent the forecasts implicitly assume a continuation of the year-specific effects that occurred during the model estimation period.

However, one limitation of this approach is the limited number of data points that are available in the period 1990 to 2000 to estimate the models to be used to assess the pattern of over- or underprediction during the period from 2001 to 2010. Of course, including dummy variables in the resulting model estimated on the full period reduces the degrees of freedom in the model estimation, which needs to be carefully considered in deciding how many dummy variables to include. Therefore the model development started with very simple models and progressively added variables, retaining them if they improved the model fit and had statistically significant coefficients of the expected sign and the values seemed plausible.

The detailed evolution of the model specification is described in Appendix D. The model development was based on the use of a multiplicative (log-linear) demand model with the total regional enplaned O&D passengers per capita as the dependent variable. This model specification ensures that the marginal change in the dependent variable for a given change in one of the independent variables varies with the overall level of the dependent variable, which seems intuitively reasonable. In addition, the coefficient estimates for log-linear models give the demand elasticity, which is helpful in interpreting the reasonableness of the model estimates. The final specification is shown in Table 40.

All the coefficient estimates are statistically significant at the 5% level or better and all but that for the employment variable are statistically significant at the 1% level or better. The estimated coefficients have expected signs and the estimated values are intuitively reasonable. The estimated coefficient for average airline yield implies that total air travel demand is slightly inelastic with respect to airfares, which does not seem unreasonable since real airfares have been generally

Table 40. Model estimation results—1990–2010 (Final Model Specification).

Variable		Final Model
Intercept	Coefficient	-21.50
	t-statistic	*(-5.68)*
Average Household Income	Coefficient	2.047
	t-statistic	*(7.62)*
US Average Airline Yield	Coefficient	-0.849
	t-statistic	*(-5.93)*
Employment/person	Coefficient	0.520
	t-statistic	*(2.40)*
Pct of HH Income by Top 10%	Coefficient	-1.697
	t-statistic	*(-4.44)*
Dummy Variable 2001	Coefficient	-0.1514
	t-statistic	*(-8.31)*
Dummy Variable 2002	Coefficient	-0.3059
	t-statistic	*(-9.71)*
Dummy Variable 2003	Coefficient	-0.02347
	t-statistic	*(-10.86)*
Dummy Variable 2005	Coefficient	0.0539
	t-statistic	*(3.20)*
Dummy Variable 2009	Coefficient	-0.0901
	t-statistic	*(-5.19)*
Adjusted R Squared		0.994

declining over the period from 1990 to 2010 and as airfares decline some households and businesses are likely to have chosen to use the savings for other purposes rather than purchasing more air travel. The estimated coefficient for employment per capita also appears reasonable. It seems reasonable that a given increase in regional employment would lead to a proportional increase in business travel, if all other factors remain unchanged. However, business travel only accounts for about half of all air travel, so a priori one would expect an elasticity of demand with respect to employment of around 0.5.

It may at first seem counterintuitive that the coefficient for the alternative disaggregated income variable would be negative, but this is what would be expected. If the top 10% of households have a higher share of total income, this implies that the rest have a lower share. As their income drops relative to the average income, their air travel propensity would tend to drop as well, and there are far more of them than those in the top 10% of households, whose air travel propensity in any case is probably not as greatly affected by changes in their income as lower income households.

Another effect of including the changing income distribution in the model is that the coefficient of average household income is much higher than would typically be found in a model that does not include this effect, implying an elasticity of demand with respect to average income of over two. This too is not unreasonable since as real incomes rise, one would expect households to spend an increasing share of their income on discretionary spending, including air travel, particularly higher income households. However, from 1990 to 2010 the positive effect of increasing average real income in air travel demand has been partly offset in the model by the negative effect of the increase in the percentage of total household income received by the top 10% of households.

The overall fit of the enplaned O&D passenger projections using the final model to the actual data is shown in Figure 14. The overall model fit is very close. Of course, one would expect a

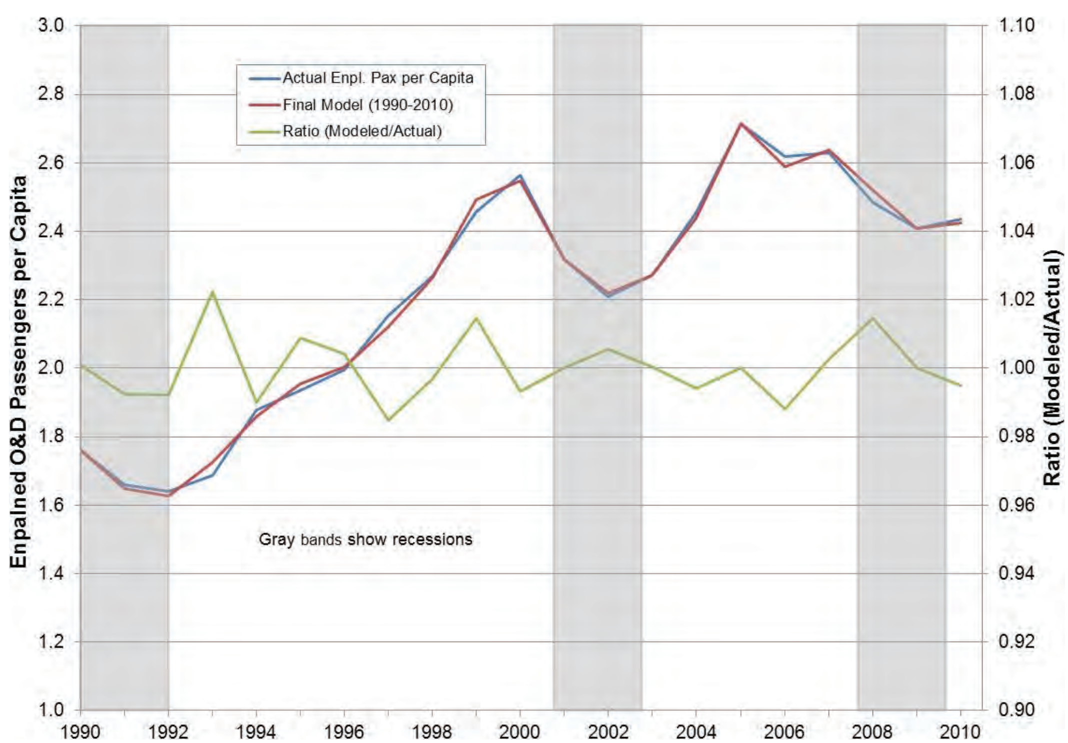

Figure 14. Comparison of projected and actual enplaned O&D passengers for Baltimore–Washington region (final model specification), 1990 to 2010.

near-perfect fit from 2001 on, since this is forced by the choice of dummy variables. However, the fit from 1990 to 2000 (which did not include the effect of any dummy variables) is essentially unchanged from that given by the same model specification but without the dummy variables that were estimated on data for 1990 to 2000.

Although the model fits the actual enplaned O&D passenger data closely, there are a number of important caveats that are discussed in more detail in Appendix D. The first is that the model is based on the socioeconomic characteristics of the Baltimore–Washington region, but the enplaned O&D passenger data includes both air trips by residents of the region and by visitors to the region. The model thus implicitly assumes that the proportion of resident to visitor air passengers is constant, so that relationships based on the characteristics of the residents of the region also predict changes in visitor trips. The second is that the model uses U.S. average airline yield as a surrogate measure for the average airfares that were available at the airports serving the region. To the extent that these average airfares differed from the national average yield, this could have introduced biases or errors in the model.

However, beyond these concerns the estimated values of the dummy variables provide a striking, and unexpected, indication of the effect of factors beyond the variables included in the model during the period for 2001 to 2010. The increase in the effect of the dummy variables each year from 2002 to 2010 raises some unexpected and interesting issues. It seems unlikely that potential air travelers would be finding the hassle or inconvenience of the post-9/11 security measures increasingly onerous 8 years after they were introduced, so the dummy variables may be reflecting other factors that were changing progressively from 2002 to 2010 but are not included in the model. Either way, the dummy variables reflect the effect of these factors (whatever they are) on demand.

Improvement from Including the Disaggregated Household Income Variable

To quantify the contribution to final model of the disaggregated household income variable, the model was re-estimated without the disaggregated income variable. The revised model gave a poorer fit to the data, with an adjusted R squared of 0.985 compared to 0.994 for the final model, in spite of having one more degree of freedom. The estimated coefficients had lower statistical significance with the exception of the coefficients for airline yield and employment. However, the increase in statistical significant for those two variables was fairly small and the estimated values of both coefficients were considerably larger than for the final model and in fact appear too high.

The overall fit of the revised model to the actual traffic was not as close as the final model, particularly for the period from 1990 to 2000, although it would probably be considered a perfectly acceptable fit to the data for most air passenger demand studies. However, the other important difference between the two models is the difference in the estimated coefficients for average household income, average airline yield, and employment per person, which have significantly different implications for the effect of future assumed changes in these variables. In particular, assuming that the relative household income distribution (measured by the percent of total income received by the top 10% of households) remains constant, the elasticity of demand with respect to average household income changes from 2.05 in the final model to 0.97 in the model without the disaggregated household income variable. This difference points out that failing to take account of changes in income distribution in air passenger demand models can result in significant biases in estimated model coefficients.

