The Climate Impacts of High-Speed Rail and Air Transportation: A Global Comparative Analysis

by

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ABSTRACT

Growing concerns about the energy use and climate impacts of the transportation sector have prompted policymakers to consider a variety of options to meet the future mobility needs of the world's population, while simultaneously addressing the impact of these systems on our environment. This dissertation focuses on air transportation and high-speed rail (or "high-speed transportation"), a sector for which demand is projected to grow substantially, and for which infrastructure and vehicle investment decisions are costly and long-lived. This research examines high-speed rail (HSR) and aviation systems in three regions to explore: 1) the historical context of high-speed rail and aviation demand; 2) potential policies that may shape HSR and aviation system demand and their environmental impacts in the future; and 3) individual mode choice between HSR and aviation. The goal of this work is to improve our understanding of demand for these systems and methods to examine their climate impacts.

Chapters 3 and 4 provide an empirical analysis of the European experience with high-speed rail and aviation systems. First, we contribute to econometric analyses of air travel demand by examining the impact of high-speed rail on air traffic. Using origin-destination demand data as well as airport demand data for two decades, our econometric analysis shows that the introduction of high-speed rail has resulted in substantial decline in air traffic on short-haul routes, as well as domestic air traffic in nations with high-speed rail infrastructure. Those cities that have higher density experience an even larger reduction in air traffic. However, we find that over this same time period, the expansion of low-cost carriers in Europe has had an even more substantial impact on increasing total air traffic within the European aviation system.

Second, we explore cooperation versus competition between high-speed rail and air transportation systems. Through case studies and travel demand analysis, we examine how air-rail connections have formed in Europe, factors that contribute to high utilization of these connections, and their impact on travel demand. We find that although capacity shifts within the air transportation system have occurred as a result of these connections, there are a number of unique factors that contribute to their success.

In Chapter 5, we shift our attention to the United States to conduct an integrated analysis of transportation and climate policies. By developing a new model to examine high-speed rail and aviation demand and their environmental impacts under alternative climate and energy policies, we find that the energy and CO_2 emission savings of high-speed rail increase substantially when combined with such policies. These savings are primarily due to the relative efficiency of high-speed rail systems combined with a shift towards less carbon-intensive electricity generation.

The first three analyses assume that price and travel time are the dominant factors influencing intercity travel choice between high-speed rail and air transportation. In Chapter 6, we explore the potential influence of environmental attitudes on individual choices between high-speed rail and air transportation. By conducting an intercept survey in China, we find that rail passengers tend to be more concerned about the environment than those individuals likely to choose air travel. Second, we find that high-speed rail accidents do have a significant impact on future mode choice, and that safety concerns play a significant role in intercity travel choice.

This dissertation concludes with an analysis of current policies that influence high-speed rail and aviation in the United States, and their long-range environmental impacts. Integrating our findings from the three regional analyses of high-speed rail and aviation, we make recommendations for future policies that shape these long-lived infrastructure systems. Given likely growth in demand for high-speed transportation in the United States and other regions, our goal is to inform future investment decisions and policies that meet these mobility needs while mitigating their energy and climate impacts.

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Chapter 1: Introduction

1.1. MOTIVATION

1.1.1. Growing Environmental Impacts of Transportation

The transportation sector accounts for a significant portion of global CO_2 emissions (i.e. one-third), and nearly 50 percent of the increase in CO_2 emissions from 1990 levels in the United States. Air transportation is responsible for three percent of greenhouse-gas emissions and five percent of global warming; however, it is among the fastest growing modes (in passenger miles) in the transportation sector. Studies of global mobility predict that over the next 50 years, general transportation volume will increase and continue its shift towards faster modes, with aviation experiencing the largest growth in mode share (Schafer and Victor, 2000). Under business-as-usual scenarios, CO_2 emissions from global aviation are expected to increase by 300 percent over the next 40 years (IEA, 2008b).

The dominant factor shaping growth of aviation emissions is continuous growth in the demand for air travel, which has increased dramatically at a global level since deregulation. On average, global air traffic increased at a rate of roughly five to six percent per year over the past 25 years (Belobaba et al, 2009). Although the recent economic downturn has resulted in a slowdown in demand, most experts predict that air traffic will continue to increase substantially during the next century. For instance, between 2009 and 2029, annual traffic growth for the Asia Pacific region is forecast to increase at a rate of 7.1 percent, annual traffic growth within China forecast at 7.9 percent, and from the Middle East to Asia Pacific at 7.5 percent (Boeing, 2008). Projected growth rates within Asia and the Middle East, as well as an increase in travel between these regions and the rest of the world is anticipated to drive significant growth in global air transportation.

In many parts of the world, including Europe, Japan, and Korea, high-speed rail (HSR) has served as an effective substitute for air transportation, particularly for intercity, short-haul travel. High-speed rail is, under most circumstances, more energy efficient and has a lower carbon footprint than aviation. One study estimates that the CO_2 emissions associated high-speed rail range from 4.0 to 27.5 per kilometer, while CO_2 emissions for air transportation are higher at 99.8 to 153.9 per kilometer (Janic, 2003). There are numerous factors that shape the climate impacts of these two modes, including vehicle efficiency, energy sources, and passenger demand. Given anticipated growth in demand for high-speed transportation services over the next half-century and beyond, this dissertation aims to improve our understanding of demand substitution between high-speed rail and aviation, and the climate impacts of these two modes.

Much of this dissertation examines *demand* for high-speed rail and aviation: how intercity air travel demand has evolved after the introduction of high-speed rail, and the influence of various factors (e.g., low-cost carriers, density, passenger preferences) that shape demand for these systems. Our focus on travel demand is primarily motivated by the underlying premise that demand is a critical driver of CO_2 emissions of the transport sector, as illustrated by Equation 1.1.

$$G = A \times S_i \times I_i \times F_{i,j} \tag{1.1}$$

where $\boldsymbol{G}$ is the carbon emissions from the transportation sector of interest, $\boldsymbol{A}$ is total travel demand (in passenger miles), $\boldsymbol{S}$ is a vector of modal share, and $\boldsymbol{I}$ is the energy intensity of each mode I, and $\boldsymbol{F}_{i,j}$ represents the sum of each of the fuels j in mode I (Schipper et al, 2000).

The empirical analysis presented in Chapters 3 and 4 on European high-speed rail and air travel demand is presented in the context of their climate impacts. In Chapter 5, we explicitly model demand for high-speed rail and air transportation in the United States under policies designed to mitigate CO_2 emissions (of all sectors, including transportation). In Chapter 6, we explore the potential influence of environmental attitudes on their decisions, moving beyond the assumption that the primary factors influencing consumer travel choice are price and demand. Finally, in Chapters 7 and 8, we discuss the implications of this research on policy and practice. The overarching goal of the three research cases and following discussion are to: a) build an improved understanding of the factors that influence demand for high-speed rail and aviation; b) examine the potential climate impacts of these systems; and c) inform policy action that will shape the design, construction, demand, and climate impacts of these systems over the long time scales during which they will be utilized.

1.1.2. Infrastructure Investment

Aviation and high-speed rail are some of the more expensive transportation infrastructures to build and maintain. However, these infrastructures also have very long life spans; the expected design life of both rail infrastructure and airports ranges from 50 to 100 years (Auld et al, 2006). While these infrastructures may require large initial investments, they are utilized over extensive time periods during which various economic, regional, and employment benefits are realized. Growing populations in several regions are a secondary motivation of this thesis, given the significant transportation infrastructure investments that are likely required to meet growing mobility needs over the next 50 years.

In the United States, one of the challenges facing the air transportation system is the limited capacity of airports. Several multi-airport, metropolitan areas (which already experience significant congestion and delays) are likely to have continued capacity problems in 2025, even after planned airport improvements (MITRE, 2007). In addition to growth in air travel demand, a contribution to airport congestion in the U.S. are frequent, short-haul flights on routes of less than 500 miles, which now represent half of all domestic flights and carry 30 percent of all passengers (Tomer and Puentes, 2009). As capacity constraints at U.S. airports continue to impact the reliability and potential safety of the air travel system, one of the issues that is being examined are alternative travel options for short-haul travel (between 100 and 500 miles), such as high-speed rail. Understanding the relationship between air transportation and high-speed rail demand is critical, in order to develop realistic demand forecasts that can inform overall transportation investment decisions.

In recent years, the development of high-speed rail has seen renewed interest in the United States. The Obama Administration made an $8 billion USD investment in high-speed rail infrastructure in the United States in 2010 through the American Recovery and Reinvestment Act (ARRA). However, there are many opponents who claim that high-speed rail infrastructure is too costly, and will not result in the ridership levels necessary to justify the construction of its infrastructure.

Answering the questions of whether high-speed rail infrastructure is: a) a sound investment in terms of meeting mobility needs, and b) a more environmentally-friendly intercity transportation alternative, both depend in large part on the demand forecasts for high-speed rail and air transportation over the next 40-50 years. Thus, it is critical to enhance understanding about the methods utilized to examine aviation and high-speed rail demand, to improve the practical techniques used to develop forecasts, and to evaluate the climate impacts of both modes.

1.2. RESEARCH APPROACH

This thesis explores three aspects of high-speed rail and air transportation demand in order to build an improved understanding of these systems and to inform future policy and planning. We explore high-speed rail and air travel demand from three perspectives: 1) a historic analysis of demand in Europe, 2) proposed high-speed rail in the United States, and 3) current demand and passsenger preferences for HSR and aviation in China. Our historic analysis of high-speed rail and air transportation presents empirical evidence of the impact of high-speed rail development on air travel, and their associated environmental impacts. Second, our analysis of proposed high-speed rail in the United States builds on existing travel demand forecasts to examine the environmental impacts of air and rail under energy policies. Last, we extend our traditional models of high-speed rail and aviation demand (which are predicated on cost and travel time), to explore additional factors that may influence traveler choice between these two modes, namely safety and environmental considerations.

1.3. THESIS OUTLINE

This dissertation is organized as follows:

- **Chapter 2** presents a broad overview of global aviation and high-speed systems, followed by the literature on policy models of transportation and energy, travel demand modeling, and environmental analysis of transportation systems.
- **Chapter 3** presents our historical analysis of high-speed rail and aviation demand in Europe. Econometric models are developed to examine the impact of high-speed rail on short-haul air travel, as well as to examine broader impacts across the air transportation system.
- **Chapter 4** explores the issue of high-speed rail airport connectivity, how it has evolved, measures of success, and its ultimate impacts on shaping travel demand.

- **Chapter 5** presents an integrated climate and transportation policy analysis of high-speed rail and air travel demand in the United States, with a particular focus the energy and climate impacts of these systems through 2050.
- **Chapter 6** extends our understanding of demand for air travel and high-speed rail by exploring the potential impact of attitudes on passenger choice between these two modes. Although travel time and price are important factors that clearly affect mode choice, new research suggests that attitudes and social norms can also have a significant influence on travel behavior.
- **Chapter 7** summarizes research findings relevant for policy and practice, presents an overview of the transportation and climate policy landscape in the United States, and makes recommendations for policy and transportation planning.
- **Chapter 8** summarizes key research findings, outlines contributions to the literature, and suggests potential areas of future research.

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Chapter 2: Background

In this chapter, we present an overview of global aviation and high-speed rail systems, models utilized for their policy and planning, and a review of the methods utilized in developing such models. Our literature review focuses on two primary areas: 1) travel demand modeling methods – that is, methods that aim to build an improved understanding of demand for transportation alternatives such as high-speed rail and aviation; and 2) environmental assessment of air transportation and high-speed rail.

2.1. A BRIEF GLOBAL OVERVIEW OF AIR TRANSPORTATION

Following the introduction of jets for commercial airline use in the 1950s, air transportation has grown in importance as a means for intercity and global travel. Two primary significant events have spurred growth in global aviation: 1) the introduction of widebody "jumbo jets" by Boeing, McDonnell Douglas and Lockheed in the 1970s, and 2) deregulation, starting in the United States in 1978 and in Europe in the 1990s, resulting in lower costs, increased productivity, and eventually the introduction of low-cost carrier (LCC) airlines.

Today, there are roughly 30 million scheduled flights carrying 2 billion passengers around the world (MIT, 2010). Historically, the United States has represented a large portion of global aviation market share (~15% in 2011); it is anticipated that U.S. air travel demand will continue to grow, albeit at a slower rate than experienced previously. Globally, emerging markets such as China, Latin America and the Middle East are projected to drive future growth in global air travel.

Air transportation is currently responsible for 8.1 percent of CO_2 emissions in the U.S. transportation sector. Research suggests that around the world, the share of the "high-speed transportation" sector will grow over time (Schafer and Victor, 2000). Most analyses suggest that the climate impacts of this sector will continue to grow at a steady pace even under the most stringent policies to mitigate greenhouse gas emissions (Winchester et al 2011). As governments around the world consider various policies to address the climate impacts of the transportation sector, this challenge has become one of the top issues discussed in the global airline industry.

2.2. THE EVOLUTION OF HIGH-SPEED RAIL

Typically designed for passenger service, high-speed rail was first developed in Japan and Europe during the 1960s. The first service, the Tokaido Shinkansen, was launched in Japan between Tokyo and Osaka in 1964. During the 1970s and 1980s, new rail technology was introduced, enabling higher top speeds (up to 436 km/ h during trial runs). In Europe, regular passenger service was introduced in France, West Germany, and Italy, and has since expanded to additional countries primarily in Europe and Asia.

The European Union defines high-speed rail as lines equipped for speeds of 250 km/h or greater (for new lines) and speed "of the order of 200 km/h" (for upgraded lines). However, the International Union of Railways also recognizes that there are rail lines capable of operating at high speeds that are not permitted to operate at maximum speed due to noise, safety, or capacity issues. In the United States, statutory definitions of high-speed rail include speeds as high as 125 mph (201 km/h) and as low as 90 mph (145 km/h).

Under most circumstances, passenger rail, including high-speed rail, is more energy efficient on a per kilometer basis. Although the United States has seen limited investment in passenger rail since the early 20th century, there has been renewed interest in the introduction of high-speed rail in recent years, as discussed further in Chapters 5 and 7. Key motivations include: meeting future mobility needs that are anticipated in growing east and west coast mega-regions and addressing growing concerns about energy use and climate impacts of the transportation sector.

2.3. MODELING AVIATION DEMAND

Aviation demand forecasting is a well-established research area that draws upon various methods to develop predictions for different aviation system planning purposes, including the following:

- National and regional traffic forecasts;
- Origin-destination (O-D) or route level forecasts;
- Airport-level forecasts (typically for capacity planning and infrastructure planning purposes);
- Forecasts for aircraft fleet planning.

This review of aviation demand modeling methods will primarily focus on methods utilized for national/regional and origin-destination forecasts, which are often used in climate policy analysis of air transportation systems. The demand modeling methods used for airport-level forecasts will also be examined, which have significant implications for infrastructure investment, including examining potential substitution by high-speed rail.

Although disaggregate, choice theory methods have come to dominate much of transportation demand analysis, econometric analysis of aggregate demand is still utilized in much of air transportation demand research and forecasting practice. Econometric analysis of annual demand is typically utilized to examine origin-destination air transportation demand, national and regional demand, and occasionally, airport-level demand. However, disaggregate, choice-based methods have become the dominant method for airport-level demand analysis and fleet forecasting. The remainder of this section highlights key developments and principles associated with both econometric and choice-based methods used for forecasting aviation demand.

2.3.1. Econometric-based methods for aviation demand modeling

Econometric analysis is often utilized to model demand at the origin-destination (O-D), national, and regional levels. Research on aviation demand at these levels is typically empirical, and relies on cross-sectional, time-series data (usually annual data) from publicly available or proprietary sources. Practitioners are likely to use historical data for a 12- to 20-year time period in order to estimate the parameters of a demand model (TRB, 2002). These models are typically estimated using regression analysis, and are then utilized to predict future demand at the O-D, national, or regional level. The majority of econometric-based demand models in the aviation sector take on the following form:

$$\ln(\text{Demand}) = \varphi_0 + \varphi_1 \ln(\text{GDP}) - \varphi_2 \ln(\text{Yield}) + \varphi_3 X + \varepsilon \tag{2.1}$$

where Demand is measured by passengers (or occasionally flights), Yield reflects the average fares paid for air transportation service, X represents a number of additional parameters that the modeler expects to influence demand, and ε is a random error term.

The primary explanatory variables of most econometric-based demand models are GDP per capita and yield (or average fare). Average household income is another variable that is often used in place of GDP. Additionally, those models that aim to forecast O-D demand (e.g., between two airports, two cities, or two regions) typically use GDP or income data from both the origin and the destination.

2.3.2. "Bottom-up" forecasts

In aviation research, "bottom-up" forecasts sometimes refer to demand models at the origin-destination or route levels, while "top-down" models of demand may refer to national- or regional-level forecasts. Route-level forecasts are also sometimes used to inform network models of aviation demand. Recent research suggests that these route-level forecasts can be significantly improved by considering local area information such as density, hub status of the airport, market power, and low-cost carrier presence (Bhadra, 2003). In practice, these forecasts might also include dummy variables associated with significant events (e.g., some models of U.S. traffic include a 9/11 dummy variable).

2.3.3. Challenges associated with quality of data

Examining true origin-destination demand for a city or airport pair can be a complex exercise, often requiring access to expensive proprietary data maintained by airlines or industry specialists. True origin-destination traffic includes those passengers who board at the origin city and disembark at the destination city; it excludes those passengers who connect to or from another flight at either end of the trip.

In the United States, true origin-destination data is available for domestic itineraries through the Bureau of Transportation Statistics (BTS) Airline Origin and Destination Survey (DB1B), which are based on a 10 percent sample of airline tickets from reporting carriers. Internationally, general air traffic data (that do not distinguish between true O-D and connecting passengers) are often publicly available through government statistical offices. Sources of true origin-destination data outside of the U.S. are often based on actual passenger bookings and collected through companies that sell the data to researchers and industry economists.

2.3.4. Emerging markets

One challenging area of aviation modeling is forecasting demand in emerging markets. Because historical air traffic data is often either unavailable, or less likely to be a strong predictor of future growth, demand models in developing and emerging countries are often supplemented by alternative methods. Forecasts of emerging market demand usually rely on economic analysis of the underlying factors that impact air transportation demand (e.g., GDP growth, personal income, etc.). They are also often informed by expert industry opinion, changes in world trade, and analysis of air transportation in other world regions (TRB, 2002).

2.3.5. Choice theory methods for aviation demand modeling

Disaggregate behavioral analysis which builds on the concept of random utility maximization (RUM) has become one of the dominant tools for travel demand analysis. More than three decades of methodological innovations in the areas of choice theory, data collection, and statistical tools have been developed to examine transportation problems (McFadden, 2000). Methods based on choice theory have become a common tool for aviation demand analysis, though they are not used as extensively as for examining intercity rail transportation. In aviation research, choice modeling primarily used for fleet planning and multi-airport region demand modeling.

2.3.6. Multi-airport region demand modeling

A particularly interesting choice problem in the aviation sector is the choice that consumers must make when flying to or from a major metropolitan area with multiple airports. For example, consumers in the New York City metro area, which is served by John F. Kennedy, La Guardia, and Newark airports, are likely to base their airport choice decisions on accessibility of the airport, the price of a ticket from each airport to their final destination, or whether their preferred airline offers frequent service through the airport. Several of the metropolitan areas in the U.S. include three or more airports; thus, researchers or practitioners often utilize multinomial logit (MNL) or nested logit formulations to examine airport choice. More advanced demand modeling methods, discussed further in Section 3 and 4 below, have been applied to airport choice in recent years (Hess et al, 2005, 2006).

One significant effort to model a multi-airport region is the Regional Airport Demand Allocation Model (RADAM), developed for Southern California's complex regional aviation system. RADAM is a multinomial logit (MNL) model that generates and allocates current demand and forecasted air passenger and cargo demand to airports. It is a bottom-up model, generating demand through a geographically based zonal system (Cambridge Systematics et al, 2003). Although it may be one of the more innovative disaggregate demand models used by practitioners, the modeling methods utilized in the model are not as well publicly documented as many researchers would like,

2.3.7. Aviation demand modeling in practice

A number of public and private organizations utilize the aforementioned demand modeling methods to develop forecasts for business planning purposes or infrastructure development. To a large extent, planning carried out by urban transportation planners is based on disaggregate methods, while air transportation planning, conducted by national or international agencies and commercial airlines, is typically based on aggregate data analysis.

Econometric analysis methods are heavily utilized by the key agencies and companies that forecast air traffic, including:

- the International Civil Aviation Organization (ICAO) Forecasting and Economics Support Group (FESG);
- the International Air Transportation Association (IATA);
- the Federal Aviation Administration (FAA); and
- Boeing and Airbus.

The majority of the organizations above provide documentation on the methods utilized for their air traffic forecasts, including the commercial airlines (e.g., Boeing's Current Market Outlook).

Metropolitan Planning Organizations (MPOs), such as the Southern California Association of Governments, typically utilize the four-step transportation demand modeling method: trip generation, trip distribution, mode choice, and traffic assignment. Surveys of the region's inhabitants and disaggregate demand modeling methods are the main tools used to forecast demand, primarily for local urban planning purposes. One of the key advantages of these methods is that they often more accurately reflect local residents' preferences, as compared with more aggregate methods. However, the methods of many MPOs have been critiqued for their limited capability to capture tourist demand, which may comprise a significant amount of travel (e.g., in regions such as Florida and California).

2.3.8. Current limitations

In recent years, there has been a growing concern regarding the ability of traditional demand modeling techniques to produce reliable forecasts of air traffic and airport-level demand (Tretheway, 2010). There is significant uncertainty associated with numerous parameters that impact air transportation (e.g., airline profitability, economic growth, and fuel prices). Recent research projects funded by the Transportation Research Board (TRB) are currently developing systems analysis methods to incorporate uncertainty into airport decision-making.