In order to understand how well these two models would predict future enplaned O&D passenger traffic, ex-post forecasts were performed using both models for the period from 2010 to 2015, for which the actual traffic and values of the socioeconomic data were available. This required assumptions about values of the dummy variables for 2002 on and 2003 on for the years after 2010. It was found that keeping their combined effect constant at their values in 2010 gave a closer fit to the actual traffic than allowing them to continue changing at the rates estimated for the period up to 2010. Under this assumption, the projected traffic levels in each year from 2011 to 2015 given by the final model underestimated the traffic in 2011 by less than 1% and overestimated the traffic in subsequent years by between 1% and 3%, with an average error over the 5-year period of a 1.7% overestimate. In comparison, the revised model without the disaggregated household income variable underestimated the traffic in all 5 years by between 1% and 4%, with an average underestimate of 2.2%.

Although this difference between the two models may not seem very large, if the two models are used to develop projections over a longer time frame, as is typically done for airport master planning and similar studies, the difference in the estimated model coefficients can lead to very different outcomes. For example, developing a 25-year forecast from 2015 to 2040 assuming an annual increase in real household income of 1.8% per year (approximately the average annual increase in real household income from 1990 to 2010) and holding the other socioeconomic factors constant (including the relative distribution of household incomes and the average airline yield) gave an increase in enplaned O&D passengers per capita of 149% using the final model but only 49% using the model without the disaggregated household income variable.

Summary and Conclusions

The two most important findings from the more detailed demand modeling of the Baltimore-Washington region, beyond the greatly improved fit of the modeled enplanements to the actual data, are (1) that including a variable for the percentage of total household income received by the top 10% of households by income not only improved the model fit to the data but significantly changed the effect of average household income on predicted air passenger enplanements, and (2) that the changes in enplaned passengers after 2001 appear to be greatly influenced by factors beyond the continuous variables included in the models that reduced the demand well below the levels that would have been expected from relationships estimated on the period from 1990 to 2000. While some of these factors are well recognized, such as the changes in the security measures after the 9/11 terrorist attacks or the 2007 recession, the dummy variables included in the model allow these effects to be quantified. More importantly, these effects do not appear to have dissipated by 2010 and may have continued at least for several years thereafter.

Thus the more detailed analysis of the Baltimore-Washington Region confirms the findings from the initial analysis using a much simpler model specification and a limited number of variables that including a disaggregated household income variable improves both the model fit and forecast accuracy, although the improvement over the same model with only an aggregate household income variable is not large. However, it should be noted that the ex-post forecast comparison was only performed for a relatively short 5-year period and the improvement in accuracy from accounting for changes in the distribution of household incomes could increase significantly over a longer forecast period, particularly if there are future changes in household income distribution. Of course, this will not be known at the time any forecasts are prepared, but what is important is that including a disaggregated household income variable in an air passenger demand model allows forecasts to be prepared assuming different scenarios of future changes in household income distribution and an analysis to be performed of the sensitivity of forecast levels of air passenger demand to possible changes in household income distribution.

Analysis of Case Study Results

The case study results can be analyzed along several dimensions, from focusing on strictly statistical considerations to applying a broader perspective that takes in what the results may say about the passenger aviation industry and its evolution within the broader economy. This discussion will begin with the results from the case study regressions that were based on models with a limited number of explanatory variables, and then turn to the more detailed analysis of the Baltimore–Washington airport system.

Several largely statistical factors contribute to the case study results. Among the baseline case study regressions, which use a single aggregate socioeconomic variable (along with the oil price variable), there is some variation in the goodness of model fit from case study to case study airport. For each individual case study airport, the model goodness of fit measure (adjusted R squared) generally does not differ much when different aggregate socioeconomic variables are used as independent variables (along with the oil price variable). This is not surprising, since for each case study airport's service area (MSA), the individual aggregate socioeconomic variables are strongly correlated—each one carries similar information about changes in the regional economy as the others.

This strong correlation among socioeconomic variables also extends to the disaggregated socioeconomic variable used in the alternative case study regressions: the percentage of a region's households with income exceeding $100,000 in 2009 dollars. Because of this, the introduction of the disaggregated household income variable as an additional independent variable, together with one of the aggregate socioeconomic variables used in the baseline regressions for each case study airport, tends to slightly increase the regression's adjusted R squared but also generally results in much less precise coefficient estimates. The parameter estimates for the alternative equations are less likely to be statistically significant because of the higher standard errors on the socioeconomic variables caused by the presence of two strongly correlated variables as independent regression variables. This phenomenon, called variance inflation, results from the fact that the two correlated variables (because they are so similar statistically) bring largely overlapping information to the regression estimation. This correlation between the independent variables (they are not fully independent of one another statistically) limits the extent to which the disaggregated household income variable can bring additional explanatory power to the baseline model specifications with only a single socioeconomic variable.

Inclusion of the disaggregated household income variable as an independent regression variable in the alternative specifications nearly always causes a significant change in the coefficient estimate for the aggregate socioeconomic variable compared to the coefficient estimate in the baseline equation. This effect may be a statistical artifact of the strong positive correlation between the disaggregated household income variable and each of the aggregate socioeconomic variables. On the other hand, the result may not be particularly surprising, because the disaggregated household income variable (the percentage of households with incomes exceeding $100,000) inherently increases as average household incomes rise, since the growth in average income moves an increasing proportion of households above $100,000. This in turn explains the strong correlation between the disaggregated household income variable and the average household income variable (as well as the other socioeconomic variables that are strongly correlated with average household income). Naturally, since the change in the disaggregated household income variable is partly reflecting the growth in average household income, including it in the model will impact the estimated contribution of the other aggregate socioeconomic variable to enplaned O&D passengers, as reflected in the model coefficients.

It is true that the additional inclusion of the disaggregated socioeconomic variable in the alternative regression estimations raises the model's goodness of fit to the actual airport enplanement data, as measured by the slight increases in adjusted R squared for the alternative regression specifications. However, these improvements are not large, which prompts the question of whether the improvement in model fit is sufficient to justify the resulting loss of statistical significance of the estimated regression coefficients for the other socioeconomic variables. Although it may at first appear that the simpler models that use only aggregate socioeconomic variables perform well enough without the disaggregated household income variable, this places undue emphasis on model fit over the reasonableness of the estimated values of the model coefficients. What matters for a model that is to be used to project future air travel demand is not only how well it fits historical traffic data but whether the demand relationships implied by the estimated model coefficients and variables included in the model appear reasonable. Omitting any measure of household income distribution from a model implies that future levels of air travel demand are unaffected by changes in household income distribution. This not only defies common sense but runs counter to the findings of the analysis of a large number of air passenger and household travel surveys undertaken as part of the current project, which clearly show that the distribution of household incomes has a major effect on the average number of air trips that those households make each year.

Although these relatively simple baseline and alternative model specifications used in the case study comparison result in relatively high goodness of fit results for several of the case study airports, this is not the case for all the case study airports and the forecast performances are mixed for both baseline and alternative case study model specifications. This suggests that other variables than the two or three included in the models may also matter for determining annual enplanements at individual airports. These other influences likely include one-time historical events, such as the 9/11 terrorist attacks, or continuing effects of macroeconomic events such as the Great Recession which began in 2007. In addition, as shown in the more detailed analysis of the Baltimore–Washington region, the oil price variable turned out to be a poor measure of changes in airfares over the estimation period of the models.

In addition, the U.S. air transportation industry has itself experienced tremendous change over the period from 1990 to 2010. These industry changes have led to changes in passenger service, especially at smaller airports, that are only partially related to, or not easily attributable to, changes in the national or regional economy. These "outside the model" influences on an airport's annual enplanements will reduce the explanatory power of the chosen independent model variables even if those variables can reasonably be expected to influence airport air passenger demand. Of course, what this is saying is that, to adequately reflect these external influences, one needs a more complex model.

Hence, many of these conclusions about the case study models are related to the relative simplicity of the equations used in those models. The more detailed analysis of annual enplanements for the Baltimore-Washington airport system also conducted as part of the case study analysis is an effort to develop model specifications that can account for some of these limitations. In particular, an alternative disaggregated socioeconomic variable was used to address the correlation between the aggregate and disaggregated household income variables used in the simpler case study regression models. Further, dummy variables were used to address the importance of historical and industry supply side changes for airport system O&D enplanements, especially in the years following the 9/11 attacks (which include the 2007 Great Recession). The statistical significance of the parameter estimates on those dummy variables indicates that, at least for the Baltimore-Washington region, the annual O&D enplanements for the regional airport system were strongly influenced during the period from 2001 to 2010 by factors not accounted for by the air service and socioeconomic variables included in the models.

As with the initial, simpler case study models, the more detailed model of annual enplanements in the Baltimore–Washington system found that the inclusion of a disaggregated household income variable did not result in a large improvement in the (already high) model goodness of fit compared to a model relying only on an aggregate household income variable, although as noted above, model goodness of fit is not the only consideration in deciding whether any particular variable adds value to a model.

As found with the initial case study results, the inclusion of the disaggregated household income variable in the more detailed models of Baltimore–Washington airport system O&D enplanements led to a significant change in the parameter estimate for the aggregate household income variable that was included in both the baseline specification and the specification that also included the disaggregated variable.

CHAPTER 5

Other Approaches to the Use of Disaggregated Socioeconomic Data in Air Passenger Demand Analysis

The previous chapter described the results from incorporating a particular example of regional disaggregated socioeconomic data into the econometric modeling framework that is commonly used (with aggregate socioeconomic data only) in airport analyses of passenger enplanements over time. This chapter presents analyses of new forms or sources for disaggregated socioeconomic data about air passenger as well as other approaches to incorporating disaggregated socioeconomic data into air passenger demand analysis.

The new types of data result from the capture of passenger data through their credit card purchase behaviors. These data are of increasing interest to marketers and others because they provide increasingly individualized insights in consumer purchasing patterns and decisions.

The examination of other approaches involves two ways of characterizing air passenger demand analysis and the potential roles for disaggregated socioeconomic data in each of them. The first approach makes use of the differences in propensities to travel by air that can be developed from the analysis of passenger and consumer survey data. These differences in propensity are suggestive of additional ways to specify econometric models of air passenger behavior that include disaggregated information on population cohorts that exhibit greater propensities to travel by air.

New Forms of Disaggregated Socioeconomic Data for Passenger Demand Analysis

Thus far, this report has highlighted how traditional sources of disaggregate socioeconomic data have been used in airport demand modeling applications. Traditional data sources typically include surveys of air travelers (e.g., airport surveys, travel surveys, consumer expenditure surveys, etc.). As discussed in Kressner and Garrow (2012), there has been increasing interest in using non-traditional data sources for travel demand modeling applications. The interest is motivated in part by the explosion of large, third-party data sources that offer the potential of lower data collection costs per respondent. These big datasets, which range from mobile phone signal traces and GPS data to credit card spending patterns, collectively provide detailed spatial and temporal data about individuals' behaviors and mobility patterns, often in real time. This chapter provides an overview of new sources of socioeconomic data, including credit card transaction and cell phone data that may be useful for airport demand modeling applications. Given a broad overview of the potential applications of nontraditional data sources, the section concludes with a description of an in-depth study conducted as part of the current project to assess the potential of using credit card reporting data for air travel demand modeling applications

Credit Card Transaction Data

In many sectors of the economy, it is becoming increasingly recognized that the credit card transaction records maintained by credit card companies contain detailed information about spending patterns by individual card holders that can be potentially highly valuable for marketing and other purposes. Although the credit card companies of course know the identity of each card holder, privacy considerations prevent the release of data in a form that would allow the individual card holder to be identified. Even so, the credit card companies recognize the potential value of suitably de-identified information derived from the transaction data and are actively exploring ways to market this information. At the same time, potential users of this information are exploring ways to utilize the transaction data and link these data to broader socioeconomic characteristics, given the constraints that the specific individual making each transaction is not known.

Multiple firms have explored ways to link credit card transaction information to disaggregate, individual-level consumer characteristics, with varying levels of success. For example, both American Airlines and the Airlines Reporting Corporation (ARC) explored whether they could merge socioeconomic data to individual ticket transactions. The key challenge is that the zip code associated with the airline ticket purchase is that of the merchant, not the individual traveler. Thus, all customers who purchase an airline ticket through Expedia, for example, have an Atlanta zip code associated with the ticket purchase. Other information, such as the passenger's name and origin airport, can be provided to companies that maintain databases of customer addresses and demographics [see Binder, et al.(2014); Kressner and Garrow (2012); and MacFarlane, Garrow, and Mokhtarian (2015) for example applications in travel demand modeling]. The companies can use this information to link to their customer database which contains socioeconomic information. However, the individual's name and home metropolitan area may not provide enough information to uniquely identify a home zip code or census sub-region for the passenger, especially for common last names, such as Smith or Li (Carvalho, 2015; Howard, 2015). ARC estimates that his approach results in a unique match for approximately 10% of its tickets. For some applications, most notably determining catchment areas, this match rate is sufficiently large to provide useful information for airports (Howard 2015).

Sometimes, additional information about the customers is available that enhances the ability to identify detailed travel histories for individual travelers. For example, a major credit card approached ARC because they were concerned that, due to the recent wave of mergers in the airline industry, many of their elite customers were no longer allowed to use their elite credit card to access airlines' airport lounges. The major credit card company wanted to identify which airports its elite customers were using, so that it could invest in an airport lounge for those customers. The major credit card company sent a list of credit card numbers and customer names to ARC, which ARC then matched to its ticketing database. The ability to use customer name and credit card numbers allowed ARC to identify travel histories for these elite customers (e.g., how often they travelled and which airports they most often used). The credit card company merged these travel histories with its internal customer database to link its elite customers' travel histories and socio-demographic information. Armed with this information, the credit card company built a number of airport lounges for its customers in the United States (Howard 2015).

These are some examples of how credit card information has been used for concession planning/facility location in the airline industry. Depending on the level of transactional detail that is available, these data could also potentially be used to identify how often individuals travel by air, which airport(s) and airline(s) they use, and whether they pay for parking at or near the airport. As part of the current project, we obtained credit card transaction data from a financial planning firm to explore this research question in more depth.

Cell Phone Data

Over the past decade, there has been increased interest in using mobile phone signal traces and GPS data from cell phones to anonymously track individual customers through time and space. According to Bill King of AirSage (King 2014; King 2016) several airports and planning organizations have used cell phone data to identify catchment areas and/or to identify the number of passengers that have traveled in a specific travel corridor. The latter is particularly helpful for understanding the overall market potential in high speed rail corridors served both by both auto and air, as in the case for a study conducted for the Atlanta–Charlotte corridor (King, 2015). For privacy reasons, the identification number assigned to a particular cell phone is scrambled every 30 days, which effectively limits any data analysis to one based on cross-sectional (versus longitudinal) data.

There is also a growing number of airport ground access studies that have made use of cell phone data to identify travel patterns to and from airports. With some processing, it is possible to distinguish between trips by air passengers and those by airport employees and between trips by residents of the region and visitors to the region. Past studies using cell phone data have included an analysis of the geographic distribution of ground trip ends for travel to and from Ontario International Airport in California on a regular weekday, a regular weekend day, and the day before Thanksgiving, and an analysis of travel between Detroit Metropolitan Airport and hotels in downtown Detroit (King 2014).

These are some examples of how cell phone data have been used to identify ground transportation movements to an airport or passenger volumes by mode in a specific corridor. Due to the need to protect individuals' privacy, limited demographic and socioeconomic information about the travelers is available; however, some information can be obtained by identifying a (relatively large) geographic area in which the individual likely lives, such as the individual's home zip code. These data could also be helpful for identifying resident trips from home to airport, resident trips from work to airport, and non-resident trips from the airport.

Other Data Sources

There are numerous other potential sources of disaggregated data on traveler behavior. These sources include airline ticket booking and reservation data, other location-tracking devices that take advantage of cell phone signals, social media data, vehicle license plate data that is routinely collected in airport parking facilities, web search data from visitors to web sites, and transaction data collected in the course of airport concession sales or other airport operations.

ARC has also worked with airports to understand the (likely) movements of connecting passengers in its terminals. This is useful for concession planning. By modeling which gates connecting passengers arrive at and depart from, airports can forecast high foot-traffic areas. ARC built a model of connecting passenger movements by linking its ticketing data, which provided the sequence of flights the customer purchased, to gate information. ARC also explored whether it could assign a value to connecting passengers by associating aggregate socio-demographic Census information (such as the average household income for the passengers' home zip code). However, the low match rate with passenger names and origin airports made it difficult for ARC to identify large differences in customer demographics across connecting airports (Howard 2015).

Other airports have explored whether they can use location-based devices, such as beacons, to assist in airport operations planning and concession planning. Some airports, such as London Gatwick, have installed low-cost beacons throughout their concourses (McCartney 2015). These beacons allow the airports to passively collect precise information about the location of individuals who have cell phones with Bluetooth-enabled technologies, that is, beacons provide complete journey information for a sample of passengers [i.e., when did the passenger enter the airport, when did the passenger enter (and leave) security, which security line did the passenger use, which stores did the passenger pass by or visit, which restrooms did the passenger use, how long was the passenger in the gate area, when did the passenger board the aircraft, etc.]. This precise location information is anonymous, meaning no information other than the location about the passenger is known. (Cosmas and Wollersheim, 2015). However, individuals who choose to identify themselves or provide details about their trip can receive "customized GPS-like directions to their gate," as in the London Gatwick application (McCartney 2015). Nonetheless, this information can be used to help airports better understand their operations (such as where and when queues form) and plan the layout of their concessions and passenger facilities. The precise location of this technology also allows airports to push surveys to customers, e.g., to survey passengers boarding a particular flight when they are in the boarding area (Cosmas and Wollersheim 2015).