Another key limitation of current air transportation demand modeling activity is the exclusion of high-speed rail competition in origin-destination (or "bottom-up") forecasts in the U.S. and in many other world regions. The growth of high-speed rail service, particularly in Europe and Asia, has significant implications for aviation demand forecasts on short-haul routes, as well as at the airport and multi-airport region level. Although preliminary studies examine the substitution of high-speed rail for air transportation for specific corridors (Steer Davies Gleave, 2006), there is limited research that examines the widespread impacts of high-speed rail on reducing domestic air traffic.

2.4. INTERCITY DEMAND MODELING

Intercity demand modeling efforts focus on examining and forecasting demand between cities or regions, typically over distances of 100 miles or more. Much of the research and practical application in this area use the four-step modeling method, with a significant focus on examining mode choice. Several attempts to develop a national-level intercity mode choice model of the United States have been made, utilizing disaggregate demand modeling techniques and data from the BTS National Travel Surveys (NTS) (Ashiabor et al, 2007). Although the body of literature on intercity demand modeling is quite expansive, this review focuses on the key insights from intercity modeling efforts that are particularly salient for high-speed rail and aviation demand modeling.

2.4.1. Airport choice and access times

The most recent attempt to develop a U.S. intercity mode choice model was attempted by Ashiabor et al in 2007, and included two advancements particularly relevant for modeling aviation and high-speed rail competition. This intercity demand model examined the choice between automobile and commercial air transportation, using a nested model formulation in order to incorporate airport choice and access and egress distances (Ashiabor et al, 2007). One of the key challenges associated with modeling airport choice in multi-airport regions in the United States (and a challenge associated with examining choice between air transport and high-speed rail), is that there is not systematic data collection on airport access and egress through the National Travel Surveys. In Ashiabor et al's modeling effort, a method was developed to calculate automobile travel times for the choice model, as well as to estimate the access and egress times for airport choice (in multi-airport regions) for a large number of cities and regions.

Additional examples of models that incorporate access times into airport choice include studies by Hess and Polak, applied to the San Francisco Bay Area and London (2005, 2006). These models differ from the Ashiabor et al in that they focus on airport choice in a specific region (i.e. they are not intercity demand models), they utilize survey data collected by local transportation agencies, and they utilize more advanced demand modeling methods, discussed further in Section 2.5.5.

2.4.2. Functional form and elasticity estimates

Alternative demand model formulations were explored in Oum's study of interregional freight demand (1989). As mentioned previously, there is significant variation in demand modeling methods; sources of this variety include the use of aggregate versus disaggregate data, as well as the choice of functional form. Oum suggests that disaggregate data often more difficult to obtain, that thus preliminary analysis using aggregate data is often useful.

Oum explored a variety of functional forms to examine interregional freight demand, finding that the choice of functional form has a significant impact on the elasticity estimates obtained for level of service variables. Given that the majority of practical applications of aviation, high-speed rail, and intercity demand models utilize elasticity estimates as one component to forecast future demand, this finding suggests that practitioners should carefully consider how functional form may influence forecasts of future demand.

2.5. HIGH-SPEED RAIL DEMAND MODELING

There is a significant body of rail demand modeling literature focused on examining historical demand where high-speed rail (HSR) has been constructed and provides service, as well as potential corridors where HSR infrastructure is being considered. This section provides an overview of empirical studies of existing high-speed rail demand and their key conclusions, forecasting studies for potential HSR service, advanced methodologies that are frequently applied to rail demand modeling, and current limitations and controversies.

2.5.1. Empirical analysis of high-speed rail and air transportation competition

In the past decade, several studies have emerged that analyze the substitution of high-speed rail for air transportation, particularly in Europe and Asia (Park and Ha, 2006; Clever and Hansen, 2008). The majority of these studies are focused on mode choice between two major cities, utilizing choice modeling methods to examine revealed preference (RP) data, and (occasionally) stated preference (SP) data. For example, the study by Park and Ha includes stated preference data collected prior to the opening of the Korea Train eXpress (KTX), as well as measured actual demand following the opening of the high-speed rail line.

Studies on revealed preferences between air transportation and high-speed rail often use logit model formulations and similar explanatory variables: travel time, fares, access time, frequency, trip purpose, and income. Through their analysis of the Japanese case, where there is more aggressive competition between HSR and air transportation than in Europe, Clever and Hansen expand on the analysis of accessibility, frequency, and reliability. Their study concludes that high-speed rail is the dominant choice for trips where there are either very short or very long access distances (2008). Other studies also indicate that the accessibility of high-speed rail and station choice is a critical factor that may significantly impact mode choice (USGAO, 2009).

Comparative studies based on European high-speed rail development have examined historical market share and general trends in air transportation and high-speed rail demand. A few studies documenting air transportation and HSR in France, Spain, and Japan conclude that it is very difficult for air transportation to compete effectively in short-haul markets of 500 kilometers or less (Park and Ha, 2006; USGAO, 2009). A multiple case study prepared for the European Commission documented eight intercity routes where air and high-speed rail are present (Steer Davies Gleave, 2006). This report's key conclusion was that rail journey time (i.e. not distance) was the most significant factor impacting market share (see Figure 2.1). Given that HSR speeds can vary substantially (from 200 kilometers per hour to 350 kilometers per hour), it can be concluded that the more precise and effective method is to incorporate travel time into demand models (versus travel distance).

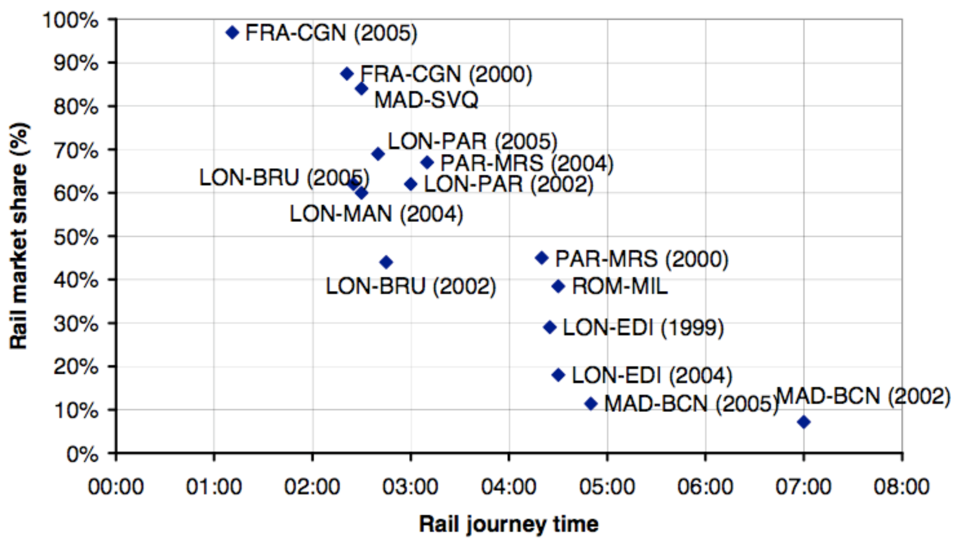

Figure 2.1 Market share versus rail journey time (source: Steer Davies Gleave, 2006)

A final key consideration that may be important for examining future high-speed rail demand is that of network structure. Previous development of high-speed rail in Europe was somewhat limited in that HSR lines often connected major cities, and did not benefit from careful planning of the overall network or consideration of the accessibility high-speed rail (Vickerman, 1996). However, the European Commission adopted an action plan in 1996 to develop a trans-European transport network that would include a number of cross-border high-speed rail lines to link the (largely) national high-speed rail systems that currently exist (Decision No 1692/96/EC). If completed, this substantial high-speed rail expansion would result in a more complex network structure for Europe that might necessitate more advanced high-speed rail demand modeling methods (e.g., that might draw from network models of air transportation).

2.5.2. Econometric methods to examine high-speed rail demand

As compared with transportation demand analysis in the air transportation sector, there are relatively few published empirical studies of rail demand using econometric methods. The scarce literature in this area is primarily due to the following challenges: limited access to quality data and limited competition between railways (and thus limited analysis by independent agencies). The national railways themselves utilize econometric methods to examine historical demand to forecast future demand; however, these studies are typically unpublished and confidential.

Based on the published econometric studies of rail, there appear to be several similarities between demand analysis of air transportation and rail. Growth in the economy (as measured by gross domestic product or personal income) is the key driver for both air and rail travel. Secondly, empirical analysis of these systems is complicated by a similar challenge: the difficulty of obtaining true origin-destination data, which is perhaps more complicated for rail than for air travel. Rail operators often offer rail cards that provide discounts on rail fares; the presence of these discounts make it quite difficult to accurately account for rail fares. Additionally, rail operators often offer special fares are only valid for a particular segment of the trip, forcing passengers to purchase tickets separately for two or more segments that are part of a single trip (Owen and Phillips, 1987). This is quite similar to the issue of connecting flights; however, rail operators most likely have less information about their passengers, and thus obtaining true origin-destination data is more challenging (if not impossible).

An econometric analysis of British rail demand by Owen and Phillips revealed a few insights that are particularly relevant for examining the interaction of high-speed rail and air transportation (1987). First, the main sources of competition for the rail operator included air travel and intercity bus services. In addition to the United Kingdom, there are a number of other countries and regions where express bus service obtains a substantial portion of market share (e.g., Korea and the Northeast Corridor of the United States). A second key insight of this econometric analysis was a major event that fundamentally changed demand between London and the cities furthest form London (i.e. Edinburgh, Glasgow and Newcastle). As a result of a British Railways strike in 1982, combined with increased competition between airlines, rail demand between these cities never recovered. This finding is similar to econometric studies of time series data that recommend adding variables to account for major events that fundamentally alter demand functions. Furthermore, it reconfirms the interrelationship between rail and air transportation demand, implying that major disruptions to service may result in long-term shifts between one mode to another.

2.5.3. High-speed rail forecasting methods

Demand modeling of potential high-speed rail service has received much attention from researchers and practitioners over the past several decades. In fact, much of the choice modeling methodology that is now utilized for a variety of transportation modes was partially motivated by the development of rail service in the U.S. Northeast Corridor. Modeling methods that were previously used to forecast passenger rail primarily included gravity models, which dominated through the 1960s (Meyer and Straszheim, 1971). However, they were not easily able to handle mode split. Just before 1970, the Department of Transportation funded a number of studies to develop new travel demand analysis methods, motivated by the Northeast Corridor Project and the San Francisco Bay Area Rapid Transit (McFadden, 2000). Since then, disaggregate behavioral travel demand analysis has become a dominant tool for forecasting high-speed rail (as well as a dominant method to examine travel demand).

Demand modeling efforts for proposed high-speed rail corridors in Australia, France, Germany, Texas, Florida, Chicago, and a number of other regions have produced a substantial number of academic studies and consulting reports. The majority of these studies have utilized disaggregate modeling methods based on choice theory. The following section summarizes a common modeling framework, as well as the advanced techniques that have been developed for, or applied to, high-speed rail demand modeling.

2.5.4. Choice theory methods for high-speed rail demand modeling

Modern forecasting of potential high-speed rail demand is often based on examining the diversion of other modes to high-speed rail, particularly from aviation, as suggested by Brand et al (1992). One recommended approach includes using separate relationships to estimate the diversion from each existing mode to high-speed rail. Using revealed preference (RP) data and the aforementioned approach, a multinomial mode choice model was developed by Brand et al to determine the market share and total volume of passenger trips for competing modes. These techniques were applied to forecast ridership in Florida, Texas, and the Northeast Corridor (in the 1990s).

The majority of efforts to forecast high-speed rail throughout the 1990s and 2000s utilized demand modeling methods based in choice theory. A common approach that has emerged to examine the choice for potential high-speed rail is the nested logit formulation, where transportation alternatives that are likely to be correlated are "nested" under the same branch, and their errors are assumed to be correlated (see Figure 2.2). This nested structure is often expanded to include trip purpose and access mode (with nests added above and below, respectively).

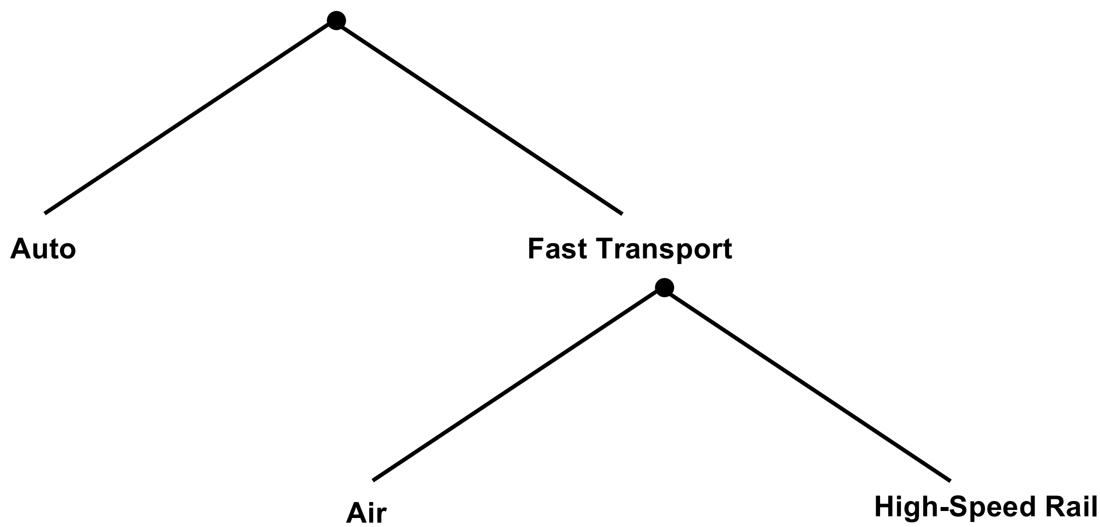

Figure 2.2 Common nested logit structure for high-speed rail choice

Early applications of nested logit models were utilized by academic researchers and practitioners to forecast high-speed rail demand for the Chicago-Milwaukee-Twin Cities corridor (TMS/Benesch, 1991) and Ontario-Quebec corridor (Forinash and Koppelman, 1993). General extreme value and nested model formulations were expanded upon by Bhat throughout the 1990s, with applications to the Toronto-Montreal corridor (Bhat, 1995; Bhat, 1997). Outwater et al has produced one of the most recent applications of a nested logit model formulation to forecast potential demand for the proposed California high-speed rail corridor (Outwater, 2009).

2.5.5. Advanced choice theory methods for high-speed rail demand modeling

In addition to the mode choice modeling methods described above, several advancements in demand modeling have been motivated by, and have significantly contributed to, the study of high-speed rail demand. Perhaps the most widely utilized demand modeling innovation is the use of stated preference (SP) data. SP data is often collected to forecast demand for new and innovative transportation alternatives, a prime example being high-speed rail. However, because SP data is not based on actual behavior, but rather hypothetical choices, there is a significant question about the validity of using such data for demand forecasts.

Several advances in demand modeling have improved the use of SP data to forecast transportation demand, including the combination of revealed preference (RP) and stated preference data (SP), and methods to address potential correlation problems that are often present in SP data. By combining RP data (actual choices) and SP data (hypothetical choices), one can developed improved demand models for examining new transportation alternatives. However, there are a number of key issues associated with utilizing SP data: including the following: 1) there are likely differences in the variances of random components of RP and SP utility functions, which can be corrected for by estimating a scale parameter; 2) there is potential correlation between RP and SP observations (collected from the same individuals); 3) SP survey data often includes several responses from the same individual, resulting in potential correlation between errors; 4) "self-selection" or "inertia" may influence an individual's stated preference (e.g., whether they were surveyed at the airport or through a license-plate based method may influence an individual's stated preference). Ben-Akiva et al provides a unifying framework for incorporating different types of survey data, with a particular focus on methods to address the challenges associated with combining revealed and stated preference data (1994). Over the past 15 years, combined RP and SP models have become the dominant method of choice for modeling high-speed rail demand. One of the earliest applications of these methods was a study on the "Very Fast Train" in Australia (Gunn, Hensher, and Bradley, 1993).

Various mixtures of logit models are another key innovation in demand modeling that have been applied to examining high-speed rail demand (though primarily in academic literature). The key characteristic of these methods is the use of flexible correlation structures of the error terms, which allows one to examine models that include alternative specific variances of the transport modes, random coefficient specifications to capture taste heterogeneity, and correlation of panel data (Walker et al., 2007). Additionally, latent variable models that can capture constructs such as perceptions and attitudes have added to the set of tools available for improved choice models. However, two of the key challenges associated with utilizing these techniques in practice are the added complexity of mixed logit model formulations, and in some cases, limited software tools that enable their use by general practitioners.

2.6. CONTRIBUTIONS OF THIS RESEARCH

Given the rapid advancements of high-speed rail technology and the clear interaction between high-speed rail and aviation demand, there are some current limitations in the methods that are used to examine these transportation modes. First, there are three fairly basic techniques that would improve aviation and rail demand modeling: 1) more widely integrating high-speed rail into aviation demand models, 2) expanding the methodologies utilized for high-speed rail demand modeling to include network-based methods (for regions where appropriate), and 3) improving the data collection and accessibility of rail data. Second, there are a few complex issues that should be addressed to improve demand models of aviation and high-speed rail: 1) developing methods to examine complimentary relationships between HSR and air transportation demand; and 2) linking choice models and forecasts of HSR and aviation and environmental impact analyses. Finally, it is clear that there is a gap between academic research and demand modeling in practice, which has significant implications on transportation policy and infrastructure investment. This dissertation concludes with a summary of key findings and recommendations for policy and practice in Chapter 7.

2.6.1. Methodological limitations and opportunities

Econometric-based aviation demand modeling methods that are widely used in academic literature and in practice currently do not incorporate the impact of high-speed rail. Based on case study analysis of major city pairs where high-speed rail competes against air transportation, it is clear that air traffic levels are often significantly impacted by the introduction of high-speed rail, as well as improvements in high-speed rail service (e.g., in the form of faster travel times). Aviation origin-destination modeling methods in several regions would likely result in improved forecasts by integrating high-speed rail.

Future models of high-speed rail demand, particularly studies of Europe and other regions where integrated rail networks are planned, should draw from the substantial body of literature on network-based methods used to examine air transportation demand. Although there are numerous applications of network methods to freight rail, the similarities between high-speed rail passenger demand and air transportation passenger demand are more significant. Two major regions where these methods are likely to be needed include: the planned Trans-European high-speed rail network (TEN-R) and the $300 billion USD high-speed rail network planned by China, both of which are likely to have a complex network structure.

2.6.2. Examining complementarity between aviation and high-speed rail

Disaggregate choice models that are predominantly used to examine the relationship between high-speed rail and aviation focus on substitution between the two transportation modes (Gaudry, 1998). However, the relationship between these two "high-speed" transportation modes is much more complex. First, in many regions, there is often latent demand for high-speed transportation that, after the development of high-speed rail, may more easily be served. Second, airport-level capacity constraints and the lower (on average) profits that airlines earn from short-haul flights suggest that it may be beneficial for airlines to shift their landing slots at airports from short-haul to medium- and long-haul flights. This may be more attractive and feasible if high-speed rail can fill the need for short-haul travel, particularly if HSR lines are linked to airports. There is a significant need to explore this complimentary relationship between HSR and air transportation, as well as the implications that it might have on passenger demand (TRB, 2010).

2.6.3. Additional opportunities and challenges

High-speed rail is often considering a lower-carbon alternative to air transportation, and is being promoted in many regions as part of overarching climate policy plan (e.g., Europe, the U.S.). However, whether or not high-speed rail reduces the environmental footprint of the transportation sector depends on several key issues:

- environmental impact of the infrastructure development;
- ridership levels;
- fuel and electricity prices, and how they might adjust under climate policies; and

- interaction between high-speed rail demand and air transportation demand, particularly the challenge of estimating induced demand.

Identifying methods to incorporate the above issues into demand modeling methods is a complex issue. Models utilized in other fields, for example computable equilibrium models used to examine the impact of climate policy scenarios on prices and demand, could be coupled with demand models of high-speed rail and aviation to explore these questions.

This dissertation presents research in the areas outlined above in order to improve models of aviation and high-speed rail demand, as well as methods to estimate their long-range energy use and climate impacts.

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Chapter 3: The impact of high-speed rail and low-cost carriers on European air traffic

Our analysis of high-speed rail and aviation demand begins by examining the historical European experience over the past two decades. In this chapter, we examine the impact of high-speed rail development on European air traffic, providing an econometric analysis of origin-destination traffic as well as airport-level traffic (i.e. enplaned passengers at the airport). This system-wide analysis aims to build an improved understanding of the factors that impact air-rail substitution and its impact on the broader aviation system.

3.1. INTRODUCTION

Under business-as-usual scenarios, CO_2 emissions associated with global aviation are expected to increase by 300 percent over the next 40 years (IEA, 2008b). Driving this upward trajectory is the continuous growth in the demand for air travel, which has increased dramatically since deregulation in the United States and elsewhere (Belobaba and Odoni, 2009). Although the recent economic downturn has resulted in a slowdown in demand, it is predicted that globally, over the next 50 years, general transportation volume will increase and will shift towards faster modes, including primarily aviation (Schafer and Victor, 2000). Concerns about the climate impacts of air travel have prompted consideration of policies to mitigate greenhouse gas (GHG) emissions of this sector, particularly in Europe and the United States. However, recent studies indicate that the potential for such policies to reduce aviation emissions is limited, as air travel demand is somewhat price inelastic and the opportunities for airlines to replace more CO_2-intensive energy sources with less CO_2-intensive energy sources are limited (Winchester et al., 2011).

High-speed rail (HSR) is often promoted as a lower-carbon alternative to air travel and, in some nations, identified as one component of a climate policy agenda, e.g., in the United States in 2009 (FRA, 2009). There is some evidence from the European experience that HSR is, in fact, a competitive alternative to air transportation, particularly for short-haul, intercity travel. In the past decade, several studies have emerged that examine the substitution of high-speed rail for air transportation, particularly in Europe and Asia (Clever and Hansen, 2008; Park and Ha, 2006; Grimme, 2006). A multiple case study prepared for the European Commission documented eight major intercity routes where air and rail compete, finding that rail journey time was the most significant factor impacting market share (Steer Davies Gleave, 2006). This study also suggests that there is significant variation in how high-speed rail impacts the air-market share of different intercity corridors.