Many airports, such as Akron-Canton, use social media (including Twitter, Facebook, LinkedIn, etc.) to connect with their passengers. Through parsing unstructured texts, these data feeds can help airports identify general sentiments of passengers towards an airport, e.g., do passengers like the concession offerings? Social medial also allows airports to more directly interact with the local community and better understand who are their most vocal advocates. This can be particularly helpful during the airport expansion planning process (Cosmas and Wollersheim 2015).

License plate information has been used to identify the catchment area for an airport. For example, Frankfurt Airport uses the license plates of individuals parking at the airport to model its catchment area. This is possible because German license plates use one to three letters to link the vehicle to the county in which the vehicle is registered. The license plate data can then be used to predict catchment areas, which can be validated by results from airport surveys of its customers. This approach can also be used in airports in other countries that have a way to associate license plates to geographic areas, such as the United States on a state level (Cosmas and Wollersheim 2015). Similar to the use of beacons in airports, customers who elect to provide more information can receive more personalized services. For example, passengers who provide their flight itinerary information at the time they park in Düsseldorf airport can have a robot park their car and return it to a designated pickup area after they land (McCartney 2015).

Web search data can also be used to determine which individuals are searching for multiple airports. Many airlines are using these data to better understand airport choice in multi-airport regions (Hotle and Garrow 2014).

Many airports have duty free stores that scan boarding passes of passengers making purchases. These data are often used to model customer purchase behavior as a function of the customer's destination, flight number, nationality, and gender (Cosmas and Wollersheim, 2015).

Some examples of how disaggregated data on traveler behavior has been used in the airline industry include revenue-generating applications (e.g., through concession planning and/or targeted marketing) and cost-reduction applications (e.g., through improving operational efficiencies and better allocation of airport staffing levels). Passively collecting data provides the advantage of collecting "more" and potentially "more complete" information about travelers, but it is not perfect. The need to protect individual's privacy often prevents the ability to directly link disaggregated socioeconomic information to individual-level transaction data.

Spotlight: A Study of How Credit Transaction Data Can Be Used to Model Air Passenger Behavior

As part of the current project, we conducted an in-depth study to see how credit transaction data could be used to model air passenger behavior. Our analysis (detailed in Appendix E)

Table 41. How often trip characteristics were identified in sample of financial data.

Trip Characteristic	Percent Identified
Airline	100
Price	97
Group size	99
Booking date	95
Destination	38
Outbound departure date	26
Outbound departure date range	39
Inbound return date	30
Inbound departure date range	40
Outbound departure airport (or inbound arrival airport)	6
Outbound arrival airport (or inbound departure airport)	3

highlights several challenges we faced in re-purposing existing (and de-identified) data for a new application. As part of the analysis, we needed to:

- Develop algorithms to determine the home zip code for the credit card holder;
- Use text parsing to identify which transactions involved the purchase of an airline ticket; and
- Use the sequence of transactions to identify when an individual left their home zip code and (likely) traveled by air to a different destination.

We conducted a case study of the Los Angeles area that included all zip codes located within 100 miles of five airports in the Los Angeles area: Burbank (BUR), John Wayne (SNA), Long Beach (LGB), Los Angeles (LAX), and Ontario (ONT). Based on a sample of 50 households in this study area, we determined how often the trip characteristics shown in Table 41 could be identified. As seen in the table, information about the airline, price, group size, and booking data was easily identified from the data, but information on the travel dates, where the individual actually went, and what airports the individual used were much more difficult to infer from the transactional data. We also discovered that the distribution of air travel party size for the air trips in the financial transaction database is quite different from that found in recent air passenger surveys. As shown in Table 42, the financial transaction database contains a much larger percentage of air trips with two more travelers than the air passenger surveys.

Based on the analysis of the financial transaction database, we conclude that financial transaction data show promise for being used in the future, but currently lack some critical information (most notably the ability to consistently identify the airports used). Further research is needed to identify how complete and representative these financial transaction databases are. It can be expected that, if the market penetration and consumer acceptance of using online financial tools grows, so too will the value of the collected financial transaction data for planning applications.

Table 42. Comparison of group size distributions.

Group Size	Financial Transaction Data	SFO 2014/15 Air Passenger Survey[1]	MWCOG 2013 Air Passenger Survey[2]
1	4.2%	53.7%	51.5%
2	74.1%	32.4%	35.6%
3+	21.7%	13.9%	12.9%
Average	2.46 pax	1.71 pax	1.71 pax

[1] Survey responses for U.S. residents making personal trips (domestic and international)
[2] Survey responses for MWCOG regional residents making personal trips (domestic and international)

Approaches to Air Passenger Demand Model Specification

The case study analysis in the previous chapter has demonstrated one approach to incorporating disaggregated socioeconomic variables into air passenger demand models, albeit in a fairly simple way. However, the research team has identified four different ways disaggregated socioeconomic data could be incorporated into air passenger demand models:

- Use of variables that reflect the shape of the distribution of the explanatory variable in a single relationship in addition to variables that reflect the aggregate or average value of the explanatory variable (the approach used in the models described in the previous chapter);
- Use of separate variables for different ranges of the explanatory variable in a single relationship;
- Use of separate relationships for different ranges of each explanatory variable; and
- Use of a simulation approach that generates a measure of trip propensity for individuals with specific values of the explanatory variables.

Alternative Approaches

Use of Variables Reflecting the Shape of the Distribution of Explanatory Variables

This approach might include, for example, variables for the 20th and 80th percentiles of the household income distribution in addition to the average household income. Since air travel propensity varies with income, the resulting demand model could be expected to indicate how air travel demand is sensitive to changes in the distribution of household incomes as well as the average or aggregate income. For models where the explanatory variables are multiplied together (such as the common log-linear model), the variables for the distribution percentiles should be expressed as ratios of the average income rather than in monetary terms to avoid having two income values multiplied together.

Although in principle this approach could be applied to any socioeconomic variable, it makes most sense to apply it to the income variable, since it is known that income distributions have been changing over time, that air travel demand varies with household income, and data on household income distributions for each year are readily available from the U.S. Census Bureau. The U.S. Census Bureau report *Income and Poverty in the United States: 2015* (Proctor, Semega, and Kollar 2016) includes a table showing the household income distribution for each year from 1967 to 2015. The data show that households with an income of $200,000 or more in constant 2015 dollars increased from 2.1% of all households in 1985 to 5.1% of all households in 2005 and 6.1% of all households in 2015. Conversely, households with an income of $25,000 per year or less declined from 24.6% of all households in 1985 to 22.0% of all households in 2005 and 22.1% of all households in 2015. Perhaps of greater relevance for air travel demand, the percent of households with incomes between $50,000 and $100,000 declined from 33.3% of all households in 1985 to 30.4% of all households in 2005 and 28.8% of all households in 2015.

Although the annual changes in these percentages are not large and the trend has been fairly stable over the last 30 years, some of the increase in air travel over that time period is clearly due to the changing income distribution (a higher percentage of households in the higher income brackets that have a higher air travel propensity) rather than the change in the average household income. This showed greater year-to-year variability, increasing from $61,049 in 1985 to $76,878 in 2005 (a 25.8% increase) and to $79,263 in 2015 (3.2% increase from 2005), but declining in some years, particularly during recessions.

In addition to income, there is the question of whether to include distributional variables for other demographic or socioeconomic variables in air travel demand models. Analysis of air passenger and household travel surveys has shown that air travel propensity varies by age, gender, race/ethnicity, and educational attainment, as well as income, although some of these effects may be correlated. For example, the analysis of demographic trends presented in Chapter 3 shows that the median income of households with a head of household age 65 or older has grown faster than all other households. The extent to which changes in the distributions of these characteristics may help explain changes in the demand for air travel can be addressed in air passenger demand model development by examining the correlation between model residuals and variables measuring the changes in the distributions of these characteristics.

One potential challenge to the application of this approach that needs to be explored in model development work is the extent of correlation between the distributional and aggregate variables, which would make it difficult or impossible to obtain statistically significant coefficients for both types of variables in the same model. Both types of variables are slow-moving and generally change in a consistent direction, so are quite likely to be highly correlated.

Use of Separate Variables for Different Ranges of Explanatory Variables

This approach provides greater flexibility in reflecting the effect of the underlying distribution of particular socioeconomic variables, such as income or air traveler age, by defining separate variables for different income or age ranges. However, this imposes two limitations on the analysis. The first is a more complex functional form, since the variables for each value range for a given factor cannot simply be multiplied together. Rather, terms for the demand generated by each subset of the total population formed by the various value ranges (each of which may well have a multiplicative form) must be added together to give the total demand.

For example, a simple model using total household income (H) and average airfare (P) might take the following form:

$$\text{Pax} = \left(\text{a1} \times H1^{\text{b1}} \times P^{\text{c1}}\right) + \left(\text{a2} \times H2^{\text{b2}} \times P^{\text{c2}}\right) + \ldots + \left(\text{an} \times Hn^{\text{bn}} \times P^{\text{cn}}\right)$$

where $H1$, $H2$, . . . , Hn represent the total household income for different income ranges.