Previous studies on air-rail competition focuses on market share between the two modes and on a handful of major corridors where high-speed rail development has occurred. Building on the existing literature, this chapter examines the factors that influence the substitution of high-speed rail for aviation by developing an expanded panel dataset of European air traffic, high-speed rail travel times, regional demographics, and airport characteristics. The dataset includes 66 airport pairs, and 28 to 46 origin-destination pairs over 13 years. Utilizing this data, the extent to which rail improvements have reduced total air traffic in Europe is examined, as well as the variation in these air traffic trends. We also examine the role of low-cost carrier (LCC) service in the region and the impact of expanded service on origin-destination traffic and airport-level traffic. The results have implications for transportation policy decisions, including strategies to reduce greenhouse gas emissions in the transportation sector, aviation system planning, and rail infrastructure investment.

The remainder of this chapter is organized as follows. Section 3.2 provides an overview of the types of econometric models and functional forms often utilized to model aviation and high-speed rail demand, as well as key results from previous studies examining high-speed rail and aviation demand in Europe. Section 3.3 describes the dataset utilized in this analysis, highlighting selection of panel data and airport-level characteristics. Section 3.4 provides an overview of modeling approaches to examine the role of high-speed rail and low-cost carrier service on European air traffic and estimation results. Section 3.5 discusses the key findings from this analysis, a brief overview of the policy implications, and potential extensions for future research.

3.2. RELATED WORK

3.2.1. Econometric models of aviation demand

Although disaggregate, choice theory methods have come to dominate much of urban transportation demand analysis, traditional econometric models are still heavily utilized in *air* transportation demand research and forecasting practice. Econometric models of demand are a dominant tool for examining origin-destination (O-D) demand, national and regional demand, and occasionally, airport-level demand. Research on aviation demand at these levels is typically empirical, and relies on cross-sectional, time-series data (usually annual data) from publicly available or proprietary sources. Practitioners are likely to use historical data for a 12- to 20-year time period in order to estimate the parameters of a demand model (TRB, 2002). These models are typically estimated using regression analysis, and are then utilized to predict future demand at the O-D, national, or regional level. The majority of econometric-based demand models in the aviation sector take on the following form shown in Eq. 3.1.

$$\ln(\text{Demand}) = \beta_0 + \beta_1 \ln(\text{GDP}) - \beta_2 \ln(\text{Yield}) + \beta_3 X + \varepsilon \tag{3.1}$$

where *Demand* is measured by passengers (or flights), *GDP* is some combination of the average gross domestic product at the origin and destination, and *Yield* reflects the average fares paid for air transportation service, *X* represents a number of additional parameters that the modeler expects to influence demand, and ε is a random error term. The primary explanatory variables of most econometric-based demand models of air transportation are household income and yield (average fares).

Recent research suggests that origin-destination level forecasts of air transportation can be significantly improved by considering local area information such as density, hub status of the airport, market power, and low-cost carrier presence (Bhadra, 2003). In practice, these forecasts might also include dummy variables associated with significant events (e.g., some models of U.S. traffic include a 9/11 dummy variable). A recent study on the role of low-cost carrier entry examines how incumbents respond prior, during, and after the entry of Southwest Airlines, demonstrating that even the *threat* of entry has an impact on air transportation capacity and air traffic at the O-D level (Goolsbee and Syverson, 2008). These studies and others suggest that incorporating airport-level characteristics (such as the presence of high-speed rail service) result in improved forecasts of air transportation demand.

3.2.2. Econometric models of high-speed rail demand

There is a significant body of rail demand modeling literature focused on examining *potential* demand where high-speed rail (HSR) infrastructure is being considered, as well as realized behavior where HSR has successfully been constructed and provides service. This section provides an overview of empirical studies of existing high-speed rail demand and their key conclusions, forecasting studies for potential HSR service, and advanced methodologies that are frequently applied to rail demand modeling.

In the past decade, numerous studies have examined the substitution of high-speed rail for air transportation in Europe and Asia (Park and Ha, 2006; Clever and Hansen, 2008). The majority of these studies are focused on mode choice between two major cities, utilizing choice modeling methods to examine stated preference (SP) data, or revealed preference (RP) data. For example, the study by Park and Ha includes stated preference data collected *prior* to the opening of the Korea Train eXpress (KTX), as well as measured actual demand following the opening of the high-speed rail line. Stated and revealed preference studies often use logit model formulations and similar explanatory variables: travel time, fares, access time, frequency, trip purpose, and income.

Comparative studies based on European high-speed rail development have examined historical market share and general trends in air transportation and high-speed rail demand. A few studies documenting air transportation and HSR in France, Spain, and Japan conclude that it is very difficult for air transportation to compete effectively in short-haul markets of 500 kilometers or less (Park and Ha, 2006; GAO, 2009). A multiple case study prepared for the European Commission documented eight intercity routes where air and high-speed rail are present (Steer Davies Gleave, 2006). One of this report's key conclusions was that rail journey *time* (i.e. not distance) was the most significant factor impacting market share (see Figure 3.1). Given that HSR speeds can vary substantially (from 200 kilometers per hour to 350 kilometers per hour), it can be concluded that the more precise and effective method is to incorporate travel *time* into demand models (in place of, or in addition to, distance).

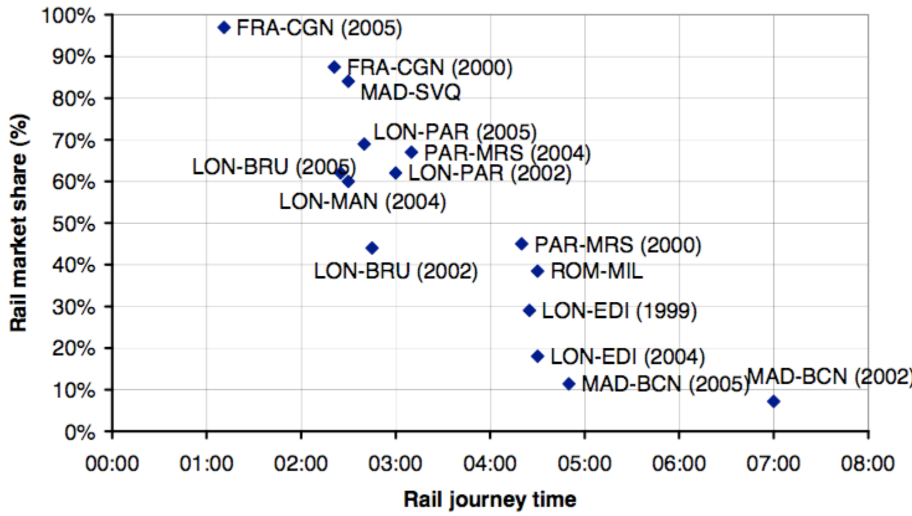

Figure 3.1 Market share as a function of rail journey time (source: Steer Davies Gleave, 2006)

Through this analysis, limited rail data (i.e. rail travel time, from 1990-2010) was collected in order to improve econometric models of origin-destination air traffic. This work builds on previous literature focused on rail and aviation market share by utilizing the traditional methods from aviation demand forecasting to demonstrate that rail journey time has a significant impact on air traffic decline in short-haul aviation markets. By including a large number of short-haul air traffic routes in Europe, we are also able to examine how regional variations (e.g., in household income, density, airport status) affect the decline in air traffic after the introduction of high-speed rail as a competitive alternative.

3.3. DATA SOURCES AND SELECTION

3.3.1. Data sources

The primary data utilized as our core predictor variables in this analysis are summarized in Table 3.1. All variables were gathered from publicly available data sources, including the statistical office of the European Union (Eurostat), the Energy Information Administration, European rail operator timetables, airport annual reports, press releases, and low-cost carriers.

Table 3.1 Key variables and sources

Dimension	Variable	Sources
Aviation demand	Air traffic	Eurostat, Transport: Air transport: Detailed air passenger transport by reporting country and routes: Passengers carried UK Civil Aviation Authority, UK Airport Statistics: Dom Air Pax Route Analysis: Scheduled Passengers
Price/ fares	Jet fuel	EIA Annual Europe Brent Spot Price
GDP	GDP	Eurostat, Annual national accounts: Regional economic accounts: Gross domestic product indicators: Gross domestic product (GDP) at current market prices by NUTS 3 regions
Population and density	Population and density	Eurostat, Regional Statistics: Regional Demographic Statistics: Population and area: Density
Rail competition	Rail travel time	RENFE, SNCF, DB Bahn, National Rail, British Rail
Low-cost carrier presence	Low-cost carrier offers service	Airport publications, news articles, and press releases announcing low-cost carrier routes

Aviation demand. The primary metric for air traffic that is available through Eurostat is the total *Passengers Carried* for an airport pair. This metric includes all passengers who travel between two airports, including those passengers who may be connecting to, or from, another flight. Outside of the United States, examining the true origin-destination traffic for a city pair is a complex exercise, often requiring access to expensive proprietary data maintained by airlines or industry specialists. True origin-destination traffic includes those passengers who board at the origin city and disembark and the destination city; it excludes those passengers who connect to or from another flight at either end of the trip.

For the purposes of this analysis, we examine the total passenger traffic between an O-D pair, including connecting passengers. This exercise is useful for the following reasons: 1) conducting a preliminary study with easily accessible data can serve as a useful starting point for a more accurate and expensive analysis (Bonvino et al., 2009); 2) airport-rail connectivity can enable connecting passengers to travel by rail for the short-haul portion of their journey, and travel by air for the long-haul portion. The potential for cooperation between aviation and high-speed rail has been observed in previous literature (Grimme, 2006; TRB, 2010), and thus it is useful to develop models that include connecting passengers when examining air and rail demand on short-haul routes.

Price/ fares. In this study, we use jet fuel as a proxy for airfares. Origin-destination *yield* is the most precise metric one can utilize in econometric models of aviation demand. Given that airfares vary significantly based on the class of ticket purchased, and *when* the ticket is purchased, aviation *yield*, or average operating revenue per passenger-mile, is often used as a metric for airfares. Similar to the challenge of obtaining true origin-destination air traffic data, origin-destination yield data (outside of the U.S.) is only available through proprietary industry sources.

Jet fuel is one of the largest expenditure of airlines, and previous literature suggests that airlines pass a high portion of these costs onto the consumer. In this study, we attempt to use jet fuel as a proxy for airfares. Through estimation results, we find similar price elasticities as airfares.

Demographic Data. Regional GDP, population, and density data were obtained through Eurostat's statistical databases for the origin and destination of each airport pair. For the O-D demand analyses, different combinations of origin and destination data were explored to determine which combination yielded the strongest explanatory power: separate origin and destination variables, a variable representing the geometric mean of the origin and destination data, and a variable representing the average mean of the origin destination data. In the final origin-destination model specifications, all three variables (GDP, population, and density) were found to yield the greatest explanatory power when incorporated as a geometric mean of the two regions. For the airport-level analyses, the GDP, population and density data for the region where the airport is located was utilized in the model development.

Rail competition. In order to determine rail journey times for the O-D pairs of interest, timetables for rail operators in Europe were accessed to gather the necessary travel time data. Historical timetables were accessed either by directly contacting the rail operator, or by searching through historical records. Rail data was gathered from RENFE (Spain), SNCF France), DB Bahn (Germany), National Rail (UK), and British Rail (UK). Rail travel times decreased *substantially* for several corridors in Spain, France, and Germany over the time period of interest; however, rail travel times actually became worse for some journeys in the UK when rail was first privatized, and then improved after a change of contract to Virgin Trains in 1997.

The rail journey time data was also utilized to determine the *presence* of high-speed rail service in the airport-level analyses, where "high-speed rail" is defined by the European Union standard of 200 kilometers per hour (124 mph) for upgraded track and 250 kilometers per hour (155 mph) or faster for new track.

Low-cost carrier presence. A dataset was constructed to examine the potential impact of low-cost carrier impact on airport-level traffic. For each airport included in our analysis, the years when low-cost carriers offered service were determined by examining new articles, airport publications, and press releases of European low-cost carrier airlines announcing the opening of the new route. Low-cost carrier entry at an airport was often initiated by one of the older low-cost carrier airlines (Ryanair, Germanwings, Flybe, or XL Airways); service then often expanded as other carriers attempted to enter the airport.

3.3.2. Route, airport, and city selection

Origin-destination analysis. This chapter examines all direct, short-haul air traffic O-D pairs in the four major European countries that generate the most air traffic: France, Germany, Spain, and the United Kingdom. The analysis includes all short-haul air traffic pairs in these countries where rail service is available; included are all routes where rail journeys can now be made in less than five hours and where air carriers provided service at some point in time between 1990 and 2010. There are numerous O-D pairs where we observe a significant decline in air traffic after the introduction of high-speed rail, as well as others where the reduction in air traffic was less substantial.

Airport and city pairs. In this analysis, *airport* pairs are examined, as well as *city* pairs. A city pair is defined as an origin city and destination city between which passengers might travel via air or rail. However, several major European cities are considered "multi-airport regions", where passengers can chose to travel through one of two or more airports. For example, passengers in London can travel through one of five airports (Heathrow, Gatwick, London City, Luton, and Stansted) and passengers in Paris can travel through one of two airports (Charles de Gaulle and Orly). For our *city* pair analysis, the traffic from all airports serving an origin and destination are aggregated to determine the total traffic between the city pair. In the case of London and Paris, the traffic between all five London airports to all two Paris airports is aggregated into one passenger traffic figure for each year.

Airport traffic analysis. This chapter also includes an *airport*-level analysis of air traffic demand, in order to examine the impact of high-speed rail and low-cost carriers on airport utilization. For the airport-level analysis, our dependent variable is annual passengers on board (including both departures and arrivals). Our data selection includes all of airports included in the previous O-D traffic analyses, major airports in France, Germany, Spain, and the UK.

3.4. MODEL STRUCTURE AND ESTIMATION RESULTS

The goal of this analysis is to examine the extent to which improved rail travel times have impacted air traffic demand in Europe, the regional factors that influence variation of these air traffic trends, and the potential influence of low-cost carriers over the same time period. Four model formulations were developed to investigate these effects: 1) a city (or multi-airport region) model of origin-destination demand; 2) an airport-to-airport model of origin-destination demand; 3) a model of national air traffic demand originating at the airport; and 4) a model of intra-European Union (EU) demand originating at the airport. The latter two models aim to improve our understanding of the impact of high-speed rail, low-cost carriers, and other factors on airports, a common congestion bottleneck of air transportation systems around the world.

3.4.1. Impact of high-speed rail on origin-destination air traffic: city-pair analysis

To examine whether improved rail travel times have affected origin-destination air traffic in Europe, a model specification was developed to estimate the effect of characteristics that are likely to impact air travel demand, as well as rail travel time. Eq. 3.2. defines the basic structure of the models utilized in the analyses in Section 3.4.1. and 3.4.2.

$$\ln(\text{O-D Demand}_{it}) = \beta_0 + \beta_1 \ln(\text{Rail}_{it}) + \gamma\,(X_{it}) + \mu_i + \varepsilon_{it} \qquad (3.2)$$

Eq. 3.2. is similar to the model specifications found in the literature and in practice (TRB, 2002; Bhadra, 2003), where vector X represents the following parameters that are known to influence air traffic demand: GDP, population, density, and fuel price (as a proxy for airfares). The inclusion of *Rail Travel Time* is added to the model to estimate the relationship between rail travel times (that change over the time period when improved rail service is introduced) and air travel demand.

Estimates were obtained using ordinary least squares (OLS) regression and a variance components model. A Breusch-Pagan test was used to determine the presence of heteroscedasticity in the classic linear regression (OLS) model for both the city and airport pair analyses. The test statistics indicated that the OLS model specifications were inefficient; however, the estimates for the OLS and variance components model specifications yield similar results.

The variance components model specifications included a random effects estimator and a fixed effects estimator. In the random effects model specification, μ_i in Eq. 3.2 is assumed to be independent of X_{it}, Rail Travel $Time_{it}$. That is, $E[\ \mu_i \mid X_{it}$, Rail Travel $Time_{it}\ ] = 0$; the individual specific effect is uncorrelated with the independent variables. In our fixed effects model specification, it is assumed that μ_i is not independent of X_{it}, Rail Travel $Time_{it}$. In order to test whether the random effects model provides consistent results, we perform a Hausman test. Our null hypothesis H_0 is as follows: the coefficients estimated by the efficient random-effects model are the same as the coefficients consistent fixed-effects model. For both the city and airport pair analyses, we fail to reject the null hypothesis at a P=0.05 significance level; that is, we can assume that the random-effects model is consistent.

Table 3.2 summarizes estimation results from alternative model specifications under the assumption that we have random individual differences.

Table 3.2 Effect of improved rail travel times on O-D air traffice between cities

	(1)	(2)	(3)	(4)
Natural log of:				
GDP	0.297	2.280**	3.548**	5.192**
	(0.714)	(0.872)	(1.273)	(1.696)
Fuel price		-1.863***	-2.360**	-2.304*
		(0.476)	(0.714)	(0.906)
Population			1.961*	1.818
			(0.997)	(1.126)
Density			-0.427	-0.376
			(0.549)	(0.603)
Rail travel time				4.734***
				(0.834)
Constant	8.066	-5.472	-41.774*	-82.329***
	(7.389)	(8.111)	(19.187)	(24.589)
N	n=53, T=2-15, N=579	n=53, T=2-15, N=579	n=52, T=1-15, N=539	n=31, T=1-15, N=326
R^2	0.163	0.185	0.181	0.296
Significance codes	* $p<0.05$ ** $p<0.01$ *** $p<0.001$			

Our alternative model specifications include first the key factors that are known to affect air travel demand (GDP and price), followed by additional factors that are typically utilized in econometric models of air transportation (population and density). The last model specification incorporates a rail time parameter to examine the effect of rail travel times on air traffic.

The elasticities of demand for air travel with respect to GDP and price are similar to previous studies on air travel demand elasticities. In the city pair model, jet fuel price elasticity of demand estimates for air traffic are between -1.863 and -2.304, similar to the range of airfare price elasticities observed for intra-Europe short-haul air traffic (-1.23 to -1.96) (Intervistas, 2007). Based on these preliminary results and further analyses in the remainder of this chapter, jet fuel appears to serve as a useful proxy for airfares. GDP elasticity of demand estimates from the literature represent a much wider range (0.46 to 5.51) (Intervistas, 2007). Our estimates for GDP fall within a similar range.

The addition of rail travel time appears to add significant explanatory power to our model. The large positive value of the rail travel time coefficient suggests that as rail travel times are reduced, air traffic volumes are also reduced. Although these estimation results are likely influenced by significant air traffic reductions on corridors such as Frankfurt-Cologne, where air traffic was reduced to zero, the results do have implications for aviation planning at a broader system-wide level.

In the United States, density tends to have a positive effect on air travel. It has been suggested that density can be viewed as representative of economic activities, and thus we would anticipate that it has a positive impact on origin-destination demand (Bhadra, 2009). An interesting observation from these model estimates is that the density coefficient is negative. The negative effect of density on air traffic is possibly a result that is more likely to be observed in Europe, where the availability of rail is more prevalent in major cities with higher levels of density and perhaps more likely to be utilized over air travel for short-haul, intercity travel.

3.4.2. Impact of high-speed rail on origin-destination air traffic: airport-pair analysis

In this section, origin-destination air travel demand is examined from airport to airport, as opposed to the previous aggregation at the city level. The airport pair model presents an improved analysis for several reasons. First, GDP and density can be observed at a more precise regional level utilizing Eurostat data; that is, the GDP and density data utilized in these models are associated with the specific urban regions where airports are located, as opposed to aggregated at the mega-city region. Second, we incorporate information about hub airports. As might be expected, the presence of a hub by a major airline is likely to have a positive effect on air travel demand. Airlines are more likely to increase frequency and reduce fares on routes serving airports where they have establish a hub in order to maintain market share, thereby positively affecting air travel demand.

Table 3.3 summarizes estimation results from alternative model specifications under the assumption that we have random individual differences.

Table 3.3 Effect of improved rail travel times on O-D air traffic between airport pairs

	(1)	(2)	(3)	(4)	(5)
Natural log of:					
GDP	0.280	3.394***	6.039***	5.857***	5.468***
	(1.420)	(0.831)	(1.061)	(1.060)	(1.181)
Fuel price		-2.287***	-3.412***	-3.312***	-2.913***
		(0.445)	(0.558)	(0.558)	(0.624)
Population			1.182	0.424	0.810
			(0.748)	(0.800)	(0.711)
Density			-2.484***	-2.511***	-2.479***
			(0.509)	(0.536)	(0.554)
Hub (origin)				2.491*	2.713**
				(1.013)	(0.951)
Hub (destination)				2.115	3.132†
				(2.168)	(1.830)
Rail travel time					5.261***
					(0.857)
Constant	6.516	-17.229*	-38.367**	-26.818	-57.746***
	(5.966)	(7.506)	(13.654)	(14.483)	(14.473)
N	n=94, T=1-15, N=1124	n=94, T=1-15, N=1124	n=92, T=1-15, N=1083	n=92, T=1-15, N=1083	n=69, T=1-15, N=835
R^2	0.073	0.094	0.113	0.119	0.172
Significance codes	† $p<0.10$ * $p<0.05$ ** $p<0.01$ *** $p<0.001$				

The relationships between air travel demand and GDP, fuel price, population, density, and rail travel times are estimated with similar results as our previous analysis. Due to the improved resolution of data in this model specification (with demographic data at the intra-urban level versus mega-city level), we obtain more significant coefficient estimates for GDP and density. The relationship between air travel demand and urban density is estimated to be between -2.479 and -2.511; that is, a 10% increase in density could lead to a 25% reduction in air traffic demand for short-haul origin-destination airport pairs. Although changes in density occur over long time scales, the result nevertheless provides some supporting evidence that high-speed rail may be more competitive against air travel in cities where there is greater density, which make intuitive sense given the city-center to city-center nature of high-speed rail.