This formulation allows for a different income and airfare elasticity for each income range, although the model structure could be simplified by restricting each income range to have the same airfare elasticity (i.e., c1 = c2 = . . . = cn = c) or even the same income elasticity (i.e., b1 = b2 = . . . = bn = b) although it would be surprising if in fact air travel demand for households in different income ranges had the same sensitivity to changes in income. Nonetheless these are research issues that could be explored.

The second limitation is the need for a much larger number of data points for estimating the larger number of model coefficients implied by the approach. This suggests that this approach would be more appropriate to use with a large panel dataset, such as the demand in multiple O&D markets or for a single model that is estimated across a number of airports or regions.

The resulting model segmentation is also likely to result in model functional forms (such as the one shown above) the coefficients of which cannot easily be estimated using standard linear regression estimation techniques. Therefore, research is needed to identify appropriate statistical techniques to estimate such model functional forms, such as the use of maximum likelihood estimation or nonlinear regression.

Use of Separate Relationships for Different Ranges of Each Explanatory Variable

This approach avoids some of the technical challenges of the second approach by estimating separate models for different subsets of the population. Although this is likely to require a less complex functional form for each model, it requires an estimate of the demand generated by each subset of the population. Since there is no way to obtain this from the reported air passenger traffic, it requires air passenger survey data to segment the reported traffic into the air trips made by each subset of the population. However, segmenting the models in this way not only simplifies the model estimation process (since the model for each segment can have the same functional form as a model developed using aggregate data), but allows a much finer definition of the population subsets than would be practical with the second approach.

The challenge with applying this approach is that most airports have limited air passenger survey data (or none at all) that can be used to estimate the proportion of the total air passenger traffic in each subset of the population. Even those airports that have undertaken several air passenger surveys over time typically do not have survey data for every year. In these cases it would be necessary to interpolate the proportions between the years for which survey data is available. To assess the likely validity of this approach, it would be helpful to undertake some analysis of how much these proportions vary from year to year (at least for those years for which survey data is available).

For airports where air passenger survey data is only available for one year, the proportions for other years can be estimated by applying the trends from airports for which multiple surveys are available. This is obviously less satisfactory than having survey data for multiple years, but may still be better than ignoring the differences between subsets of the population entirely.

One potential approach, although one that would require a significant amount of data analysis, would be to examine trends over time in the spending on air travel and number of air trips by households in the different subsets of the population, using data from the CES, which is available on an annual basis. Although the sample size of the CES is not large enough to obtain reliable data for a given geographical area served by a specific airport or regional airport system, it is large enough to allow some segmentation between major metropolitan areas and smaller communities in general, as well as differences between different regions of the United States (defined broadly).

Use of Simulation to Generate Estimates of Air Travel from Trip Propensity Data

This approach takes a much more disaggregate approach to forecasting air travel demand based on air travel propensity relationships identified through analysis of air passenger survey data rather than a conventional econometric approach that attempts to fit a model to observed data using regression or other techniques. Although this approach requires a much greater amount of data than traditional econometric techniques that are based on reported air passenger traffic and fairly aggregate measures of potential causal variables, it avoids the inherent constraints imposed by the functional form of any given econometric model and provides much greater flexibility to vary the assumptions used for future values of the causal variables.

However, while past air travel propensity relationships can be determined from survey data, these relationships do not explicitly consider the effect of changes in pricing. Any practical application of this approach must also include a way to incorporate changes in airfares and other travel costs as well as changes in air travel propensity that result from trends in the level and distribution of socioeconomic variables.

The effect on air travel propensity of changes in airfares and other air travel costs can be assessed by applying estimates of the price elasticity of air travel demand. This has been extensively studied for airfares and estimates exist for different types of air trip, as discussed in the literature review documented in Chapter 2. Generally, it has been found that the airfare price elasticity for business travel is somewhat less than –1 in an absolute sense (i.e., air travel declines somewhat less than proportionately to an increase in cost) while airfare price elasticity for nonbusiness travel is somewhat greater than –1 in an absolute sense, reflecting that nonbusiness travel is generally more discretionary than business travel. If airfares decline in real terms, households choose to make more air trips at the expense of other consumption, and vice versa if real airfares rise.

Although the exact airfare price elasticity for households with a given set of characteristics will not be known to any degree of precision, using an approximate elasticity value will correct for much of the effect of airfare changes and any errors this introduces can be corrected by calibrating the results to actual air passenger traffic levels.

Where air passenger survey data is available for surveys undertaken at the same airport over a period of time (as is the case for several of the airports or regions studied in the current project), trends in air travel propensities for survey respondents with a given set of socioeconomic characteristics can be determined and applied to years for which survey data is not available. If these changes in trip propensity can be shown to be reasonably consistent across different airports, even if the actual trip propensity values differ, then they could be applied to airports for which survey data is only available for one year, or even to airports for which no air passenger survey data is available, by adjusting the resulting estimates of total air passenger demand to conform to the actual air passenger traffic levels.

Given estimates of air travel propensity for households with any given set of household characteristics for a given year, taking into account the effect of changes in airfares and travel costs, the total number of air trips at an airport or for a region in a given year can be estimated by generating a synthetic sample of households with appropriate characteristics from the regional distributions of household characteristics and then simulating the number of air trips that each of these households would be expected to take in the year. The resulting projected air trips can then be calibrated to the actual passenger traffic for past years and the resulting calibration factors used to forecast future air travel, based on scenarios for future trends in socioeconomic characteristics and future trends in airfares and other travel costs.

Implementation Considerations

Business and Personal Travel

The analysis of air passenger and household travel surveys has shown, not surprisingly, that the distributions of household characteristics of those making business and personal trips are significantly different. More important from the perspective of air passenger demand modeling, the factors influencing the demand for business and personal air travel are also likely to be different. In reality, it is not households that generate business trips but businesses (although of course those making business trips are members of households). Therefore the level of business trips at an airport is likely to depend on the composition and size of the local economy, as well as other factors unrelated or only indirectly related to the distributions of household characteristics in the region served by the airport.

This suggests that one dimension of disaggregation in air passenger demand modeling would be to distinguish between business and personal trips. This could be fairly easily accomplished by the last three approaches discussed earlier, but would be more difficult to address using the first approach discussed, although one such approach has been demonstrated in the detailed analysis of the Baltimore-Washington region described in Chapter 4. The underlying concept in each of the latter three approaches is to add terms to the demand function to cover business trips or (in the case of the third approach) simulate personal and business trips separately. Of course, this requires knowing the split between business and personal travel, but this can be obtained from air passenger or household travel survey data in exactly the same way as estimating the proportion of trips by households with different characteristics.

Although the simulation of business travel could be based on the number of households with given characteristics in the region and the business trip propensity by household, it would be more logical to base the simulation of business trips on employment by sector. This would allow forecasts of future air passenger demand to reflect projected or assumed changes in the growth of employment by sector. Similarly, in the second and third approach, the demand function terms for business travel could use variables reflecting the composition of the local economy and employment levels rather than household characteristics.

Developing estimates of business air trip propensity relative to sectoral employment would require analysis of air passenger or household travel survey data, or other data sources, to identify the distribution of business trips by economic sector. Unfortunately, few air passenger surveys ask about the type of firm or organization that business travelers are employed in and given the large number of economic sectors and the likely variation in business travel propensity per employee, obtaining this information in sufficient detail from air passenger or travel surveys would be very unwieldy. Furthermore, including sufficient terms in a single air passenger demand model to address many different sectors would result in an excessively complex functional form for which it would be extremely difficult, if not impossible, to obtain statistically significant coefficient estimates.

A more practical approach would be to use total employment and an estimate of average business air trip propensity obtained from a separate analysis of business air trip propensity in each sector and the sectoral composition of the local economy. This is still sensitive to changes over time in the sectoral composition and can reflect anticipated future changes. Since estimating business air trip propensity by sector from air passenger or travel survey data is problematic, it may be more productive to analyze differences in business spending on air travel by sector. There is a considerable amount of data on business travel from a wide range of sources (see https://www.creditdonkey.com/business-travel-statistics.html for examples) that could provide estimates of trends in business travel expenditures and average costs per trip (which would allow expenditures to be converted to trips). The 2007 input-output model of the U.S. economy available on the website of the U.S. Bureau of Economic Analysis provides a detailed breakdown of spending on air transportation by economic sector. Although these data are only for one point in time, the relative business air trip propensities across different economic sectors are likely to be fairly stable, since they are largely determined by the types of activities undertaken by employees in firms or other organizations in each sector. Therefore these data can be combined with trend data from other sources to obtain estimates of business air travel propensity by sector for other years.

Air Trips by Residents and Visitors

Analysis of air passenger survey data has also shown that there are differences in the composition of air passenger trips at a given airport between those made by residents of the region served by the airport and visitors to the region. Although the approaches described earlier make sense for air trips generated by residents of a region, it is less clear that they apply to air trips by visitors. At a minimum, the distributions of household characteristics for visitors are likely to be different from those for residents, and in any case the air trips to a region made by visitors are not the only air trips that those people made. There may be a degree of symmetry for some types of trip between trips made by residents and those made by visitors. For example, trips by residents to visit family and friends elsewhere may be balanced by trips by visitors to visit family and friends in the region. However, for other types of trip, such as those for vacations, attending college, or medical treatment, there is no reason to expect that the levels of air trips by visitors are likely to be similar or proportional to those by residents.

Data from air passenger surveys performed at the same airport over time can provide some indication of whether the composition of the different types of trip appears to be fairly stable over time. The U.S. DOT 10% O&D data can be analyzed to show the extent of the variability in the split of air trips at a given airport between residents and visitors over time as well as any overall trends. Since these data are available on an annual basis, they can be used to divide the total air passenger traffic at an airport into three components: outbound trips by residents, inbound trips by visitors, and connecting passengers. Since the latter are largely a consequence of airline network and hubbing strategies rather than the demographic and socioeconomic composition of the region where the hub airport is located, forecasting connecting traffic requires a different approach from that for O&D traffic that is beyond the scope of the current project.

Although all four approaches to incorporating disaggregated socioeconomic data in air passenger demand models can be applied as well to modeling visitor trips as resident trips, the variables used may well be different, particularly for personal trips by visitors for purposes other than visiting friends and family.

In using the 10% O&D data to separate total traffic into the three directional components, care should be taken to make adjustments in the analysis for one-way trips. While these undoubtedly do include some genuine one-way trips, most are an artifact of travelers purchasing two separate tickets, typically on different airlines to obtain a lower overall round-trip fare or more convenient flight schedules. Even for those that are genuine one-way air trips, it is not clear whether the traveler is a resident of or visitor to the region containing the first airport in the itinerary. It is therefore reasonable to assume that the proportion of one-way trips in each direction that are outbound trips by residents of the region containing the first airport in the itinerary reflects the directional split given by the round trip itineraries in the data. Where appropriate questions have been included in air passenger surveys to identify respondents who were making a one-way air trip, these data can be used to estimate the true proportion of actual one-way trips in each direction.

CHAPTER 6

Final Perspectives and Future Research Opportunities

Research for this project has examined a wide range of existing studies of air passenger demand and air passenger activity by many types of researchers, as well as the types of data typically used to design and conduct these studies, along with the sources of these data. This effort has focused both on understanding how and why these studies were conducted and the extent to which the studies made use of disaggregated socioeconomic data.

The research team used what was learned about the state of practice in modeling air passenger demand as a starting point for new research into how disaggregated socioeconomic data could be used to improve the modeling of passenger demand and observed enplanements. This new research proceeded along several paths. One of these research paths investigated what could be learned from air passenger, household travel, and consumer survey data about how air passenger travel demand varies with the disaggregated demographic and socioeconomic information about air travelers that is typically collected in these surveys.

A second research path investigated the effects of including a disaggregated socioeconomic variable in traditional models of air passenger demand at individual airports (which already make use of aggregated regional socioeconomic variables). This research took a case study approach, evaluating the results from including a disaggregated socioeconomic variable in traditionally structured regression models of annual O&D enplanements for eight U.S. airports or airport systems.

A third path examined alternative ways new specifications and equation forms could incorporate disaggregated socioeconomic variables or relationships in models of air passenger activity at an airport or in an airport system. This effort used insights from the analysis of past air passenger surveys and the differences in the propensities to travel by air of different socioeconomic cohorts revealed by those analyses.

The fourth research path evaluated the usefulness of new forms of disaggregated socioeconomic data about air passengers. These data were developed from de-identified financial transaction records of individuals who made use of personal financial management software. While only a small fraction of such consumer spending is directly related to air travel choices and behavior, these digital forms of data collection represent a rapidly evolving frontier for the development of information about consumer purchase choices in a wide range of markets, including passenger aviation.

These four research avenues pursued in this project together comprise a multifaceted approach to developing an improved understanding of the potential value of disaggregated socioeconomic data in the analysis of air passenger demand for airports. Aspects of this overall approach directly address the four forward-looking questions identified in the introduction to this report:

- How does air passenger behavior differ across socioeconomic cohorts or subgroups, especially with respect to individual propensities to choose to travel by air?
- Can disaggregated socioeconomic factors be introduced into traditional approaches to modeling air passenger demand at individual airports or systems of airports, and do those variables provide new information compared to a baseline of traditional air passenger demand modeling using aggregate socioeconomic variables?
- Can new approaches to structuring econometric models or other approaches be developed and used to realize the value of incorporating disaggregated socioeconomic data in understanding or modeling air passenger demand?
- Are there new forms of disaggregated socioeconomic data, or new ways of collecting such data, that can be used to model or study air passenger demand at airports and in regions?

In this report we have summarized how we conducted project research to address these questions, and also reported the results from these research efforts. In the remainder of this chapter, we present the findings from our research and the research opportunities that we believe these findings open for future researchers.

Summary of Research Approach

This research project has investigated the effectiveness of incorporating the use of disaggregated socioeconomic variables in studies of air passenger demand and air passenger activity at airports. The research was organized to first identify how such studies have been conducted and reported in the past. The review of these past examples extended across research conducted by a wide range of individuals and organizations, including academics, governmental and industry organizations, and airport practitioners and consultants. The research next covered the types of data that have been used in studies of air passenger demand as well as the types and sources of disaggregated socioeconomic that could also be used in such studies. This research identified trends in the evolution of age and household income cohorts in the United States. The research then extended to an analysis of air passenger and consumer surveys to identify ways the propensity of individuals to travel by air vary by their demographic and socioeconomic characteristics, such as age, gender, or household income.

The research then used a case study approach to examine the effects of adding a disaggregated household income variable as an independent regressor to more traditional models using aggregate socioeconomic variables. This model performance comparison was done for eight case study airports using observations of annual O&D enplanements between 1990 and 2010 for seven U.S. airports and one U.S. airport system. This approach permitted the assessment along several dimensions of the impact of incorporating this type of data in air passenger demand modeling.

A second case study analysis was conducted using data from the Baltimore–Washington airport system to examine the effectiveness of more sophisticated model formulations, again comparing model performance without and with the inclusion of a form of disaggregated socioeconomic variable among the independent variables of the regressions.

The research then examined the potential for using new forms of disaggregated (or more individualized) socioeconomic data for air passenger demand modeling, based on individual financial transactions data from a group of individuals.

Summary of Findings from Research

The primary goal of the research project was to investigate the extent emerging or ongoing socioeconomic changes in the population (such as the age structure of society, increased immigration, wealth concentration, geographic redistribution of the population, and changing views on the use of disposable income) are likely to influence the future demand for air travel and may not be well captured in current approaches to air passenger demand modeling. More specifically the research explored whether the inclusion of disaggregated socioeconomic data, such as regional distributions of age, gender, or household incomes, in air passenger demand models can improve the ability of those models to anticipate future changes in the overall demand for air travel and composition of the air traveling public.

The research found that the use of air travel by different subsets of the population (in terms of household income, age, race and ethnicity) varies widely. It is clear that changes in the distribution of these characteristics across the population are likely to have a significant impact on future air travel demand. In particular, an increasing concentration of wealth and income in the wealthiest segment of society appears likely to reduce the amount of air travel compared to a less concentrated distribution for any given level of total income, excluding the effect of other factors, for reasons discussed earlier in this report. At the same time, increasing concentration of wealth and income may continue to change air travel in more qualitative ways, with airlines charging separately for service amenities that some segments of the traveling public are willing to forego in order to obtain a lower airfare. Similarly, an aging population will move an increasing proportion of the population into age ranges that make fewer air trips per year than those in the age range from 45 to 65 that make the most air trips per year on average.

The research explored a number of different ways of reflecting these trends in air passenger demand studies and models, although an attempt to develop models of enplaned air passenger traffic for eight case studies of individual airports and one regional airport system that incorporated disaggregated variables that reflected the distribution of household incomes met with mixed success. Adding a disaggregated household income variable to relatively simple models that used only two aggregate socioeconomic variables did not noticeably improve the ability of the models to either explain past air passenger enplanements or predict future passenger traffic levels in a simulated forecasting exercise. However, a more complex model using a different disaggregated household income variable did show improvement in either its ability to explain past levels of air passenger enplanements or its ability to predict future air passenger traffic. While this improvement was not large, the implications for future levels of air passenger demand of the change in the implied demand elasticity (model coefficients) between the model without the disaggregated income variable and the model with the variable were significant. This finding has broader implications beyond the specific models estimated in the research. Elasticity values obtained from air passenger demand models are sometimes used or quoted in other studies. If these values are biased due to the omission of disaggregated socioeconomic variables in the models from which they were obtained, this could distort the results of these other studies.