3.4.3. Impact of high-speed rail on domestic airport traffic

In the following two sections, air travel demand at the airport level is examined to explore the potential impact of improved rail service and introduction of low-cost carrier service on European airports. There are several motivations for forecasting air travel demand data, including primarily: 1) forecasting origin-destination traffic for airline and air traffic management planning purposes; and 2) forecasting airport-level traffic for airport capacity planning. The previous sections address the former; Sections 3.4.3, 3.4.4, and 3.4.5 address the issue of airport capacity and examine the factors that influence demand at the airport level.

Utilizing airport-level passenger air traffic data, we develop the model specifications outlined in Eq. 3.3 and Eq. 3.4.

$$\ln(\text{Airport Demand}_{it}) = \beta_0 + \beta_1 \ln(\text{Rail}_{it}) + \beta_2 \ln(\text{LCC}_{it}) + \gamma(X_{it}) + \varepsilon_{it} \qquad (3.3)$$

$$\ln(\text{Airport Demand}_{it}) = \beta_0 + \beta_1 \ln(\text{Rail}_{it}) + \beta_2 \ln(\text{LCC}_{it}) + \gamma(X_{it}) + \mu_i + \varepsilon_{it} \qquad (3.4)$$

Both equations are similar to the previous model specification (Eq. 3.2), where vector *X* represents the following parameters that are known to influence air traffic demand: GDP, population, density, fuel price, and hub status. The *Rail* parameter represents the presence of high-speed rail service (as defined in Section 3.2). The *LCC* parameter indicates whether or not low-cost carrier service is present at the airport.

Estimates were obtained using ordinary least squares (OLS) regression (Eq. 3.3) and a variance components model (Eq. 3.4). For this dataset, a Breusch-Pagan test determined that the null hypothesis of homoscedasticity could not be rejected for our OLS model specification. Using a Hausman test, it was determined that the random effects model specification provides consistent results to a fixed effects estimator. Table 3.4 summarizes the estimation results for OLS and random-effects model specifications of this data.

Table 3.4 Effect of high-speed rail presence on national air traffic

	OLS	RE
Natural log of:		
GDP	0.220	0.047
	(0.163)	(0.282)
Fuel price	-0.203***	-0.202*
	(0.032)	(0.092)
Population	0.640***	0.721**
	(0.089)	(0.250)
Density	0.204***	0.252*
	(0.046)	(0.117)
Hub	0.897***	0.831†
	(0.151)	(0.429)
High-speed rail	-0.487***	-0.119*
	(0.098)	(0.059)
Constant	2.431	2.409
	(2.136)	(4.694)
N	N=386	n=38, T=6-13 N=389
R^2	0.395	0.386
Significance codes	† p<0.10 * p<0.05 ** p<0.01	*** p<0.001

First, a model of national air traffic is developed, excluding all international traffic, in order to examine the relationship between air travel demand and the parameters of interest. In this airport-based analysis, the models estimate similar relationships between air travel demand and GDP, fuel price, population, and hub status. Jet fuel price elasticities are estimated at -2.203 and -2.202, and are significant.

As compared with the origin-destination analysis in Sections 3.4.1 and 3.4.2, the density coefficient estimate is observed to be positive and significant, at 0.204 and 0.252. As mentioned previously, density is often positively correlated with air travel demand. In this model, air traffic includes *all* national air traffic, including routes that were not included in the previous analysis focusing on short-haul travel.

As anticipated, the presence of high-speed rail in an airport market has a negative impact on national air traffic originating from (and arriving to) that airport. The coefficient estimate falls between -0.119 and -0.487.

3.4.4. Impact of high-speed rail and low-cost carriers on intra-EU airport traffic

Another key factor influencing airport traffic over the timeframe of this analysis is the growth of low-cost carrier (LCC) service in Europe. LCCs such as Ryanair, Germanwings, and easyJet expanded their services substantially from the 1990s to today, primarily focusing on intra-EU, mid-haul travel markets. The presence of low-cost carrier service is incorporated into a model specification to examine this impact on EU passenger traffic at the airport level. The estimation results are presented in Table 3.5.

Table 3.5 Effect of low-cost carrier entry on intra-EU traffic

	OLS	RE
Natural log of:		
GDP	0.183	1.020^{***}
	(0.136)	(0.136)
Fuel price	-0.172^{***}	-0.019
	(0.033)	(0.017)
Population	0.574^{***}	0.896^{***}
	(0.084)	(0.249)
Density	0.337^{***}	0.237^{*}
	(0.043)	(0.107)
Hub	1.390^{***}	0.930^{*}
	(0.137)	(0.434)
High-speed rail	-0.186^{*}	$-0.009^{\dagger}$
	(0.093)	(0.049)
Low-cost carrier	0.893^{***}	0.209^{***}
	(0.105)	(0.045)
Constant	1.680	-11.092
	(1.865)	(3.826)
N	N = 460	n=38, T=6-15 N=481
R^2	0.576	0.613
Significance codes	* p<0.05 ** p<0.01	*** p<0.001

The traditional factors that influence air traffic (GDP, fuel price, population, density, and hub status) are estimated with coefficients of the sign and magnitude that are expected. The presence of high-speed rail appears to negatively affect intra-EU air traffic at the airport level, though not as substantially or significantly as it does national air traffic. Given that many intra-

EU destinations served by an airport are not likely located within a distance where high-speed rail would be competitive, this is a logical result.

The role of low-cost carrier presence at European airports has a significant positive impact on intra-EU travel demand. Combined with the presence of LCCs at an airport, the primary drivers of intra-EU traffic appear to be GDP and population. Fuel price appears to play a less important role in these markets.

3.4.5. Implications for airport capacity planning

Our final analysis compares models of national, intra-EU, and total passenger traffic at the airport level. Using a random effects model specification we compare the impact of high-speed rail and low-cost carrier presence on airport-level traffic for all three cases. The estimation results are summarized in Table 3.6.

Table 3.6 National, intra-EU, and total airport level traffic

	Domestic	Intra-EU	Total
Natural Log of:			
GDP	0.064	1.020***	0.340
	(0.284)	(0.136)	(0.185)
Fuel price	-0.201*	-0.019	-0.075
	(0.093)	(0.017)	(0.067)
Population	0.724**	0.896***	0.786***
	(0.254)	(0.249)	(0.205)
Density	0.253*	0.237*	0.305***
	(0.119)	(0.107)	(0.092)
Hub	0.823†	0.930*	1.223***
	(0.436)	(0.434)	(0.357)
High-speed rail	-0.123*	-0.009	-0.023
	(0.059)	(0.049)	(0.039)
Low-cost carrier	-0.054	0.209***	0.114**
	(0.058)	(0.045)	(0.038)
Constant	2.226	-11.092	-1.629
	(4.748)	(3.826)	(3.453)
N	n=38, T=6-13 N=389	n=38, T=6-15 N=481	n=38, T=6-13 N=395
R^2	0.386	0.613	0.599

Population and density appear to play a similar positive role in affecting air traffic at the airport level in all three analyses, though density appears to play a smaller role in driving national air traffic. Similarly, the hub status of an airport appears to have a greater impact on total air traffic, which is likely driven by airlines striving to maintain market share for international, long-haul flights that are typically more profitable.

Domestic air traffic appears to be the most sensitive to increasing jet fuel prices (as proxy for airfares), as compared with intra-EU or total traffic. One potential explanation is that as jet fuel prices increase (and thus airfares likely increase) in the domestic air travel market, passengers have greater flexibility in reducing their travel or switching to alternatives modes (e.g., auto, rail, or intercity bus).

As we might expect, the presence of high-speed rail plays a greater role in reducing domestic air traffic, as compared to intra-EU or total airport traffic (e.g., where the coefficient estimates are small and not significant). It appears that as domestic traffic declines, capacity shifts are likely to take place, where short-haul flights are substituted at the airport level by medium- and long-haul flights.

3.5. CONCLUSIONS

3.5.1. Key Findings

Based on this study of an expanded dataset of air traffic in Europe, it can be concluded that the presence of high-speed rail and expansion of low-cost carriers has had a significant impact air travel demand. In addition, this analysis improves our understanding of the impacts that high-speed rail and LCC service have on the broader air transportation system by examining airport-level demand for different travel markets.

Short-haul origin-destination air travel demand has clearly been affected by the introduction of improved rail travel times for the four major European countries included in this analysis: France, Spain, Germany, and the United Kingdom. The primary factors that also influence travel in these O-D markets are GDP (positive effect) and fuel price (negative effect), as well as density (negative effect). The negative impact of density on short-haul air travel supports a wide belief that high-speed rail may serve as a more competitive alternative where there is increased density.

The analysis of airport-level air traffic data provides insight into the complex nature of the air transportation system and the various factors that shape travel demand. First, while it is clear that while high-speed rail has played a significant role in *reducing* domestic air travel in Europe, at the same time, low-cost carriers have had a more significant influence on *increasing* travel, primarily to medium-haul destinations within the EU. From an airport utilization perspective, these shifts in airport traffic have likely resulted in enhanced mobility for intercity travel between destinations for which limited alternatives exist. However, from a climate policy perspective, these shifting trends have likely resulted in an increase in the impact of aviation on our environment.

3.6. POTENTIAL EXTENSIONS

3.6.1. Examining the shift of capacity from short-haul to longer-haul traffic

As suggested above, the reduction of, or slower growth in short-haul flights would likely result in an increase of available landing slots at European airports, where capacity in the air transportation system is most constrained. Furthermore, airlines typically earn a greater profit on longer-haul flights than shorter-haul flights due to the disproportionately higher costs associated with the landing and take-off of flights (e.g., in the form of landing fees and greater consumption of fuel required for takeoff/landing). Globally, it has been observed that many airlines have shifted capacity from shorter-haul travel to longer-haul travel for this reason.

Over one hundred airports in Europe implement “slot” control mechanisms to manage capacity issues, including Frankfurt, Charles de Gaulle, and Heathrow. The number of flights per hour or half hour is capped, and the slots are auctioned off to airlines to purchase landing slots. Given the relatively substantial costs associated with landing an aircraft, the airlines have a significant incentive to shift capacity to their most profitable routes. If short-haul flights became even less profitable after the introduction of a competitive alternative (i.e. high-speed rail), it is likely that airlines may have had a greater incentive to shift capacity from short-haul travel service to intra-EU or extra-EU international service. Further analysis examining airport-level traffic could yield more conclusive results for this hypothesis.

3.6.2. Cooperation between high-speed rail and airlines

Significant reductions of O-D level air traffic were observed in this study, particularly from Paris and Frankfurt. One notable similarity between these two cities that is hypothesized as an explanatory factor is the unique relationship between high-speed rail service and air carrier service at the airports in these cities. In both Frankfurt and Paris, high-speed rail lines connect directly to the airport and air carriers have operated in a cooperative (as opposed to competitive) manner with high-speed rail operators. For example, between Frankfurt and Cologne, Lufthansa reduced its air service and partnered with the rail operator, DB Bahn, to offer integrated rail-to-air service for connecting passengers (Grimme, 2006). Eventually, Lufthansa pulled all of its flights from the short-haul route.

There is limited literature on the cooperative nature of high-speed rail and air transportation; however, based on this preliminary analysis, it appears that those cities that contain direct high-speed rail lines to the airport experience a greater reduction in domestic air traffic. Further analysis could yield more useful results, and would have significant implications for decisions regarding the design of high-speed rail infrastructure in Europe and potentially elsewhere. In the next chapter, we provide an in-depth analysis of air-rail connectivity in Europe: how air-rail partnerships began, key factors that contributed to successful examples of air-rail connectivity, and their impacts on travel demand.

Chapter 3 References

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Chapter 4: Air-rail connectivity and intercity travel demand

4.1. INTRODUCTION

Over the past two decades, several studies have emerged that examine the role of high-speed rail as a substitute for air transportation on intercity travel corridors, particularly in Europe and Asia. This research on the *competition* between air and rail highlights various factors that influence the substitution between these modes, including primarily price, cost, and accessibility. In contrast, there are a growing number of cases where air transportation and high-speed rail serve in a *complementary* manner, for example, when high-speed rail service is designed with connectivity to an air transportation system. The emergence of these intermodal high-speed rail and air transportation systems has the potential to shape alternative future scenarios of travel demand, as well as the climate impacts of these systems.

Growing congestion of the air transportation system is a challenge facing many regions around the world, and is a key motivating factor for designing intermodal transportation systems that might provide better utilization of transportation infrastructure. Airports typically represent the critical bottleneck in air transportation systems, where capacity is determined based primarily on runway and taxiway infrastructure, as well as the weather conditions for takeoff and landing. However, given the network structure of most airlines, congestion at the airport level often propagates delays throughout the air transportation system. It has been suggested that in Europe, intermodal transportation policies aim to alleviate congestion without sacrificing mobility and economic growth (USGAO, 2005).

U.S. airports face significant congestion problems, particularly those in major metropolitan areas with continued population and economic growth (MITRE, 2007). In addition to growth in air travel demand, contributing to airport congestion are frequent, short-haul flights on routes of less than 500 miles (Tomer and Puentes, 2009). Although the potential for high-speed rail (HSR) to serve as a substitute for aviation on these short-haul routes is well documented, there is a need to explore how rail can also serve in a complementary mode, relieving congestion at airports by providing short-haul services in support of longer haul airline services (TRB, 2010).

In order to address future mobility needs and transportation-related environmental challenges, it is critical to develop an improved understanding of intermodal high-speed rail and air transportation systems. This chapter addresses the following key questions:

- How have airports, airlines, and rail operators cooperated to enable airport-HSR connectivity?
- What are the service characteristics of airport-HSR connectivity?
- What are the unique challenges associated with airport-HSR connectivity?
- How has air transportation demand evolved in the presence of airport-HSR connectivity?

4.2. LITERATURE REVIEW

It is clear that the expansion of high-speed rail lines in Europe has resulted in substantial shifts in mode share from aviation for short-haul intercity passenger transport in this region. These adjustments in travel behavior have significant implications for infrastructure investment decisions and the environmental footprint of the transportation sector. Both airports and high-speed rail require costly infrastructure that, once built, is typically utilized over long time scales (Auld et al., 2006). Given the interrelationship between demand for aviation and high-speed rail, increasing our understanding of the factors that shape intercity travel demand for these two modes is critical for long-range transportation system planning.

In the past decade, several studies have emerged that analyze the substitution of high-speed rail for air transportation, particularly in Europe and Asia (Park and Ha, 2006; Clever and Hansen, 2008). The majority of these studies are focused on mode choice between two major cities, utilizing choice modeling methods to examine revealed preference (RP) and/or stated preference (SP) data. A few studies documenting air transportation and HSR in France, Spain, and Japan conclude that it is very difficult for air transportation to compete effectively in short-haul markets of 500 miles or less (USGAO, 2009). Comparative studies based on European high-speed rail development have also examined historical market share and general trends in air transportation and high-speed rail demand.

There is little existing documentation detailing the history behind how airport, airline and rail operator partnerships have been formed to enable airport-HSR connectivity. In addition, although there is much speculation about how air-rail connectivity impacts air traffic demand, there is little existing empirical analysis of systemwide air traffic trends where airport-HSR integration exists. This study will increase our understanding of how airport-rail partnerships are formed, how they are implemented, and how they impact broader aviation system demand.

4.3. METHODOLOGY

This research project utilized a multiple-case design methodology to examine aviation-rail cooperation in Europe. Data collection and analysis focuses on the country as the primary unit of analysis, with a particular focus on the nation's major airport. Germany/ Frankfurt Main Airport and France/ Paris Charles de Gaulle Airport were selected as the primary cases for this research because they are the two major airports in existence that include integrated high-speed rail and passenger air service.

4.3.1. Data

Three primary sources of data were utilized for this research: 1) interviews with key stakeholders engaged in airport-rail partnerships; 2) archival data; and 3) statistical data on air traffic demand in Europe.

Interview data for each case was gathered through telephone interviews with aviation industry experts and rail operators providing service to the airport of interest. Primary issues that were explored during interviews included:

- Relationship between the airports, airlines, and rail operators;
- Services that are provided that may support air-rail connectivity (e.g., code-sharing, bags checked through final destination, single security checkpoint, etc.);
- Other challenges that are associated with providing air-rail intercity connectivity;
- The impact of national, regional, and airport level policies on supporting air-rail connectivity.

Historical industry data was collected, including reports and conference presentations, which documented the history of the air-rail partnerships, key challenges associated with offering the integrated service, and evolution of transportation demand at each airport.

The primary quantitative data source utilized in this study is a publicly available database maintained by Eurostat, the statistical office of the European Union (EU). Eurostat's Air Transport statistical database was accessed from May through June 2011. Two of the primary metrics for air traffic available through Eurostat are total "commercial flights" and "passengers carried" for major airport pairs and airports. Total "passengers carried" includes all passengers who travel between two airports, including those passengers who may be connecting to, or from, another flight. Eurostat data was collected order to examine air traffic at the origin-destination and airport level, including domestic, intra-EU, extra-EU, international (intra-EU + extra-EU), and total traffic.

4.4. THE GERMAN CASE

4.4.1. Evolution of air transportation demand in Germany

Airport congestion, particularly at major airports around the world, is often cited as a key reason to develop air-high-speed rail connectivity. It is clear that if short-haul travel on corridors of 500 miles or less could be effectively served by high-speed rail transportation, landing and takeoff slots at congested airports could be "freed up" for longer-haul domestic or international travel (not effectively served by rail).

In the following section, we present an analysis of air traffic from the airport level in Germany, examining how passenger traffic has evolved for domestic, international, and total air traffic in the presence of air-rail connectivity (see Figure 4.1). Table 4.1 summarizes the annual average change in traffic at the top seven German airports, from 1999 through 2009.

Table 4.1 Air traffic of major airports in Germany: 1999-2009

	Domestic Traffic: 1999-2009		International Traffic: 1999-2009		Total Traffic: 1999-2009	
Airport	**Average Annual**	**Average Annual Change**	**Average Annual**	**Average Annual Change**	**Average Annual**	**Average Annual Change**
Frankfurt (FRA)	7296877	-0.03	41537512	0.02	48834389	0.01
Munich (MUC)	8738587	0.02	17581311	0.07	26319899	0.05
Düsseldorf (DUS)	3829775	0.01	10797182	0.02	14626957	0.02
Berlin Tegel (TXL)	6007973	0.02	5078354	0.08	11086328	0.04
Hamburg (HAM)	4601099	0.03	5396168	0.03	9997267	0.03
Stuttgart (STR)	2716573	0.02	4967827	0.03	7684400	0.05
Cologne/Bonn (CGN)	3225936	0.03	4295495	0.11	7521431	0.07
Average		*0.02*		*0.05*		*0.04*

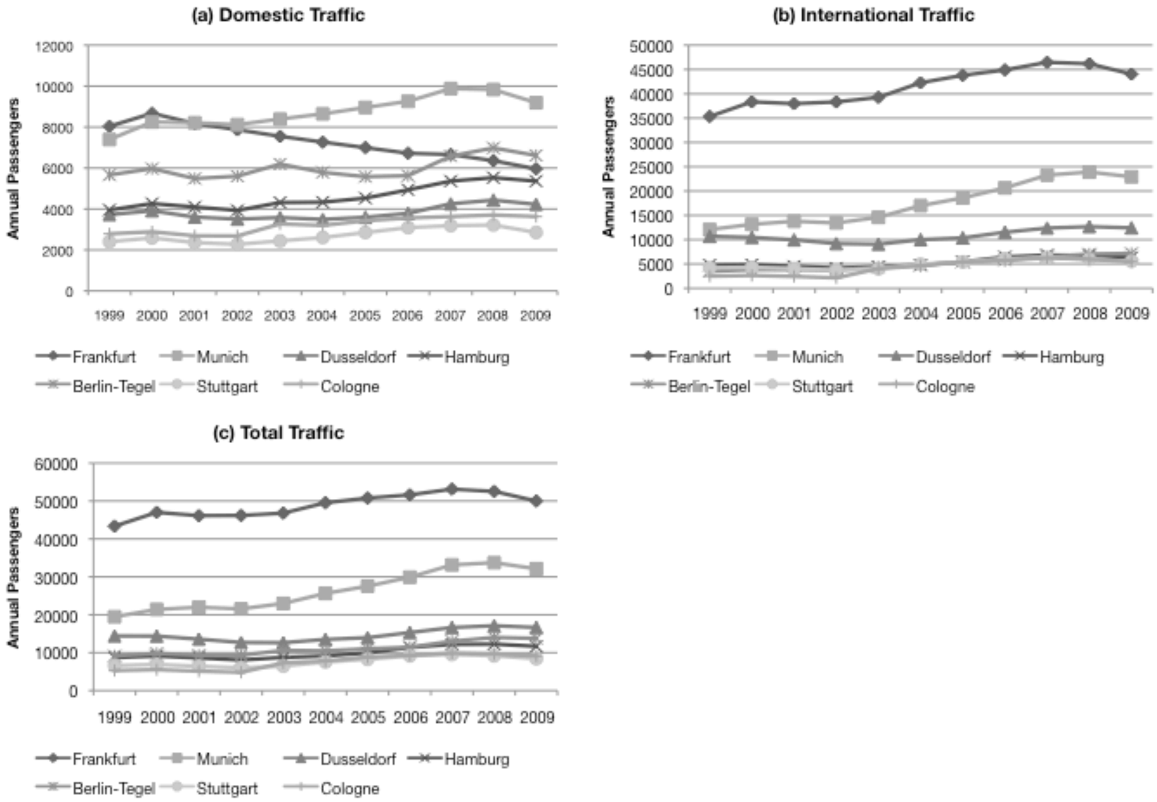

Figure 4.1 German airport domestic and international traffic

Frankfurt airport

As shown in Table 4.1 and Figure 4.1-a, domestic travel was in fact, significantly reduced after the launch of high-speed rail connectivity at Frankfurt Airport. Domestic air passenger traffic had been steadily increasing at Frankfurt airport in the late 1900s through 2000, but began to decline starting in 2001, likely influenced by the economic downturn and 9/11. This decline in domestic and international traffic can be observed at all major airports in Germany starting in 2001; however all airports except for Frankfurt experienced a recovery of domestic air traffic growth in either 2002 or 2003. Frankfurt Airport experienced an average annual change of -3% in domestic traffic between 1999 and 2009, while all other major German airports experienced an annual average growth of +2%.