Future Research Opportunities

The analysis of disaggregated response data from air passenger, household travel, and consumer expenditure surveys raised a number of issues that appear deserving of further research. These are discussed in more detail in the description of the analysis findings in Chapter 3, but can be summarized as follows:

- The analysis of the three broad categories of survey (airport intercept, household travel, and consumer expenditure) gave different estimates of air travel propensity for given population subgroups. In particular, the California Household Travel Survey appeared to undercount air trips by California residents. Further work to resolve these differences in findings from different surveys is needed.

- The analysis of the survey results looked at different socioeconomic factors (income, age, etc.) separately, but in reality they are most likely correlated. Further research to explore the implications of this correlation and develop techniques to account for different socioeconomic factors simultaneously would be valuable.
- The demand for air travel depends not only on socioeconomic factors of the population but also on the level of airfares experienced by travelers from a given region. It would be valuable to develop techniques to account for differences in airfare levels between airports or regions in order to be better able to compare findings on air travel propensity by household or air traveler socioeconomic characteristics across different airports or regions.

The case study regression analysis relied on a relatively simple model specification to investigate the effects of incorporating a specific example of a disaggregated socioeconomic variable on the performance of baseline models relying on aggregate socioeconomic variables (and another independent variable unrelated to socioeconomic factors). While the specific disaggregated socioeconomic variable chosen for these comparisons—one reflecting regional household income distributions—is a natural candidate for consideration in a model of air passenger demand, there may be other disaggregated socioeconomic variables that could be analyzed. In addition, it may be valuable to analyze other ways of introducing the information from the disaggregated variable into the regression, since the comparisons of baseline and alternative models were affected by the strong correlation between the aggregate and disaggregated variables used in the case study regressions.

The more detailed analysis of the passenger enplanements in the Baltimore–Washington regional airport system performed as part of the overall case study analysis developed a model that provided an excellent fit to the historical data using a range of independent variables that make intuitive sense and had estimated coefficients that had values that appeared reasonable and were estimated with a high level of statistical significance. As noted above, including a disaggregated variable for household income distribution not only improved the fit of the model to the data and its predictive ability but also changed the estimated values and increased the statistical significance of the other variables, suggesting that omitting such variables from air passenger demand models could lead to biased estimates of the model coefficients. However, there were aspects to this model that are deserving of further research, in particular:

- In addition to the continuous variables the model made use of year-specific dummy variables that accounted for factors not reflected in the continuous variables. These played a major role in the model fit. It would be valuable to explore other continuous variables that could account for these effects without relying on year-specific dummy variables (which are problematic in using models for forecasting).
- The model used average airline yield at a national level as the airfare price variable. However, this may not be a good reflection of airfares for any particular airport. It would be valuable to explore the use of a variable that better reflects the average airfares at the airport(s) in questions.
- The model used a disaggregated variable for household income distribution but did not consider changes in the distribution of other socioeconomic factors, such as the age of air travelers. It would be valuable to explore how to incorporate changes in the distribution of other socioeconomic factors in similar models.
- The model variables reflected socioeconomic factors for residents of the Baltimore-Washington region, but of course a large proportion of the passengers at the region's airports (over half in the case of the Baltimore-Washington region) are visitors. It would be valuable to explore how to account for socioeconomic factors of visitors as well as residents.

More broadly, the approach followed in developing the more detailed model of the Baltimore-Washington region needs to be applied to other airports and regions to determine whether the resulting models for those airports or regions also show a similar improvement or whether the results found for the Baltimore-Washington region are somehow unique to that region or maybe even an artifact of the data used in the analysis. In addition, the Baltimore-Washington region is one of the largest multi-airport regions in the country and the airports serving the region are much larger than most other individual airports to which the approach could be applied. It would be valuable to explore whether such differences in scale or the extent of the airport system being modeled also affect the applicability or performance of this modeling approach.

There are several research opportunities related to using the new data sources for airport demand modeling studies discussed in Chapter 5. We found that many of the most successful applications of using cell phone or location-based data for airports were for revenue-generating and cost-reduction purposes. In the context of airport demand studies, we found successful applications using cell phone and ticketing data to analyze airport catchment areas. In terms of future research, cell phone usage could be a source of new data on passenger choices and passenger movements through terminals. Future research could explore linking cell phone tracking data to small-area demographic and socioeconomic data to explore air travel propensity by household characteristics without the need for air passenger surveys (or to track changes between surveys). Cell phones could also be used as a tool to gather data similar to the types of data collected in traditional airport survey efforts. For example, cell phone beacons and airport-specific phone apps could invite air travelers to participate in an online air passenger survey. Travelers could download a survey form that they could complete at leisure (for example, on their flights) and then submit online when they next have an internet connection. Both of these future research opportunities help address one of the key challenges to using new sources of disaggregated data based on cell phone, GPS, or financial transactions, namely that due to the need to protect individuals' privacy there is limited socioeconomic information available from these sources directly.

Chapter 5 also discussed alternative potential approaches to incorporating disaggregated socioeconomic factors in air passenger demand studies and models. However, the resources of the project only allowed one of these approaches to be explored and then only with a very limited number of variables and for only one socioeconomic factor (household income). It would be valuable to develop techniques for applying the other approaches or including a broader range of factors and to explore their relative feasibility and effectiveness. Because the sources of data on air passenger enplanements do not typically distinguish between travel by residents of a region and visitors to a region or between travel for personal and business purposes, models of air travel demand have generally attempted to model total air travel. Since the survey analysis undertaken in the course of the project shows, not surprisingly, that the average number of annual air trips made for business and personal purposes differs considerably by household or individual characteristics, while it can also be expected that the factors influencing air travel by residents of a region and visitors to the region are different, it would be valuable to explore the feasibility and effectiveness of developing air passenger demand models that can distinguish between travel by residents of a region and visitors to the region or predict travel by trip purpose.

The foregoing potential research opportunities represent a wide range of possible research projects that would build on the work performed in the current project and that could be pursued through future research. The description of the research performed for the current project and the discussion of potential research opportunities in this report provide a fairly clear indication of how potential future research projects could be undertaken. Nonetheless, more detailed research problem statements could be developed following publication of this report.

This would allow other interested researchers to contribute suggestions and comments on the scope of future research.

Although each of the potential research opportunities would contribute to a better understanding of how air passenger demand is influenced by disaggregated socioeconomic factors and how to best reflect this in air passenger demand models, and hence there is no obvious priority between the various research needs, it would seem reasonable to focus initially on two issues: explore applying the modeling approach used for the more detailed analysis of the Baltimore–Washington region to other airports and regions in order to determine how transferable these findings are and investigate the reasons for the differences in air travel propensity between air passenger intercept surveys and household travel and expenditure surveys. A clearer understanding of the reasons for these differences would allow future research on air passenger demand to draw on a broader range of disaggregated socioeconomic data with greater confidence, as well as potentially provide useful guidance for the design of such surveys in the future.

Conclusions

Passenger aviation is often described as an important catalyst for broad economic growth and is often depicted, qualitatively and in formal models of air passenger demand, as being driven by aggregate measures of regional economic activity and growth. Yet it is also understood that air transportation is not used to the same extent by all segments of society. This project has examined whether this growing understanding of the differences in propensities to fly that depend on individual and household characteristics such as household income, age, or educational status can be used to improve models and forecasts of air passenger activity. These differences were consistently seen in analyses of a number of surveys of air passengers and consumers.

While data about distinct subgroups of individuals and households—disaggregated socioeconomic data—and about how their distributions of characteristics are changing are available, these data are sometimes correlated with the aggregate regional socioeconomic data used in the past for the airport passenger demand models used in a variety of airport studies and planning efforts. This correlation can raise statistical challenges for simple approaches to incorporating some forms of disaggregated socioeconomic data into existing models of air passenger demand. The project's analysis of the effect of incorporating a particular disaggregated socioeconomic variable into fairly simple regression models of annual enplanements in case studies of seven individual U.S. airports and one regional airport system ran into such challenges, while resulting in only modest improvements in the performance of the models that included the disaggregated socioeconomic variable. Therefore, care must be taken in including disaggregated socioeconomic variables in air passenger demand models to avoid or control for potential correlation between aggregate and disaggregated socioeconomic variables to the extent possible. It should also be recognized that there may be tradeoffs in model performance between omitted-variable bias in models that only include aggregate socioeconomic variables and a loss of statistical significance and potential bias in coefficient estimates if disaggregated socioeconomic variables are included that are partially correlated with the aggregate socioeconomic variables. As more experience is gained in using disaggregated socioeconomic variables in air passenger demand models, it should become clearer how best to resolve such trade-offs.

Although including a disaggregated household income variable in the simple case study regression models did not show a significant improvement in the predictive ability of the models, including a different disaggregated household income variable in a more complex model specification for the case study of the Baltimore–Washington regional airport system did provide an improvement in both model fit to the historical data and predictive ability. Furthermore, including the disaggregated income variable resulted in a significant change to the demand elasticities implied by the estimated model coefficients.