Total air traffic at Frankfurt Airport increased modestly during this time period, driven by a 2% growth in international passenger traffic (see Figure 4.1-b and Figure 4.1-c). There were several changes that occurred between 1999 and 2003 that improved access to Frankfurt Airport, including the following:

- Infrastructure improvements were made that improved access to Frankfurt Airport from the eastern part of Germany;
- A new long distance train station was opened at Frankfurt airport, providing a direct connection from the south of Germany for the first time; and
- The high-speed rail lines to Cologne and Stuttgart (from Frankfurt) were launched.

The infrastructure improvements described above resulted in a significant increase in the catchment area of Frankfurt Airport. With the opening of the Frankfurt-Cologne and Frankfurt-Stuttgart high-speed rail lines, Frankfurt Airport increased its catchment area by 10 million people who, as a result of the improved infrastructure, now lived within two hours of the airport. According to expert interviews and archived presentations from Fraport, in 2008 more than half (53.2%) of the originating passengers who departed from Frankfurt airport originated their journey outside of the Rhine-Main/Hesse region where the airport is based.

The expansion of Frankfurt's catchment area has impacted the ability of other major airports in Germany to compete with Frankfurt for international flights. Although it appears that Munich Airport's international traffic increased substantially from 1999 to 2009 as compared with Frankfurt's (7% versus 2%), the increase in total volume is on a similar scale: 8.7 million more passengers at Frankfurt, and 10.9 million international passengers at Munich. An interesting observation is the type of international traffic at these two airports: Munich's ratio of EU traffic to non-EU international traffic is 54/46, compared with Frankfurt's ratio of 65/35. While Frankfurt Airport may be limited in terms of capacity, it has still managed to support an increase in international passenger traffic and maintain dominance in Germany as the major long-haul international airport serving the country.

Munich airport

Munich Airport's domestic and international passenger traffic has grown substantially since 1999, by 2% and 7%, respectively. Completely rebuilt in 1992, it was established by Lufthansa as its second hub (after Frankfurt Airport). The new airport was located in 28.5 km to the northeast of Munich, where there might be fewer capacity constraints in the future in terms of runway expansion. Munich Airport is linked to two branches of the S-Bahn, a rail system that runs through the city, providing service from the city center to the airport in 40 minutes.

The new Nuremburg-Munich high-speed rail line was launched in 2006; however, it was not constructed with an connection at Munich Airport. From the rail operator perspective, the natural rail path from Munich to other major cities in Germany lies to the northwest. Although there is no airport alignment, domestic traffic at Munich Airport has declined fairly significantly, starting in 2006 when the high-speed rail line opened. Since 2006, domestic flights have declined at an average rate of 3% per year, while international flights have grown at a rate of 1% per year.

The key differences between Munich and Frankfurt Airports are: 1) the lack of opportunity for high-speed rail to provide feeder rail service for air passenger traffic (limited population) in Munich, and 2) capacity constraints at the airport in Frankfurt. In the case of highly-constrained Frankfurt Airport, it appears that the high-speed rail connection reduced domestic passenger traffic, enabling growth in international air traffic. At Munich Airport, origin-destination traffic has simply been reduced, possibly providing additional capacity for international flights.

Cologne Bonn airport

After the introduction of the AIRail service from Cologne and Stuttgart to Frankfurt, it became increasingly difficult for Cologne Bonn Airport to compete for international passenger traffic originating in Germany. Although the region where Cologne Bonn is located is fairly well populated, it is served by both Cologne Bonn, Dusseldorf Airports, and after the introduction of AIRail, also Frankfurt Airport. Over the past decade, Cologne Bonn has redefined itself as an airport with several low-cost and charter airlines, primarily serving destinations in Europe. Its EU passenger traffic has increased substantially, growing at an average rate of 17% per year since 2003 when AIRail was launched.

4.4.2. History of airport-rail connectivity in Germany

The first steps towards air and rail cooperation in Germany were motivated by the federal government in the 1970s. Through a coalition between the Social Democratic and Free Democratic parties, Lufthansa (the first German airline to become privatized) and DB Bahn (the German national railway) were pushed to work together for the benefit of the environment.

The first cooperative air-rail service offered by DB Bahn and Lufthansa was the Lufthansa Airport Express, which was in operation between 1982 and 1993. The route for an older DB Bahn train service was altered slightly in order to provide connecting air-rail service to Cologne Bonn, Düsseldorf, and occasionally Düsseldorf airport. However, this service was not competitive in terms of travel time, and the primary passengers who utilized the service were either tourists who were interested in seeing the German countryside, or passengers traveling to Bonn main station.

The successor to the Airport Express was the Lufthansa InterCity Service. Regular intercity trains, every hour, provided connecting rail service to and from Frankfurt Airport and Bonn and Cologne main stations. Connecting Lufthansa passengers would receive a coupon for the train and meal. As rail and air transfer times became shorter this service was discontinued, and the planning for the present AIRail began.

Overview of AIRail

AIRail, the present integrated high-speed rail and air transportation service in Germany, was initiated in the late 1990s, building on previous cooperation between Lufthansa and DB Bahn. The following is a brief timeline and overview of AIRail service offerings.

- **Frankfurt-Stuttgart launched March 1, 2001.** Pilot AIRail service between Frankfurt and Stuttgart was launched on March 1, 2001. A German InterCity Express (ICE) line was diverted from Hamburg and Hanover to Frankfurt and Stuttgart, with a 2-hour headway at Frankfurt.
- **Frankfurt-Cologne launched August 1, 2002.** AIRail service was launched between Frankfurt and Cologne, with a 2-hour headway at Frankfurt.
- **Next Generation of AIRail launched in May 2003.** The second generation of AIRail service was launched for both the Frankfurt-Stuttgart and Frankfurt-Cologne routes, including new service integration features, and hourly service for Frankfurt-Cologne.

Integrated Logistics and Passenger Services

In the beginning, in order to offer the connecting ICE service, Lufthansa paid DB Bahn for every seat in a separate train car reserved for AIRail passengers. Similar to the services they would have received on a flight, every Lufthansa passenger received a full meal on the train. Integrated ticketing was available from the initiation of the AIRail product in 2001 and 2002.

In May 2003, a new generation of service was launched, which included changes in: 1) improved service frequency; 2) the mechanism for Lufthansa to purchase tickets from DB Bahn; and 3) improvements in customer service. In May 2003, DB Bahn began using two ICE services (of their seven ICE services between Frankfurt and Cologne) in order to provide hourly service to Frankfurt airport, thus improving the connecting options for flights arriving from Frankfurt. During this time, DB Bahn also began implementation of a new fare system, building on revenue management strategies traditionally utilized in the airline industry. For the first time, rail travelers were encouraged to purchase tickets in advance and were given an assigned train. Rail fares were available at a 7-day advanced purchase, 3-day advance, or 1-day advance, increasing as the departure date became closer. Under this new fare system, the pricing for Lufthansa's AIRail seats was adjusted; they are now able to block a certain fixed number of seats, with the option of cancelling seats up to seven days in advance. Given that Lufthansa no longer purchases an entire rail car for AIRail passengers, AIRail and DB Bahn passengers can be seated in the same rail cars.

Baggage Handling and Security

Throughout the history of integrated air-rail service in Germany, the process for baggage handling has evolved. Initially in 2001, ICE trains were modified: sixteen seats at the end of the train were removed so that a sealed baggage container could be wheeled onto the train. Bags were not screened in Stuttgart or Cologne train stations; upon entry into Frankfurt Airport's AIRail terminal, passengers and bags were required to go through security. Stuttgart Hauptbahnhof (Central Station) and Koln (Cologne) Hauptbahnhof were assigned IATA codes: ZWS and QKL, respectively.

For the second generation of AIRail, which began in 2003, sixteen seats in a lounge at the back of the each train were reserved for luggage. This provided a capacity of 64 pieces of luggage (two per passenger); all of which could be loaded into the lounge in under 4 minutes. Under both of the previous systems, passengers were able to check their bags through to their final destinations.

Due to cost cutting measures and also because the service was not well utilized, checked-through baggage is no longer offered as part of AIRail. Passengers now transport their luggage and pass through customs on their own.

Challenges

It took several years for the AIRail product to gain market share, particularly for the Frankfurt-Stuttgart market (described further in the following section). One of the initial challenges identified by the AIRail team prior to launching the service was the need to educate potential customers about the product. The target market included passengers from all over the world, with different languages, preferences, and perspectives on rail travel. The team focused on ensuring that significant information about the service was widely available, in order to assure passengers that the integrated service was functional: that they and their bags would arrive at their final destination in a reliable manner.

A significant marketing effort was undertaken for outbound traffic (from Germany) as well. Travel agencies were invited to ride on the route for free, with mailings sent to every travel agency in Stuttgart. In order to incentivize customers to use the service, Lufthansa also offered 1000 frequent flyer miles for every leg on AIRail.

Another key challenge, from the perspective of the airline, was scheduling and computer reservation system (CRS) positioning. This was primarily a challenge for the Frankfurt-Stuttgart market, described further in our analysis of travel demand.

Other Cooperation and Agreements

In addition to the more seamlessly integrated AIRail service described in the previous section, the following summarizes two other types of agreements in place that facilitate integrated air-rail service in Germany.

Codeshares: "Rail&Fly". Starting in 1994, DB Bahn began selling rail coupons to airlines that might want to offer service to smaller destinations in Germany. For example, Cathay Pacific could issue rail coupons to passengers; when the coupons were collected on the train, DB Bahn processed them to charge the airlines for those passengers. Starting in 2004 with American Airlines, airlines began to offer official codeshares on DB trains.

Interlining: "Good for Train". DB Bahn has an interlining agreement with Lufthansa and EuroWings (now also part of Lufthansa). In the case of flight cancellations, air tickets are valid for travel on the German rail system.

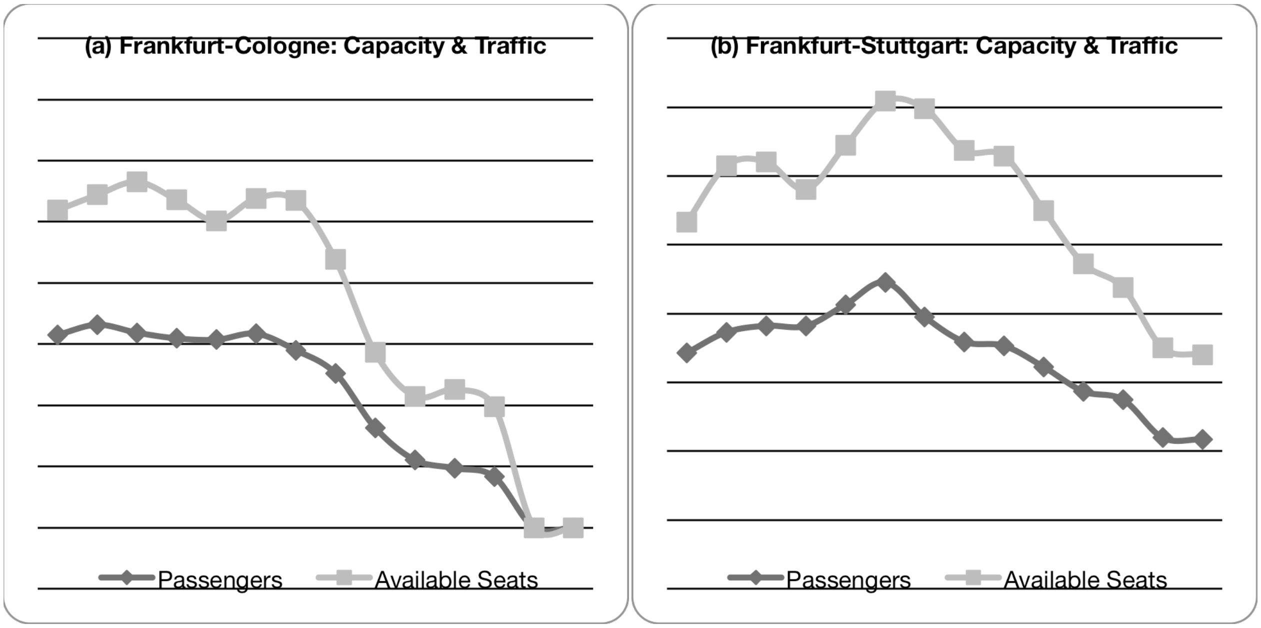

Figure 4.2 Frankfurt-Cologne and Frankfurt-Stuttgart capacity and traffic

4.4.3. Impacts on capacity and passenger traffic

The AIRail product is often highlighted as one of the primary success stories of intermodal cooperation between high-speed rail and aviation. In particular, the Frankfurt-Cologne corridor is notable because Lufthansa initially significantly reduced capacity on the route. The AIRail service is able make the journey to provide connecting service between Cologne and Frankfurt Airport in ~60 minutes, where as the Lufthansa flight took 40 to 50 minutes, plus typical airport access and wait times. When AIRail was first launched, Lufthansa cut their capacity from six daily flights to four (two of them with smaller aircraft). In 2009, they eventually stopped offering flight service altogether. Thus for Cologne-Frankfurt, capacity and passenger traffic were substantially reduced between the two airports (see Figure 4.2-a).

The impacts on aviation capacity and passenger traffic differ slightly for the Frankfurt-Stuttgart corridor (see Figure 4.2-b). As compared with Frankfurt-Cologne, capacity and passenger demand were not reduced nearly as significantly for the Frankfurt-Stuttgart corridor. However, it should be noted that both capacity and demand were also reduced between 2003 and 2010 (when the current generation of AIRail was introduced for Frankfurt-Stuttgart) as follows:

- 39% reduction in passengers;

- 46% reduction in available seats; and
- 17% reduction in flights.

Although it is clear that aviation capacity and passenger traffic were reduced between Frankfurt and Stuttgart, this corridor is not considered to be nearly as successful as the Frankfurt-Cologne corridor. In the following section, we examine the key differences between these two similar, but remarkably different intermodal connections at Frankfurt Airport.

Comparison of Cologne and Stuttgart Services

There are several differences between the Frankfurt-Cologne and Frankfurt-Stuttgart rail service, including primarily the trainset technology and position within the German rail network structure, both of which have an effect on passenger demand for this service.

Trainset Technology and Travel Times

The rail line between Stuttgart and Frankfurt utilizes InterCity Express (ICE) 1, the first series of German high-speed trains, while the line between Cologne and Frankfurt operates with a newer generation train, the ICE 3. It was designed specifically for passenger rail, and can reach speeds up to 300 km/h, as compared with the ICE 1, which operates at a top speed of 250 km/h on the Frankfurt-Stuttgart corridor. Given the different rail technology, the travel time to Stuttgart is slower (74 minutes) as compared with the travel time to Cologne (58 minutes).

The travel times appear to have had a significant influence on the popularity between the Cologne and Stuttgart AIRail services. Because the Cologne-Frankfurt travel time was competitive with flights, it was displayed on the first page of computer reservation systems (CRS) used by travel agents and online search engines. However, the Stuttgart-Frankfurt travel time was not as competitive in terms of flight time (74 minutes, compared to 50 minutes), and thus was often displayed on the second page, or several pages further, on CRS. Although for a business traveler with a final destination in downtown Stuttgart, the AIRail service might offer a competitive true origin to true destination travel time, it would likely not be booked because of its placement in the CRS. This was one of the competitive advantages that the Cologne-Frankfurt route held, as compared with Stuttgart-Frankfurt.

Network structure and frequency

The German rail network structure also has a significant impact on the different services that were possible for the two corridors. Prior to the launch of the AIRail service, DB Bahn provided passenger rail service for the Hamburg-Switzerland and Hamburg-Stuttgart corridors, utilizing the same ICE 1 trainsets, with half of the trains heading to Zurich after stopping at Frankfurt, and the other half heading to Stuttgart. As a result, the Stuttgart-Frankfurt corridor is has a 2-hour headway, whereas Cologne-Frankfurt has hourly service (as of 2003). This difference in service frequency is the second key reason that the Cologne-Frankfurt AIRail service was much more successful than Stuttgart-Frankfurt. The success of intermodal connectivity depends in part on whether or not the rail service arrives at a time to meet a bank of connecting flights at Frankfurt airport. In the case of Cologne-Frankfurt, the transfer times for travelers were minimized because of the frequent connecting rail service, but this was not possible for Stuttgart-Frankfurt.

When AIRail was first launched, the rail timetables were not coordinated with Frankfurt's flight timetables. In 2007, the timetables for both Cologne-Frankfurt and Stuttgart-Frankfurt were optimized to provide shorter transfer times. However, there was little motivation for DB Bahn to significantly alter its timetables or network structure in order to provide hourly frequency between Stuttgart and Frankfurt. The Frankfurt-Stuttgart rail service typically utilized two trainsets (offering 800 seats). From the perspective of the rail operator, there was no motivation to alter the network timetables in order to accommodate an average 32 potential connecting passengers from Frankfurt airport, particularly because the Hamburg-Zurich and Hamburg-Stuttgart routes were already well utilized by regular origin-destination rail passengers.

Although both Cologne-Frankfurt and Stuttgart-Frankfurt can largely be considered successes in air-high-speed-rail connectivity, it is clear that there are challenges associated with designing intermodal transportation systems. In particular, the key stakeholders that provide transportation services (rail operators, airlines, and airport management) have different goals, perspectives, and constraints. In the case of airlines and rail operators in particular, once a complex network structure has been established to provide transportation services to passengers, it becomes increasingly difficult to design intermodal systems.

4.5. THE FRENCH CASE

The French Train à Grande Vitesse (literally "high-speed rail") or TGV was established in the 1970s by what is now the Société Nationale des Chemins de fer Français (SNCF), France's national state owned rail company. The TGV was the third commercial high-speed rail service in the world, and today, provides extensive service between major cities in France. It is also one of only two high-speed rail systems in Europe that has a direct airport connection, at both Paris Charles de Gaulle (CDG) and Lyon-Saint Exupéry (LYS). In this section, we will examine general air traffic trends in France, the history of partnership that has enabled air-rail connectivity, and detailed analysis of how this connection has impacted demand.

4.5.1. Evolution of air traffic in France

We start with an analysis of traffic at the airport level in France, examining how domestic and international passenger demand has evolved in the presence of air-rail connectivity. Figure 4.3 provides an overview of passenger traffic for the six major airports in France.

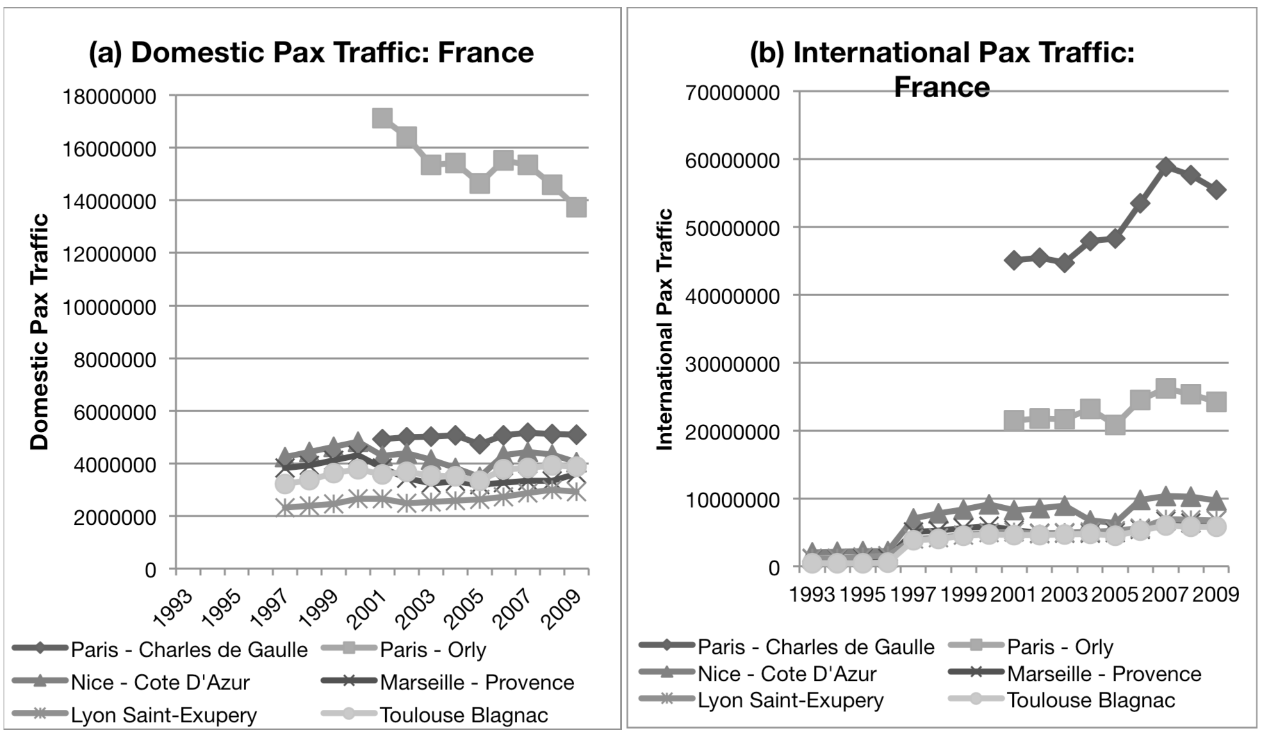

Figure 4.3 Passenger traffic at major airports in France

Both Paris Orly (ORY) and Paris Charles de Gaulle dominate the air traffic markets in France, with ORY serving as the dominant domestic hub, and CDG serving as the dominant international hub. Domestic traffic at Orly has declined since the late 1990s, falling an average of 3 percent per year since 2001. This reduction in traffic is likely due to network improvements that expanded rail service in France over this timeframe (see Figure 4.4).

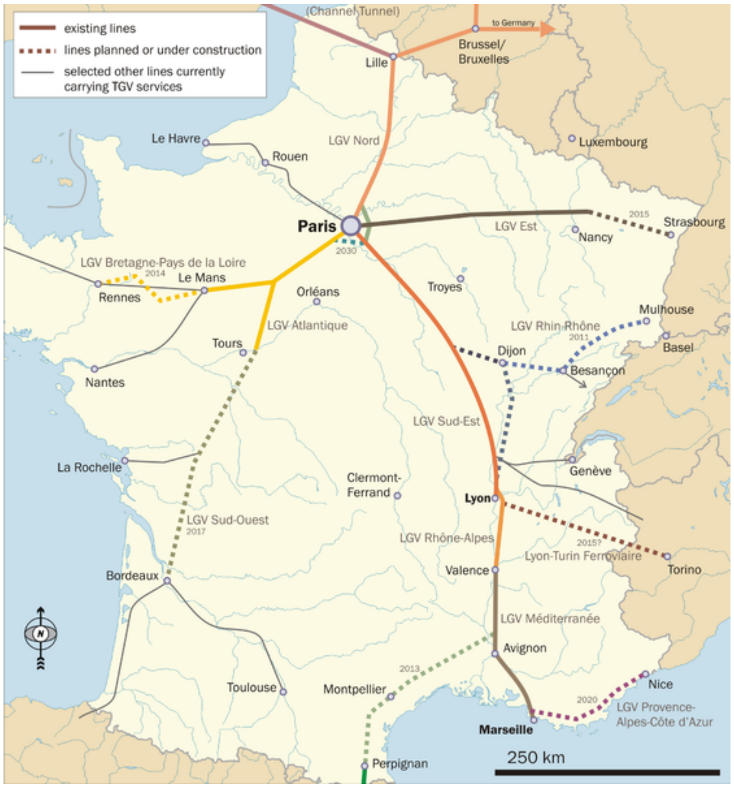

Figure 4.4 Map of TGV lines (source: Wikipedia, 2011)

In June 2001, the LGV Méditerranée extended service to two of the more populated cities in France, Marseille and Montpellier, reducing travel times to 3 hour and 3 hours 15 minutes, respectively (Arduin and Ni, 2005). As we can see in , domestic traffic has declined at Marseille Provence Airport, following the introduction of high-speed rail service. To the east of Paris, the development of TGV Est in 2007 reduced travel times between Paris and Strasbourg from roughly 4 hours to 2 hours 20 minutes, resulting in a decline in origin-destination traffic, which we expand on further below.

Based on our general analysis of airport-level air traffic trends, we observe that the major airports where average domestic traffic has increased include primarily those cities not connected to Paris by high-speed rail: Nice, Toulouse, Bordeaux, and Nantes. Contrary to what planners had anticipated, Lyon-Saint Exupéry has also experienced an increase in domestic traffic, despite a high-speed rail connection constructed at the airport. By and large, experts have concluded that this air-rail connection has failed to provide the type of air-rail connectivity that transportation planners envisioned, with only 0.05% of air passengers utilizing rail-to-air ground access (Resource Systems Group, 2011).

International traffic has grown fairly substantially at top French airports over the past decade, including primarily Paris-Orly (12% annual average growth since 2001) and Lyon-Saint Exupéry (7% annual average growth). Given that ORY does not have a direct airport connection and that passengers do not appear to be utilizing the air-rail connection at LYS, it is hypothesized that the key reasons for this growth in international traffic include: 1) the entry of low-cost carriers (LCCs); and 2) in the case of ORY, increased capacity due to the reduction of domestic O-D demand. Two LCCs have emerged to provide service in France and appear to have affected airport-level traffic: France Transavia began operations in 2007, with a hub at Orly, and Star Airlines started service in 1995, reforming as XL Airways France in 2006, with a hub at CDG. International air traffic increased substantially at these airports during the first years that these low-cost carriers entered the market (+21% at ORY), with primary growth in the intra-European Union markets that are typically served by these LCCs. However, the global economic downturn starting in 2008 appears to have resulted in a decline in traffic, a likely trend given that the LCCs primarily serve leisure travelers with higher income elasticity of demand.

Given our analysis of airport-level traffic trends in France and interviews with experts, we can conclude that high-speed rail has likely influenced observed changes in passenger demand at the airport level. The majority of airports in cities that are connected to Paris with service of roughly three hours or less have experienced a reduction of domestic O-D traffic. Over the same time period, the entry of low-cost carriers and availability of new landing slots at previously constrained airports has enabled growth of international air traffic.

4.5.2. Overview of tgvair

The partnership between the French rail operator, SNCF, and various airlines started in 1996 with Air France. At the time, Air France hoped to reduce flights between Lille and Paris, which is only one hour by TGV. The airline company was interested in selling an integrated rail-to-air travel itinerary as a complete package to customers (e.g., Lille-Paris-New York City). The first version of integrated air-rail service took the form of a code-sharing agreement between SNCF and Air France.

Over time, other airlines were interested in providing connecting service to various destinations in France via Paris. However, there were only two options for foreign airlines to provide service to Lille: 1) to purchase expensive connections from Air France, or 2) to arrange a code share with SNCF. Eventually, several airlines developed partnerships with SNCF, and the rail operator has expanded its TGVair agreement to include: Air Austral, Air Caraibes, Air Madagascar, Air Tahiti Nui, Cathay Pacific, Corsairfly, Gulf Air, Middle East Airlines, Openskies, and Qatar Airways, in addition to Air France.

Ticketing and integration of systems

Although it was not available from the start of the SNCF/ Air France partnership, an integrated ticketing system was developed for routes out of Paris Charles de Gaulle. The TGV now has a dispatch control system (DCS) that is integrated with the systems of the tgvair partner airlines. This enables SNCF to check passengers into their final destinations, as well as view all of their partner airlines' flights that provide connecting service.

Service logistics

Baggage integration has been in place since 2001, however luggage cannot be checked from the initial origin to the final destination. When passengers board domestic train services, they carry their own bags, and then go through the entire security process when they arrive at the airport.

4.5.3. Impacts on capacity and traffic

The following section provides detailed analysis of the major origin-destination routes within France. Figure 4.5 includes an overview of traffic to/from Paris Charles de Gaulle (CDG) and Paris Orly (ORY) over the past decade. Air passenger traffic between Paris CDG has declined only significantly on the Paris-Strasbourg route, where the TGV improved service from 4 hours to 2 hours 20 minutes in 2007. Capacity, as measured in annual flights, has also significantly declined on this corridor. However, for all other routes going to or from Paris CDG, passenger traffic and capacity have remained relatively stable or increased. Two of the major routes highlighted below, Paris-Nantes and Paris-Bordeaux, do not have competitive high-speed rail alternatives, thus it is reasonable for O-D traffic to steadily increase over this time period. The other two routes, Paris-Lyon and Paris-Montpellier, have experienced a relatively flat trend in passenger traffic, although there are competitive high-speed rail alternatives linking these cities directly to Paris CDG. In particular, the capacity on these routes has remained relatively stable, supporting research claims that airlines are likely to maintain a certain number

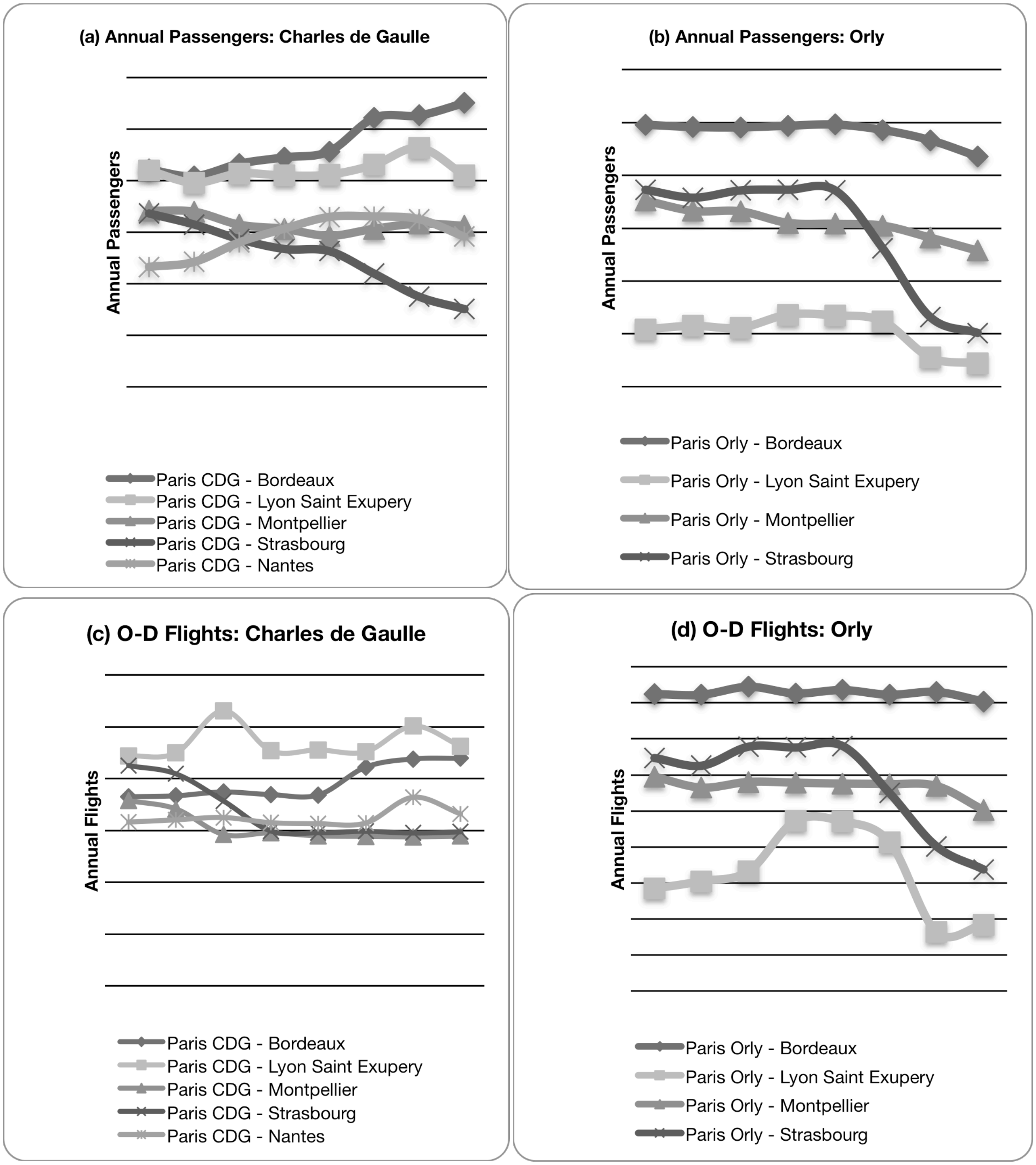

Figure 4.5 Paris CDG and ORY air passenger capacity and traffic

of flights at their hub airports in order to maintain their network, even with the presence of fast and reliable high-speed-rail-to-air connectivity (Resource Systems Group, 2011).

Paris Orly's O-D traffic trends are fairly different from Paris CDG, which is likely explained by its dominance as a short- and medium-haul airport, as compared to CDG's dominance as an international hub. Given the expansion of TGV service between Paris and France's major cities, passenger traffic from ORY has experienced a fairly steady decline. In the case of ORY, where airlines are not as concerned about feeder connecting service to international flights and the competition is less fierce, trends in capacity quite closely follow trends in passenger demand, with reductions in the number of flights offered on several routes.

By comparing capacity and traffic trends at Paris CDG and Paris ORY, empirical data suggests that air-rail connectivity may not quite have the impact on O-D traffic reduction that transportation strategies strive to achieve. In the case of this multi-airport city, the airport with the direct high-speed rail link (CDG) did experience a reduction in passenger traffic, but only a modest reduction in capacity, while ORY experienced a steady reduction in passenger traffic, and slightly more reductions in capacity.

4.6. THE U.S. CASE

We conclude this chapter with a brief analysis of one major airport in the U.S. where a true high-speed rail linkage is being considered. Building on our two previous European cases, we will comment on key lessons that are relevant for this U.S. airport, as well as outline the unique challenges that face air-rail transportation planning in the United States.

4.6.1. An overview of San Diego

San Diego International Airport (SAN), also referred to as Lindbergh Field, was the 28th largest airport in the United States in 2010, with continued passenger growth projected over the next 20 years. Aviation demand in the southern California region, including San Diego, Tijuana, and five airports in the Los Angeles area, is projected to increase 50% between 2009 and 2030, from 48 to 80 million passenger enplanements (Jacobs Consultancy, 2011). Although an extensive search was carried out to identify a second airport for the San Diego region, an alternative was not identified. The regional planning agency, the San Diego Association of Governments (SANDAG) has endorsed linking the California high-speed rail system to the airport, which could provide service starting in 2027 and potentially alleviate capacity constraints.

Characterizing airport demand

One of the key issues raised during interviews with experts regarding the San Diego case is the nature of San Diego airport's demand and the purpose of the airport-rail linkage. In the cases where high-speed rail connectivity has been highly utilized, it has often served to "feed" long-haul traffic at major international hub airports (Frankfurt, Paris Charles de Gaulle). Although San Diego airport is classified as an international airport, its market is almost entirely domestic. Only one percent of the 16,889,622 passenger enplanements in 2010 were traveling to or from international destinations (San Diego County Regional Airport Authority, 2010). However, if the proposed airport-rail connection succeeded in providing improved access to a wider catchment area in Southern California, it could simply feed long-haul domestic traffic, possibly resulting in a net increase in flight traffic at Lindbergh Field.

A secondary purpose often cited as part of integrated aviation and high-speed rail systems planning is to alleviate origin-destination air travel demand. The top domestic market at Lindbergh Field in 2010 was the San Francisco Bay Area (San Francisco, San Jose, and Oakland). The journey times for the California High-Speed Rail service to San Diego is projected to be 3 hours 56 minutes from San Francisco, and 3 hours 27 minutes from San Jose (California High-Speed Rail Authority, 2011). In order to reduce O-D air passenger traffic on a route, most experts agree that high-speed rail service should provide city-center-to-city-center journey times of ideally 3 or 3.5 hours or less. A key consideration for the San Diego case is whether the downtown alignment versus the airport alignment will provide a greater reduction of short-haul traffic, thereby alleviating congestion at San Diego airport.

4.6.2. Unique challenges in the United States

Route economics

The case of Paris Charles de Gaulle highlights the importance of route economics and air traffic networks. Major airlines at Paris CDG did not reduce their short-haul domestic flights entirely, even though the TGV provides fast, reliable service, directly at the airport. Although passenger demand had declined on many routes, carriers continued to maintain some level of scheduled service in order to feed their long-haul traffic, which are typically their most lucrative service. In the United States, the issue of network economics is even more complex, given the large number of legacy and low-cost carriers that provide both domestic and international long-haul service through hub airports. Although there are a number of airports where capacity constraints are likely to become more severe over the next 25 years (e.g., Chicago, San Francisco, the entire New York airport system), whether or not high-speed rail connectivity would provide a reduction of flights is unclear, given the complexity of air carrier competition and network economics.

Financing and rights of way

In order for integrated airport and high-speed rail to become feasible in the United States, it is obviously necessarily for high-speed rail to become viable. There are two key issues that set the U.S. case apart from the European cases considered in this study. First, financing costly high-speed rail infrastructure has proven to be a challenge, particularly in the U.S., where the issue has become highly politicized. Second, passenger rail in the United States is largely subservient to private freight railroads, where it operates over freight railroads rights of way. These two issues are intertwined and thus, for regions where existing infrastructure is utilized by both rail and freight (e.g., the Northeast Corridor), decisions about proposed infrastructure improvements for passenger rail are particularly complex. Practically speaking, in order to consider high-speed rail and airport integration at U.S. airports, it is important to recognize these two significant challenges facing the development of high-speed rail in the United States. We present an analysis and further discussion of high-speed rail in the U.S. in Chapters 5 and 7.

4.7. CONCLUSIONS

Air-rail connectivity in Europe has indeed influenced air traffic patterns in Germany and France; however, it is clear that there are many other factors that shape demand. In the case of Frankfurt-Cologne, Frankfurt-Stuttgart, and corridors at Paris Orly, origin-destination domestic traffic has been reduced as a result of the introduction of high-speed rail. Additionally, the high-speed rail lines appear to serve as successful feeders for international air traffic at Frankfurt (particularly the Frankfurt-Cologne corridor) and Paris Charles de Gaulle.

The following summarizes the key factors that appear to contribute to a successful airport-high-speed rail connection:

- **Infrastructure.** In order to provide feeder or transfer service between high-speed rail and air transportation, the rail station should be located at the airport. If the high-speed rail connection at the airport is constructed as a detour from the primary network patterns on the rail system, it is unlikely that the airport will be served with a high enough frequency.

- **Schedule and frequency.** The rail operators and airline often both have the same goal of optimizing their networks, but they are separate networks. Coordinating timetables in order to ensure that rail service meets banks of connecting flights is an important consideration.
- **Market characteristics of the airport.** In the two successful cases of this study, the primary airports with high-speed rail links were the dominant international hubs of each country. For both Paris Charles de Gaulle and Frankfurt International Airport, domestic traffic decline, and international passenger traffic increased. There are two key factors that may have influenced this growth: 1) partial alleviation of congestion at the airport by reducing domestic flights; and 2) the success of the high-speed rail lines as feeder service for international flights.

Finally, it is important to recognize that there are a number of factors that influence the evolution of air traffic, capacity, and demand at airports. In the case of Cologne Bonn and Dusseldorf Airports, the high-speed rail link to Frankfurt Airport ensured that Frankfurt would remain the dominant airport serving long-haul international destinations. During the past decade since the introduction of the AIRail service, Cologne Bonn and Dusseldorf have both reinvented themselves as airports that provide low-cost or charter service, primarily to European and seasonal vacation destinations. Cologne Bonn has been particularly successful, growing its international traffic by 11% per year since 1999.

From an environmental perspective, it is important to consider the complexity of intercity transportation networks potentially served by high-speed rail and air transportation. High-speed rail is likely to provide more competitive, reliable, and energy efficient service for short-haul intercity routes. However, it may not be the only solution for reducing the carbon footprint of the transportation sector, given that the evolution of air traffic is affected by a variety of complex factors that we discuss further in the following chapters.

Chapters 3 and 4 have provided a historical context of high-speed rail and aviation demand based on the European experience, providing an analysis of how travel demand has changed after the introduction of high-speed rail and the resulting climate impacts. In the next chapter, we explore the potential for climate and energy policies to shape future demand and climate impacts of these systems in the United States.

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Chapter 5: An integrated analysis of U.S. climate policy and proposed high-speed rail

The two previous chapters of this dissertation present analysis of the European experience with high-speed rail, with a particular focus on how the introduction of high-speed rail has impacted air travel. In this chapter, we turn our attention to the potential future of high-speed rail and air transportation in the United States. Incorporating lessons learned from the European case, future scenarios of high-speed rail and air transportation systems in the U.S. are considered, with a focus on examining intercity travel demand, the climate impacts of these systems, and policies that could shape their future.

5.1. INTRODUCTION

In 2009, the Obama administration unveiled a "Vision for High-Speed Rail in America," formalizing the identification of ten high-speed rail corridors as potential recipients of federal funds, in addition to support that would improve the existing Northeast Corridor from Washington, D.C. to Boston. Although historically the U.S. has seen limited investment in passenger rail since the 1920s and 1930s, there is now renewed interest in considering the development of high-speed passenger rail to meet future mobility needs. Several factors motivate the recent consideration of high-speed rail in the United States, including: 1) population growth and increased congestion of airports and highways, particularly in the east and west coast mega-regions; 2) the potential to create new jobs during the late-2000s recession; and 3) concerns about the growing impact of transportation on the environment.

Various reports suggest that the proposed U.S. Federal Railroad Administration (FRA) plan to develop intercity high-speed rail passenger service is part of a broader energy and climate policy agenda (FRA, 2009). Transportation is the fastest growing source of U.S. greenhouse gas emissions (GHG), accounting for 47 percent of the increase in total emissions since 1990 and 30 percent of current annual emissions (EPA, 2012). In addition, given the United States' current reliance on personal vehicles and aviation for the bulk of intercity travel, roughly 70% of the 20 million barrels of oil that the U.S. consumes per day is used for transportation. High-speed rail and passenger rail in general, is more efficient than automobiles or aircraft on a vehicle-mile basis, and has the potential to operate on non-liquid sources of energy (e.g., electrification).

Both of these factors suggest that transitioning intercity travel to high-speed rail passenger service could substantially reduce the energy and carbon footprint of the U.S. transportation sector.

Both high-speed rail and airport infrastructure require significant upfront investments – investments that are typically utilized over very long time scales. The expected design life of rail and airport infrastructure ranges between 50 to 100 years before major reconstruction (Auld et al., 2006). As policymakers consider future investment in intercity transportation infrastructure, it is increasingly important to recognize that such investments will affect demand, energy use, and climate impacts long into the future. As such, how this transportation infrastructure is utilized will be shaped by the evolution of global energy markets, potential climate policies, and technological change.

The goal of this research is to develop a new method to conduct an integrated analyses of climate policies and investment in high-speed rail infrastructure. Previous studies primarily focus on examining the impact of cap-and-trade policies on aviation and automobile transport (Winchester et al., 2011; Hofer et al., 2010; Karplus, 2011). The analysis presented in this chapter contributes to this literature by examining the impact of a cap-and-trade policy on U.S. high-speed transportation (i.e. air and rail) and the energy sector using an economy-wide model coupled with a detailed model of high-speed rail and aviation demand. The economy-wide model is utilized to estimate the impacts of energy policies on economic activity, fuel prices, and electricity generation, resolved on a U.S. regional basis. These predictions are then utilized to model new scenarios of high-speed rail and aviation demand, the energy utilization of these systems, and their associated climate impacts. The integrated modeling framework represents a new approach to examine the climate impacts of high-speed rail and aviation – an approach that enables us to simultaneously examine alternative transportation policy scenarios and the impact of alternative energy policy scenarios on the high-speed transportation sector.