Three important conclusions can be drawn from this experience:

- The way in which disaggregated socioeconomic variables are defined is important. If they are defined in a way that partially reflects the factors measured by the aggregate socioeconomic variables in a model, their addition to the model may not result in any improvement in model fit and may reduce the statistical significance of the estimated coefficients of the aggregate variables in the model.
- Simple models with relatively few independent variables that do not fit the historical data very closely are not likely to show much improvement by including variables that reflect the distribution of aggregate socioeconomic factors included in the model. This is because there are clearly factors influencing the dependent variable that are not well represented by the independent variables. It is not likely that including a variable that reflects the distribution of one of the factors measured by an aggregate variable will rectify this problem and the model estimation process may use the additional variable to account for factors that happen to be correlated with it, distorting not only the estimated coefficient of that variable but those of other variables as well.
- For use in air travel demand forecasting what matters most in a model is that the demand elasticities implied by the model coefficients accurately reflect the likely effect of the independent variables in question. Good fit to the historical data is desirable and provides some assurance that the model is reasonable, but if this is achieved through biased coefficients of the independent variables the ability of the model to correctly anticipate the effect of any given scenario for future values of the independent variables will be compromised.

An alternative approach to the modeling undertaken in the case study analysis, given initial investigation in this project, would be to develop new models or new forms of disaggregated data that may avoid some of the difficulties encountered in the case study analysis. The modest but real improvements in model performance observed in the project case studies and the consistent results from survey analysis linking respondent socioeconomic characteristics and differences in household propensity to travel by air suggest that continued research would be worthwhile in this area. Further investigation and exposition of this alternative approach to air passenger demand modeling could be the basis of additional research. In addition, a second project could focus on further development of the model specifications developed for the Baltimore-Washington region, applying them to other airports and airport systems, and explaining the modeling results and their implications. Such research may bring new insights to airport managers and decision makers facing a changing air travel marketplace.

It was noted that airports use air passenger demand studies for many purposes, from analysis of behaviors and choices of the passengers they currently serve or hope to serve to the support of an airport's planning and preparation for future passengers and services. The research conducted in this project can provide value for those who will prepare these studies for airport managers as well as for the airport managers, planners, and decision makers who will use the studies.

- Airport staff and airport consultants who prepare models and reports on air passenger demand for airport managers may find new insights in the report's analysis of air passenger surveys and the variability in the propensity to travel by air that is revealed across different demographic and socioeconomic subgroups. These new insights may influence the formulation of new models for air passenger demand or may contribute to the interpretation of results from more familiar modeling specification.

- Those engaged in air passenger modeling may also find the case study analysis and especially the investigation of new modeling specifications for air passenger demand at the Baltimore-Washington airport system suggestive of new approaches that could be taken in their own assignments.
- Airport planners and managers (and other users of air passenger demand studies) may find the report's presentations of demographic and socioeconomic trends, air passenger choices and behaviors, and the shortcomings and opportunities that are identified for formal passenger activity modeling valuable to their own needs to interpret air passenger demand studies and act on them.
- Finally, air passenger demand models are also developed and used by other aviation industry participants, such as government agencies, aircraft manufacturers, airlines, and academic researchers. Although these parties may look to models at different levels of generality or complexity, they may also find that the cautions and innovations for air passenger modeling techniques developed for this report can also contribute to their own modeling efforts.

The current research project represents an initial effort to both understand how the distribution of socioeconomic factors across the population affects the demand for air travel and to explore how to incorporate these effects in air passenger demand studies and models. It has generated a large amount of relevant information from a detailed analysis of air passenger, household travel, and other surveys, the full analysis of which will require much further work. It has also demonstrated that incorporating these effects in air travel demand models not only can improve the predictive ability of those models, but indeed is essential for them to have good predictive ability, given the underlying changes in the socioeconomic composition of society. However, much work remains to be done to develop robust models of air passenger demand that can be applied in a range of settings. This will require a sustained research effort over many years.

As the literature review undertaken in the current project has demonstrated, the state of practice of air travel demand analysis has hardly evolved at all over the past 40 years. However, the current project has laid the foundations upon which a significantly improved understanding or air travel demand and an evolving state of practice can be built through continuing future research efforts.

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Abbreviations

AAAT	Annual Average Air Trips
ACI	Airports Council International
ACI-NA	Airports Council International-North America
ACRP	Airport Cooperative Research Program
AHI	Average Household Income
ARC	Airlines Reporting Corporation
ASQ	Airport Service Quality
A4A	Airlines for America
BEA	Bureau of Economic Analysis (Department of Commerce)
BLS	Bureau of Labor Statistics (Department of Labor)
BOS	Boston Logan International Airport
BTS	Bureau of Transportation Statistics (Department of Transportation)
BWI	Baltimore/Washington International Thurgood Marshall Airport (airport code)
CATI	Computer-Assisted Telephone Interviewing
Caltrans	California Department of Transportation
CES	Consumer Expenditure Survey
CHTS	California Household Travel Survey
CPI	Consumer Price Index
CSA	Combined Statistical Area
DB1B	Database 1B (U.S. DOT airline O&D survey data)
DCA	Ronald Reagan Washington National Airport (airport code)
DfT	Department for Transport (United Kingdom)
EUG	Eugene Airport (airport code)
FAA	U.S. Federal Aviation Administration
FRED	Federal Reserve Economic Data
GDP	Gross Domestic Product
GNP	Gross National Product
GPS	Global Positioning Systems
GRP	Gross Regional Product
HH	Household(s)
HHI	Household Income
HSR	High Speed Rail
IAD	Washington Dulles International Airport (airport code)
IATA	International Air Transport Association
LAX	Los Angeles International Airport (airport code)
MDT	Harrisburg International Airport (airport code)
MSA	Metropolitan Statistical Area
MSO	Missoula International Airport (airport code)

MWCOG	Metropolitan Washington Council of Governments
NHTS	National Household Travel Survey
NPIAS	National Plan of Integrated Airport Systems
NTTO	National Travel and Tourism Office
OAK	Oakland International Airport (airport code)
OECD	Organisation for Economic Co-operation and Development
O&D	Origin and Destination
PHX	Phoenix Sky Harbor International Airport (airport code)
PUMD	Public Use Microdata
PVD	T.E. Green Airport, Providence, Rhode Island (airport code)
RASDS	New York Regional Air Service Demand Study
RPK	Revenue Passenger Kilometers
RPM	Revenue Passenger Miles
RSME	Root Mean Square Error
SFO	San Francisco International Airport (airport code)
SIAT	Survey of International Travelers
TAF	Terminal Area Forecast
TAF-M	Terminal Area Forecast Modernization
TRACON	Terminal Radar Approach Control
TUL	Tulsa International Airport (airport code)
UK	United Kingdom
U.S.	United States
U.S. DOT	U.S. Department of Transportation
WHRTAS	West of Hudson Regional Transit Access Study

Appendices

The following appendices are available on the TRB website:

Appendix A: Detailed Survey of Past Analyses of Air Passenger Demand
Appendix B: Airport Industry Use of Socioeconomic Data for Air Passenger Demand Studies
Appendix C: Additional Material on Sources of Disaggregated Socioeconomic Data
Appendix D: Detailed Case Study Analysis Results
Appendix E: Background on Other Analytic Approaches

Abbreviations and acronyms used without definitions in TRB publications:

A4A	Airlines for America
AAAE	American Association of Airport Executives
AASHO	American Association of State Highway Officials
AASHTO	American Association of State Highway and Transportation Officials
ACI–NA	Airports Council International–North America
ACRP	Airport Cooperative Research Program
ADA	Americans with Disabilities Act
APTA	American Public Transportation Association
ASCE	American Society of Civil Engineers
ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing and Materials
ATA	American Trucking Associations
CTAA	Community Transportation Association of America
CTBSSP	Commercial Truck and Bus Safety Synthesis Program
DHS	Department of Homeland Security
DOE	Department of Energy
EPA	Environmental Protection Agency
FAA	Federal Aviation Administration
FAST	Fixing America's Surface Transportation Act (2015)
FHWA	Federal Highway Administration
FMCSA	Federal Motor Carrier Safety Administration
FRA	Federal Railroad Administration
FTA	Federal Transit Administration
HMCRP	Hazardous Materials Cooperative Research Program
IEEE	Institute of Electrical and Electronics Engineers
ISTEA	Intermodal Surface Transportation Efficiency Act of 1991
ITE	Institute of Transportation Engineers
MAP-21	Moving Ahead for Progress in the 21st Century Act (2012)
NASA	National Aeronautics and Space Administration
NASAO	National Association of State Aviation Officials
NCFRP	National Cooperative Freight Research Program
NCHRP	National Cooperative Highway Research Program
NHTSA	National Highway Traffic Safety Administration
NTSB	National Transportation Safety Board
PHMSA	Pipeline and Hazardous Materials Safety Administration
RITA	Research and Innovative Technology Administration
SAE	Society of Automotive Engineers
SAFETEA-LU	Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (2005)
TCRP	Transit Cooperative Research Program
TDC	Transit Development Corporation
TEA-21	Transportation Equity Act for the 21st Century (1998)
TRB	Transportation Research Board
TSA	Transportation Security Administration
U.S. DOT	United States Department of Transportation

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