This chapter contains the following six sections. Section 5.2 provides further background on environmental and policy analysis of intercity transportation. In Section 5.3, the integrated modeling framework is detailed. Sections 5.4 and 5.5 further describe the economy-wide model and bottom-up model of the high-speed rail and aviation sector. Modeling results and sensitivity analysis are presented in Section 5.6. Section 5.7 summarizes the key findings of this study, policy implications, and opportunities for future work.

5.2. BACKGROUND

5.2.1. Environmental analysis of high-speed rail and aviation

In this section, a review of previous studies examining the environmental impacts of high-speed rail and air transportation is presented. Summarized below is literature that: 1) compares the environmental impacts of high-speed rail and air transportation; and 2) provides more detailed analysis of the environmental impacts high-speed rail under different technology assumptions.

Studies on the environmental impacts of high-speed rail in the United States are often presented in the context of mode comparison for specific corridors where HSR development is under consideration. The two U.S. corridors that have historically been thought to be the most viable for high-speed rail service are California (i.e. from northern to southern California) and the Northeast Corridor (i.e. from Boston to Washington, D.C.). Previous cost-benefit analyses of both corridors have examined several issues, including environmental impacts, as well as safety, and congestion.

The range of reported energy use associated with intercity rail varies substantially: from as low as 10.5 to 20 kWh/km (16.9 kWh/mi to 32.2 kWh/mi) for the Sud-Est and Atlantique TGV in France (Levinson, 1996), to as high as an estimated 61.8 kWh/mi for the Japanese Shinkansen 700 series (Network Rail, 2009). The reported emissions in virtually all studies assume that proposed high-speed rail corridors are electrified, and that the associated CO_2 emissions per kilowatt-hour remain constant over time, based on either the current electricity generation mix of the actual region or more often, that of the United States.

There are three key drawbacks of previous work that this study will address. First, rather than assume constant, aggregate emission rates for electricity generation, this study will utilize alternative scenarios for electricity generation on a regional basis to project high-speed rail emissions over a 40-year time period. Second, this study will conduct sensitivity analysis on the energy use assumptions of both high-speed rail service and flights. Finally, this analysis will address one of the other major sources of uncertainty in comparing high-speed rail and air transportation emissions on a per-passenger mile basis: assumptions of ridership and load factors.

5.2.2. U.S. climate policy and transportation

Several studies examine the potential impact of climate policies on the transportation sector, focusing primarily on personal vehicles and air transportation (Schäfer and Jacoby, 2006; Hofer et al., 2010; Winchester et al., 2011; Karplus, 2011). Although these studies do not focus on high-speed rail, it is worthwhile to review the key methods utilized and challenges that have been addressed in previous efforts to model the impact of climate policy on transportation.

An approach that has been utilized in several studies of the transportation sector is the coupling of an economy-wide model with a more detailed model of the transportation sector. One example includes a study on automobiles, light trucks, and heavy freight trucks, in which several models were linked to carry out an analysis of the impacts of climate policy on the transport sector (Schäfer and Jacoby, 2006). Focusing on U.S. transportation, three models were utilized to conduct the analysis: a multi-sector, economy-wide computable general equilibrium (CGE) model, a MARKAL model of vehicle and fuel supply, and a model to simulate the split of personal and freight transportation. The primary rationale behind coupling a top-down model (e.g., a CGE model) with a detailed, bottom-up model is that while the former captures the impacts of policy across sectors over time, the latter allows detailed analysis of a specific sector.

The advantage of utilizing economy-wide CGE models for such policy analysis is that they typically define multiple sectors, enabling one to capture the distribution of policy changes across sectors over time. However, in order to be tractable, these models sacrifice detail at the sectoral level. On the other hand, a bottom-up model of a specific sector, such as transportation, electricity, or agriculture, can provide rich technical detail of the sector, but has limited capability of capturing broader economy-wide policy impacts that would influence the consumption of goods in the sector of interest.

Another example of this approach that is closely related to the analysis presented in this chapter is a recent study of the impact of climate policy on aviation, in which a CGE model of the global economy is coupled with a detailed, partial equilibrium model of the aviation sector (Winchester et al., 2011). Using the economy-wide model to estimate the impacts of a cap-and-trade policy on economic activity and fuel prices, results are then utilized to create scenarios analyzed with the partial equilibrium model that estimates changes in aviation operations, the aircraft fleet, and emissions associated within this sector. The key limitation of this previous work is that it does not capture the potential of switching to alternative transportation modes. In the analysis presented here, we examine the introduction of a new mode to meet future U.S. intercity travel demand (i.e. high-speed rail), coupled with an analysis of energy policy changes that would shape the demand and emissions of both transport modes.

5.3. INTEGRATED MODELING FRAMEWORK

To conduct an analysis of the introduction of high-speed rail and the impacts of climate policy on intercity travel, an integrated modeling framework is developed as follows. Figure 5.1 provides a schematic diagram of the relationships examined in this study.

A top-down computable equilibrium model is coupled with a bottom-up, technically-detailed model of high-speed rail and air travel demand that is developed for this study. The top-down, economy-wide model utilized in this analysis is the U.S. Regional Energy Policy (USREP) model (Rausch et al., 2009). USREP is used to estimate the economy-wide impacts of two potential energy policies, a cap-and-trade policy and clean energy standard. Given these policy impacts, the bottom-up model is utilized to predict future demand and emissions adjusting key variables that influence demand and emissions in the HSR and aviation sector.

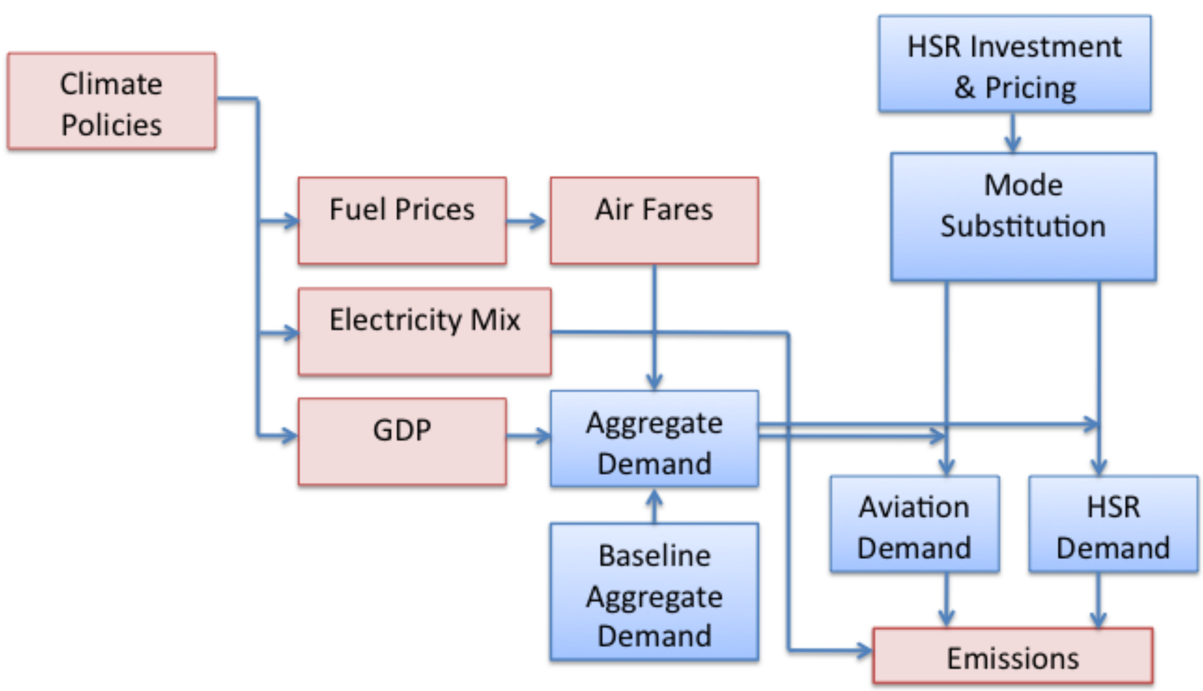

Figure 5.1 Schematic overview of integrated modeling framework

The policy impacts that are particularly relevant to the aviation and HSR sector include: economy activity (e.g., GDP), fuel price, and electricity generation. Changes to economy activity and fuel prices under climate policies would have a primary effect on intercity travel demand, while changes in electricity generation of U.S. regions could substantially alter the emission impacts of high-speed rail. Through an integrated modeling framework, this analysis explores these policy impacts might shape demand and CO_2 emissions of HSR and air transportation in California and the Northeast Corridor (NEC).

5.4. REGIONAL IMPACTS OF U.S. CLIMATE AND ENERGY POLICY

5.4.1. A brief overview of the CGE modeling framework

USREP is a multi-region, multi-sector computable general equilibrium model of the U.S. economy developed to analyze the impact of U.S. energy and climate policies on greenhouse gas (GHG) emissions. The model was developed and is maintained by the Joint Program on the Science and Policy of Global Change at the Massachusetts Institute of Technology, and has been utilized to examine the distributional impacts of potential policy on different regions, sectors and industries, and household income classes (Rausch et al., 2009). USREP identifies 12 large states and regions in the United States as shown in Figure 5.2; this regional resolution makes it particularly suited to examine travel demand and emissions of specific intercity corridors.

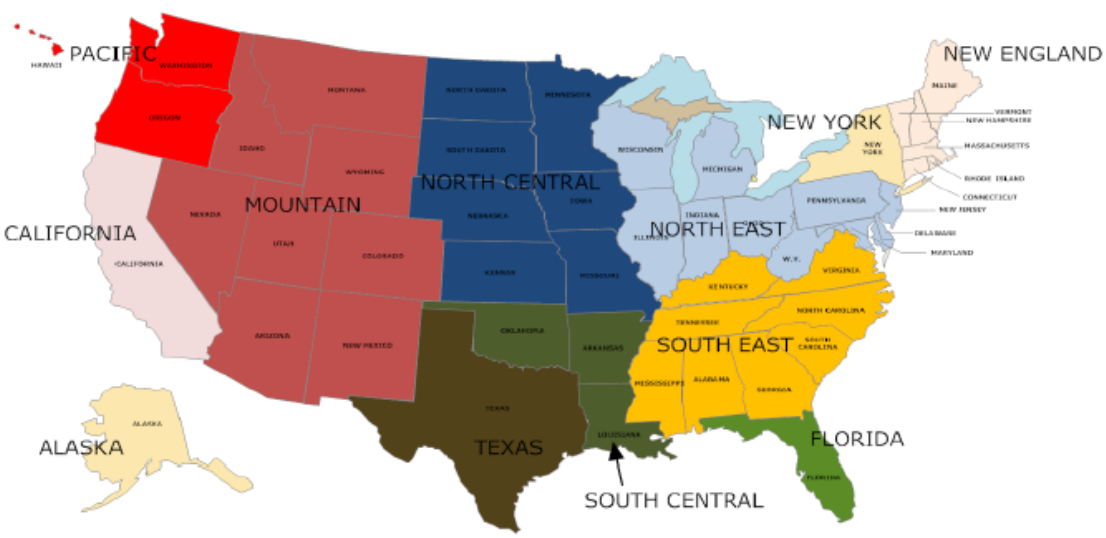

Figure 5.2 Regional aggregation in the USREP model (Rausch et al., 2009)

USREP is calibrated using economic data from IMPLAN (Minnesota IMPLAN Group, 2008) and physical energy data from the DOE Energy Information Administration's State Energy Data System (EIA, 2009). Although most data is available at the state level, the model is resolved on a regional level in order to capture differences in electricity costs and provide focus for regional policy analysis.

5.4.2. Overview of policy scenarios

Climate and energy policy scenarios considered in this analysis include a U.S. cap-and-trade policy and a clean energy standard, as described further below. Both scenarios are compared to a reference, "business-as-usual", case.

The cap-and-trade policy scenario examined in this study is based on the American Clean Energy and Security Act of 2009 (H.R. 2454) as a representative policy. H.R. 2454 was a bill in the 111th United States Congress that would have established a cap-and-trade system, setting an economy-wide target for GHG emissions. Through the bill, between 2012 and 2050, GHG emissions, measured in CO_2 equivalent (CO_2-e) units, would have been capped. The bill was approved by the U.S. House of Representatives in June 2009, but failed approval in the U.S. Senate. Although the bill was not ultimately passed, it is the best representation of a potential cap-and-trade policy in the United States, and is used as an example for the purposes of this analysis.

The second scenario considered in this study is a clean energy standard (CES) based on the Clean Energy Standard Act of 2012 (S. 2146) as a representative policy. S. 2146 would establish a standard for clean energy generation in the U.S. between 2015 and 2035. The CES would require that the largest utilities sell a certain percentage of their electricity from clean energy sources, starting in 2015. The requirement would increase in each year such that in 2035, utilities covered by the act would need to supply 84% of their total annual sales from clean sources. Under the S. 2146 framework, "clean" energy includes a wide variety of sources, including: solar, wind, nuclear, natural gas, coal with carbon capture and storage, etc.

An alternative policy scenario that we considered for this analysis is a renewable energy standard (RES), which would set a standard for large utilities to provide a percentage of their electricity from renewable sources. Unlike a CES, an RES would not include sources such as natural gas or coal with carbon capture and storage. Although the current U.S. Congress has debated several proposals that would implement a federal renewable energy standard (and several states have independently adopted some form of an RES), the current Congress has focused on the more flexible clean energy standard versus a federal renewable energy standard. Through preliminary analysis for this study, the cap-and-trade, RES, and CES policy scenarios were examined. However, due to the likelihood of implementation of a CES over an RES at the federal level, as well as the similarity of transport sector impacts from the RES and cap-and-trade policy scenarios, this chapter presents results from the business-as-usual (or reference), cap-and-trade, and CES scenarios.

5.4.3. Impact of U.S climate policy on travel demand

As described in more detail previously in Chapter 3, two of the primary factors that affect intercity travel demand are GDP and fuel price. Estimates for GDP and fuel price under climate policy obtained from the USREP model are summarized in Table 5.1. and Table 5.2. Although in the United States, GDP growth is projected to decrease slightly and fuel price is likely to increase by 2050 under climate policy, the regional distributional effects vary significantly. These variations are driven by differences in the energy intensity of primary economy activities, the CO_2 intensity of electricity production, and income levels (Rausch et al., 2009). As a result, previous findings indicate that regionally, California and the Northeast regions generally experience lower costs from carbon policies that were examined as compared with the South Central, Texas, and Mountain States.

Table 5.1 GDP under climate policy relative to the reference (by region)

Region	2020	2035	2050
United States	-0.06%	-0.33%	-0.29%
California	-0.01%	-0.30%	-0.24%
Northeast Corridor	-0.06%	-0.32%	-0.30%

Table 5.2 Fuel price under climate policy relative to the reference (by region)

Region	2020	2035	2050
United States	0.03%	0.02%	0.06%
California	-0.01%	0.01%	0.00%
Northeast Corridor	-0.05%	-0.07%	-0.13%

Given climate policy impacts on GDP and fuel prices, aggregate baseline demand in the bottom-up model is adjusted for income-induced demand change and price-induced demand change as follows. The bottom-up model assumes an income elasticity of demand of 1.8 to apply GDP changes, based on literature for U.S. short-haul aviation (Intervistas, 2007). Similarly, a price elasticity of demand of 1.54 is applied in the bottom-up model. Both the income- and price-induced demand changes are relatively modest for both regions.

5.4.4. Impact of U.S. climate policy on electricity generation

The second major policy impact examined in this study is the impact of the electricity mix on high-speed rail emissions through 2050. Figure 5.3 displays USREP results for electricity generation in California and the Northeast in the reference scenario and climate policy scenario.[1]

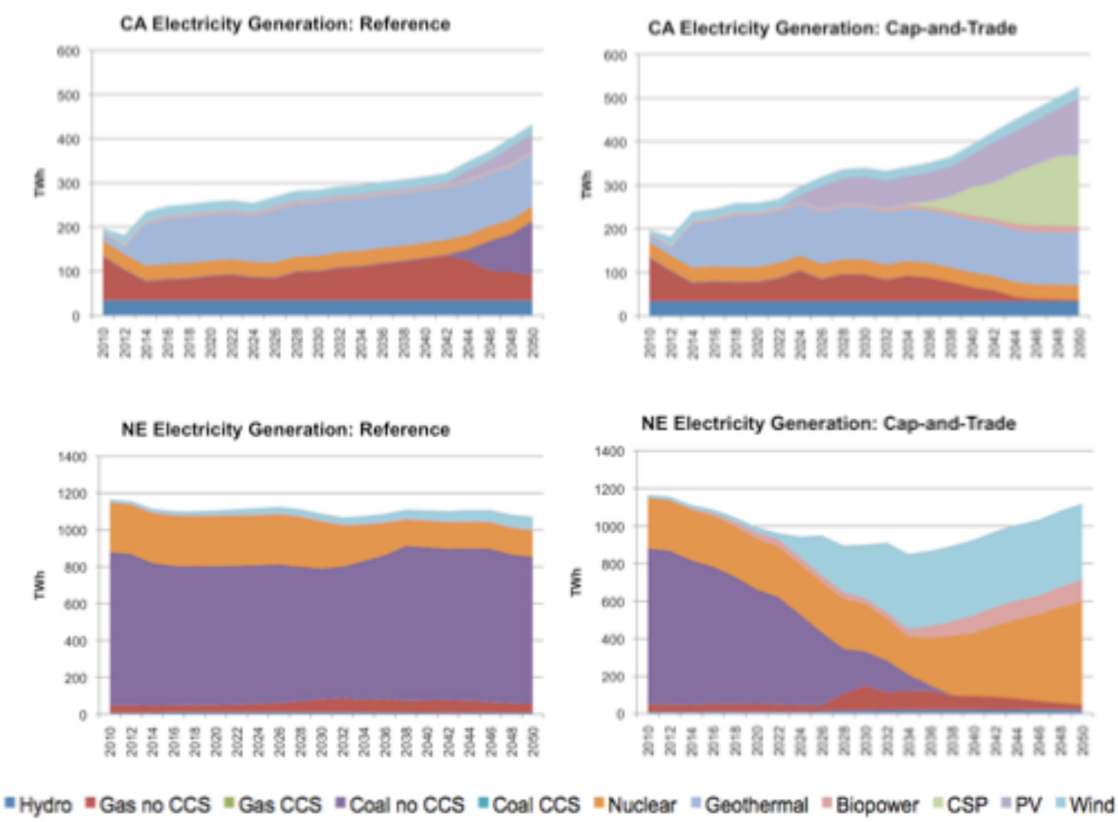

Figure 5.3 Electricity generation in California and the Northeast (source: USREP, 2012)

[1] The results of the clean energy standard scenario are not shown here to save space. See Appendix B for alternative scenarios.

Given that previous environmental comparisons of aviation and potential high-speed rail in the United States have tended to rely on U.S. aggregate electricity generation scenarios, or present-day regional scenarios, it is possible that the environmental benefits of HSR have been underestimated. Another important issue highlighted in the USREP results is the likely regional variation in electricity generation: under climate policy in California, electricity generation could shift from a relatively "clean" mix to an slightly cleaner mix, whereas in the Northeast, generation would shift from primarily coal-based generation to cleaner sources.

5.5. BOTTOM-UP MODEL OF HIGH-SPEED RAIL AND AVIATION

In order to forecast demand and emissions of the high-speed rail and aviation sector, a bottom-up model is developed that, given policy impacts on GDP, fuel price and electricity generation, estimates long-range energy use and climate impacts emissions of the HSR and aviation sector. Figure 5.4 provides an overview of the modeling framework detailed in the following section.

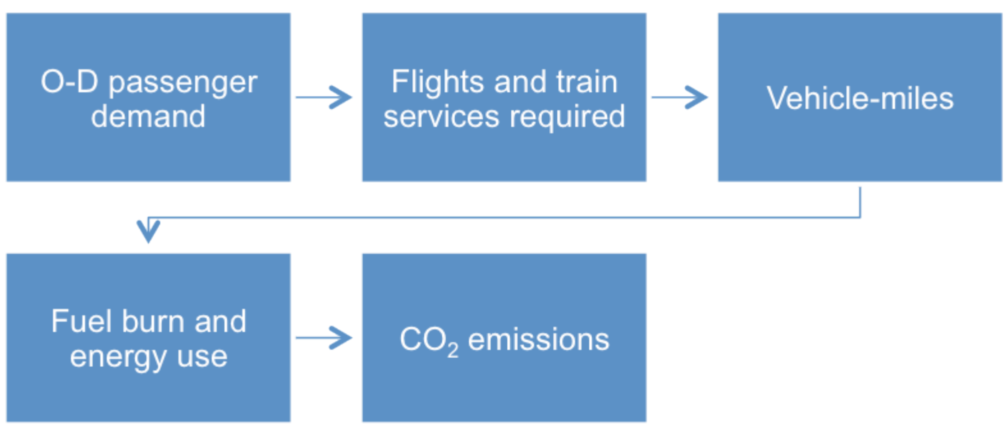

Figure 5.4 Schematic overview of bottom-up model of high-speed rail and aviation sector

5.5.1. Origin-destination passenger demand

Baseline passenger demand forecasts are based on regional forecasts for all origin-destination airport pairs in California and the Northeast Corridor where high-speed rail may eventually compete with air transportation (see Appendix B for a complete list of airport pairs).

The California forecast data is based on reports and analysis prepared for the Bay Area Regional Airport System Plan (RASP) Analysis 2011 Update. The Northeast Corridor forecast data is extrapolated from Bureau of Transportation Statistics, Form 41, T-100 data.[2]

As described in Section 5.4.3, GDP-induced demand change and price-induced demand change are applied to the baseline forecasts in the climate policy scenarios. Policy impacts on GDP are applied to the demand forecasts with an elasticity of 1.8. For fuel price, it is assumed that fuel costs comprise 20% of direct operating costs for regional jets in the United States (Babikian et al., 2002). Additionally, as is common in long-run assessments of the impact of climate policies on aviation, we assume that airlines pass through the full costs of fuel price increases to consumers (Anger and Köhler, 2010). Given the above data and assumptions, the reference and policy demand forecasts are represented in Figure 5.5. Similar to previous studies on the impact of climate policies on aviation, reduced GDP and increased fuel prices have a relatively modest impact on air travel demand.

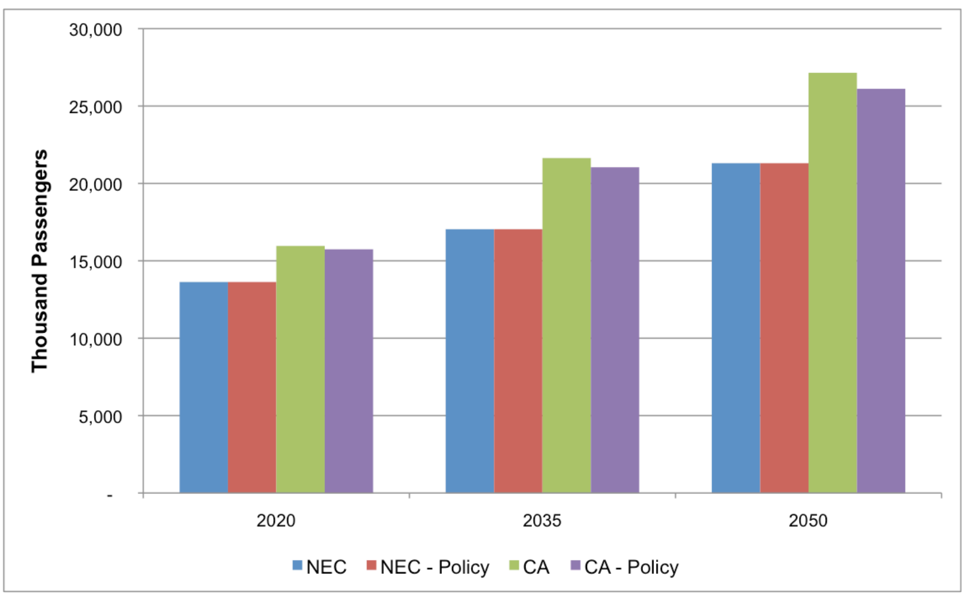

Figure 5.5 Passenger demand in the reference and policy case

[2] Further details on the demand forecast sources and methods are described in Appendix B.

5.5.2. High-speed rail substitution scenarios

High-speed rail development scenarios considered in this analysis include a no-build scenario, a moderately competitive HSR system scenario, and a very competitive HSR scenario, defined as follows.

The California High-Speed Rail Authority business plan and ridership forecasts include two pricing scenarios: one in which the HSR fares are assumed to be 83% of airfares, and one in which they are assumed to be 50% of airfares. The predicted diversion from air transportation to high-speed rail that has been projected is summarized in Table 5.3. for the moderately competitive rail price scenario (e.g., the 83% of airfares case). The alternative scenario is shown in Appendix B. These substitution rates are applied to our reference and policy air transportation demand forecasts to obtain the HSR scenario forecasts of aviation and HSR demand.

Table 5.3 Assumed diversion to high-speed rail by airport-market pair in California: HSR fares 83% of airfares (source: Gosling, 2010)

		2020			2035		
Market		**OAK**	**SFO**	**SJC**	**OAK**	**SFO**	**SJC**
Los Angeles	**LAX**	16.3%	21.7%	21.7%	49.4%	65.8%	65.8%
Orange County	**SNA**	12.5%	16.7%	16.7%	38.1%	50.8%	50.8%
Burbank	**BUR**	16.7%	22.3%	22.3%	50.8%	67.7%	67.7%
Ontario	**ONT**	5.2%	7.0%	7.0%	15.9%	21.2%	21.2%
Long Beach	**LGB**	12.6%	16.8%	16.8%	38.2%	50.9%	50.9%
Palm Springs	**PSP**	4.8%	6.4%	6.4%	14.5%	19.3%	19.3%
San Diego	**SAN**	5.1%	6.8%	6.8%	15.3%	20.3%	20.3%

5.5.3. Vehicle requirements to meet passenger demand

Estimates of energy use and CO_2 emissions associated with travel demand are based on representative vehicle types and load factors determined through the process described below.

To determine the appropriate representative aircraft and load factors associated with these intercity travel corridors, we examine the aircraft fleet data for operations carried out between the airport-market pairs of relevance in California and the Northeast Corridor. Based on an analysis of Bureau of Transportation Statistics (BTS), Form 41, T-100 data, the Boeing 737 series was utilized to carry out 49.2% of all short-haul, intra-California flights in 2010 (BTS, 2010). The extensive use of the B737 in this corridor is likely due to the significant presence of Southwest Airlines in these markets (and the propensity of low-cost carriers to maintain a common fleet – in Southwest's case, the B737 series). Based on the BTS Form 41 data, the B737 Classic series (-300, -400, -500 models) currently comprise a greater portion (i.e. 60%) of the aircraft fleet used in these markets. The following aircraft capacity, energy use, and emissions estimates in our reference analysis below are thus based on the B737-400.

Load factors for the California and Northeast Corridor flights are also based on analysis of BTS Form 41 data. Between 1990 and 2010 the average load factor for short-haul California flights was 0.66, and 0.55 for flights in the Northeast Corridor region. The B737-400 can be configured to seat 128 passengers (with first class) or 137 passengers (e.g., the Southwest configuration). We assume an average 132 number of seats per aircraft for this analysis. Provided the representative aircraft assumption, number of seats per aircraft, and load factors, the number of total flights required to meet the forecasted passenger demand is estimated for each scenario.

The representative vehicle assumed in this analysis is based on a California High-Speed Rail Authority memo detailing possible trainset technologies and configurations under consideration, as well as their energy requirements (CHSRA, 2003, 2009). In this analysis, the representative vehicle is assumed to be a 16-car trainset (seating 900 passengers), that consumes 74.2 kWh of electricity per train mile. We assume load factors ranging from 25% to 50% for HSR ridership in the reference case. Further analysis is conducted to test these assumptions in Section 5.7.

5.5.4. Energy use and CO_2 emissions

Using our representative aircraft assumption described above, energy use and CO_2 emissions are estimated as follows. Fuel burn data are calculated based on 737-400 data reported in the EMEP/CORINAIR Emission Inventory Guidebook (EMEP/CORINAIR, 2007). This particular guidebook was utilized because of its detailed reporting of fuel burn and emissions for separate phases of an aircraft flight. It is widely recognized that short-haul flights typically require more fuel than longer-haul flights on a vehicle-mile basis, due to the disproportionate amount of fuel required by an aircraft during landing and take-off (LTO) phase versus during cruise (see Figure 5.6). Table 5.4 reports the fuel burn for LTO and cruise-mile for a B737-400.

Figure 5.6. Landing and take-off phase (source: IPCC, 1999)

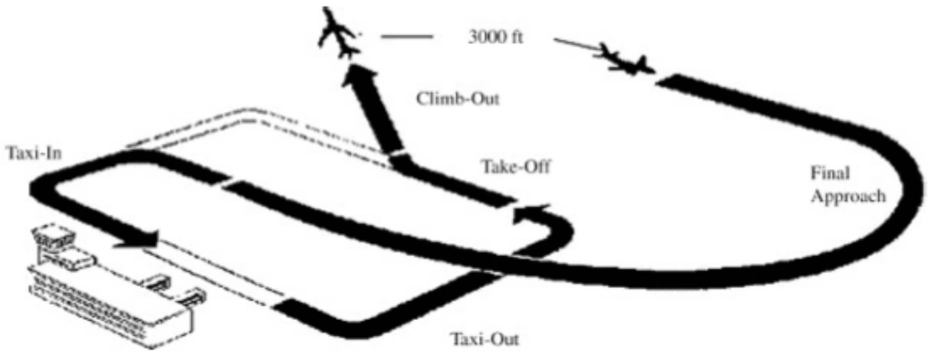

Figure 5.6 Landing and take-off phase (source: IPCC, 1999)

Table 5.4 Emissions for B737-400 (source: EMEP/EEA 2006)

Flight phase	Fuel burn [kg]
LTO phase [total]	825.4
Cruise [per mile]	5.0

Total annual aircraft fuel burn is thus calculated through Equation 5.1, where *Flights* are the total flights on corridor *i* per year, and *Dist* is the distance of corridor *i*.

$$\text{Aircraft Fuel Burn} = 825.4 \text{ kg x } \sum \text{Flights}_i + \sum [\ 5.0 \text{ kg x Flights}_i \text{ x Dist}_i\ ] \qquad (5.1)$$

High-speed rail emissions are estimated based on the assumed energy use of 74.2 kWh/mile described in the previous section, coupled with electricity generation by region results from USREP for each scenario (e.g., reference, cap-and-trade, clean energy standard). The total CO_2 emissions of high-speed rail are then estimated based on Equation 5.2 below, where *Trains* is the total number of train services required to meet passenger demand per year, *Dist* is the distance (miles) between the origin and destination, *Elect* is the assumed energy use (kWh/train-mile), $CO2_S$ is the rate of CO_2 emissions per kWh associated with a source S, Gen_S is the total electricity generation from source S in the region in each year (kWh), and Gen_T is the total generation of electricity from all sources in the region during each year.

$$CO2_{HSR} = \text{Trains x Dist x Elect x } \Sigma\ [CO2_S \text{ x } (Gen_S / Gen_T)] \qquad (5.2)$$

In the following section, we present the total CO_2 emissions from air and rail for California and the Northeast Corridor estimated using the methodology described above.

5.6. INTEGRATED MODEL RESULTS

5.6.1. The California case

Total CO_2 emissions from the aviation and high-speed rail sector in California for the reference and policy scenarios are presented in Figure 5.7. Not surprisingly, our results indicate that the cap-and-trade (CAT) and clean energy standard (CES) policy scenarios combined with "low fare" high-speed rail scenario lead to the greatest reduction in total CO_2 emissions in 2035 and 2050. In the following analysis, the results of all seven policy scenarios are described in detail.

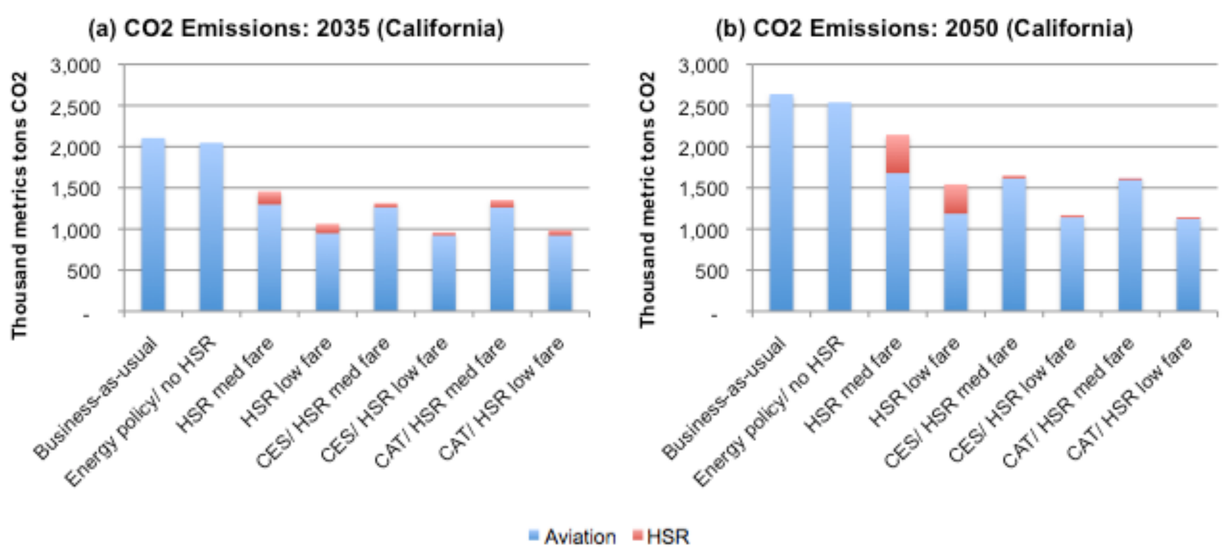

Figure 5.7 Total aviation and high-speed rail CO_2 emissions: California

Energy policy without HSR. Consistent with previous studies focused solely on the aviation sector, our modeling results indicate a relatively small reduction in CO_2 emissions under the energy policy scenario without the development high-speed rail. As described in Section 5.4.3, the impacts of reduced GDP and increased fuel prices in the climate policy scenarios have only a modest effect on passenger demand, and thus a limited effect on the CO_2 emissions of the aviation sector (-3% from the reference case in 2035, and -5% in 2050).

HSR without energy policy. The introduction of high-speed rail as a new mode for intercity travel within California is projected to have a significant impact on air travel, resulting in a substantial reduction in CO_2 emissions. In the medium fare scenario (rail fares set at 83% of airfares), total emissions reduction in the aviation/ HSR sector is estimated to be 31% per year in 2035; in the low fare scenario (rail fares set at 50% of airfares), the total emissions reduction is estimated to be 49% from the reference.

HSR with energy policy. Not surprisingly, the environmental benefits of introducing high-speed rail concurrent with energy policies are greater than without. Energy policies would likely have a modest effect by reducing total travel demand. However, their greater impact is projected to be the shift of electricity generation to cleaner sources, thereby reducing emissions of the high-speed rail sector. The result is fairly significant, particularly over the long run. In 2050, total CO_2 emissions are estimated to be 14% to 20% lower per year than in the high-speed rail scenarios without energy policy.

In the California case, the reduction of CO_2 emissions from aviation and HSR is affected similarly by the cap-and-trade policy and clean energy standard. The total emissions from aviation and high-speed rail estimates are within 1% to 2% for the CES and CAT scenarios. Given that California's electricity generation mix already includes a relatively large percentage of non-carbon intensive sources (as compared to other states and regions), the relative environmental gains of a cap-and-trade policy over a clean energy standard are quite modest in the California case – when applied to their impact on the transport sector.

5.6.2. The Northeast Corridor

There are several similar trends in the model estimation results in the Northeast Corridor as in the California case. Estimated CO_2 emissions from aviation and high-speed rail for the Northeast Corridor are presented in Figure 5.8. Energy policy without the introduction of high-speed rail has only modest results on reducing total emissions in this sector; in this case, less than 1%. A cap-and-trade policy or clean energy standard combined with the introduction of Next Generation ("Next-Gen") high-speed rail in the Northeast Corridor would lead to the greatest environmental savings (between 51% and 56% in 2050).

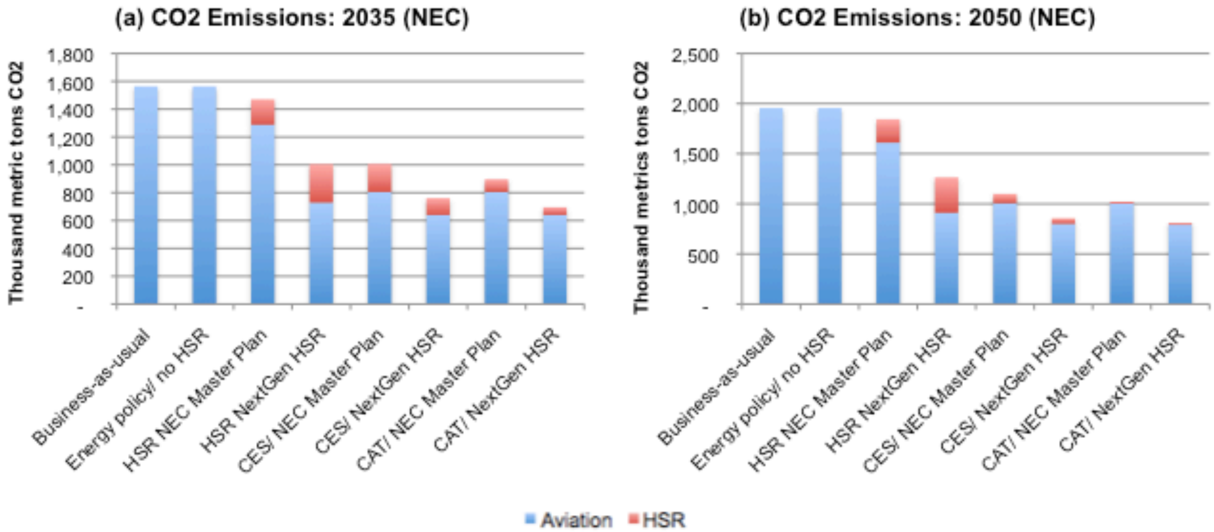

Figure 5.8 Total aviation and high-speed rail CO_2 emissions: Northeast Corridor

One of the primary differences between the results from California and the Northeast Corridor is the relatively larger impact that a cap-and-trade policy or clean energy standard would have on reducing the emissions of high-speed rail. The states that lie along the Northeast Corridor currently rely more heavily on carbon-intensive energy sources for their electricity generation, and thus the emissions savings in the energy policy scenarios are much more significant than the high-speed rail scenarios without energy policy: from a 36% per year reduction in 2035 (without energy policy), to a 51% or 56% reduction in 2035 with CES or CAT, respectively. The CO_2 emissions reductions of all policy scenarios compared with the reference scenario are summarized in Table 5.5.

Table 5.5 Annual CO_2 emissions savings compared with the reference scenario

	California		NEC	
	2035	**2050**	**2035**	**2050**
Energy policy/ no HSR	-3%	-4%	-0.01%	-0.01%
Moderately competitive HSR	-31%	-19%	-6%	-6%
Very competitive HSR	-49%	-42%	-36%	-35%
CES/ HSR (mod. competitive)	-38%	-37%	-36%	-44%
CES/ HSR (very competitive)	-54%	-56%	-51%	-56%
CAT/ HSR (mod. competitive)	-36%	-39%	-43%	-48%
CAT/ HSR (very competitive)	-53%	-57%	-56%	-59%

5.7. SENSITIVITY ANALYSIS

Given the various assumptions that are necessary to develop this intetgrated model of climate policy and transportation development, the following section presents a senstitivy analsysis of our assumption to examine the robustness of our results.

5.7.1. Load factors of aviation and high-speed rail

A major factor that can influence projections of total CO_2 emissions of the transportation sector is the load factor assumed in the analysis. This is particularly true for high-speed rail and air transportation, where transportation capacity can range from less than 50 to over 300 seats for an aircraft and 600 to 1200 seats for a high-speed rail trainset. As described in Section 5.5.3, our model generates the number of vehicles required to meet passenger demand based on an assumed load factor. Figure 5.9 presents total emissions for the aviation and high-speed rail sector under alternative load factor assumptions for air and rail.

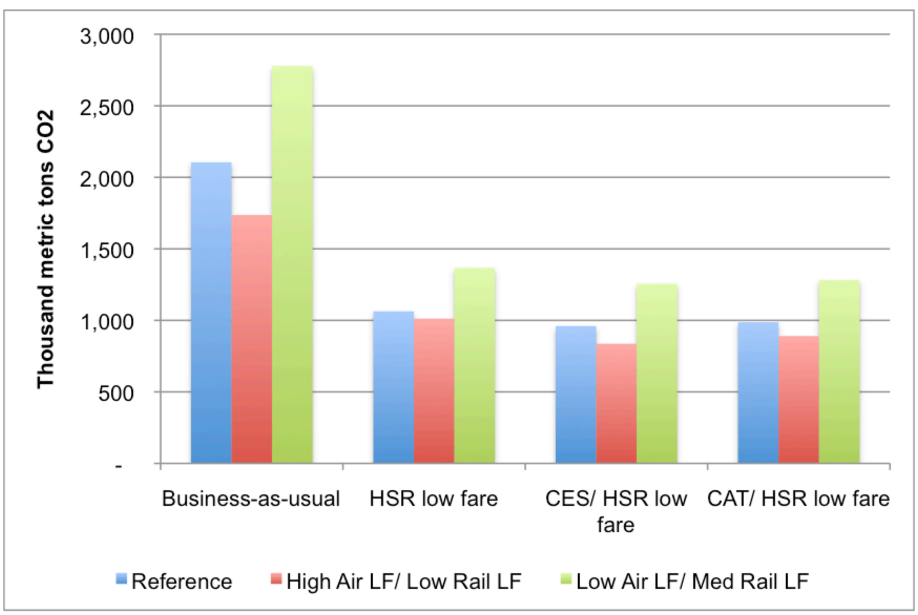

Figure 5.9 Total annual CO_2 emissions of aviation and HSR in California under different load factor assumptions (in 2035)

The key factor that influences total emissions from this sector are the assumptions about aviation load factors (LF), which are adjusted from 0.50 (in the "Low Air LF" scenario) to 0.80

(in the "High Air LF") case. As described in Section 5.5.3, an aviation load factor of 0.66 is assumed for the reference scenario, based on an analysis of the past 20 years of passenger demand for California's short-haul airport-market pairs. Finally, although rail load factors are also adjusted from 0.25 to 0.50, their impact is relatively modest due to the relatively high energy efficiency of high-speed rail.

Figure 5.10 presents similar sensitivity results for the Northeast Corridor. For this region, aviation load factors are adjusted from 0.45 (in the low LF case) up to 0.80 (in the high LF case). The reference case, also based on an analysis of historic demand in this corridor, is assumed to be 0.55. The trends are fairly similar in this case, with the exception of the high-speed rail scenario without energy policy. In this scenario, the low load factor assumed for high-speed rail (0.25), limits the total emissions savings that would otherwise be gained with a load factor of 0.50.

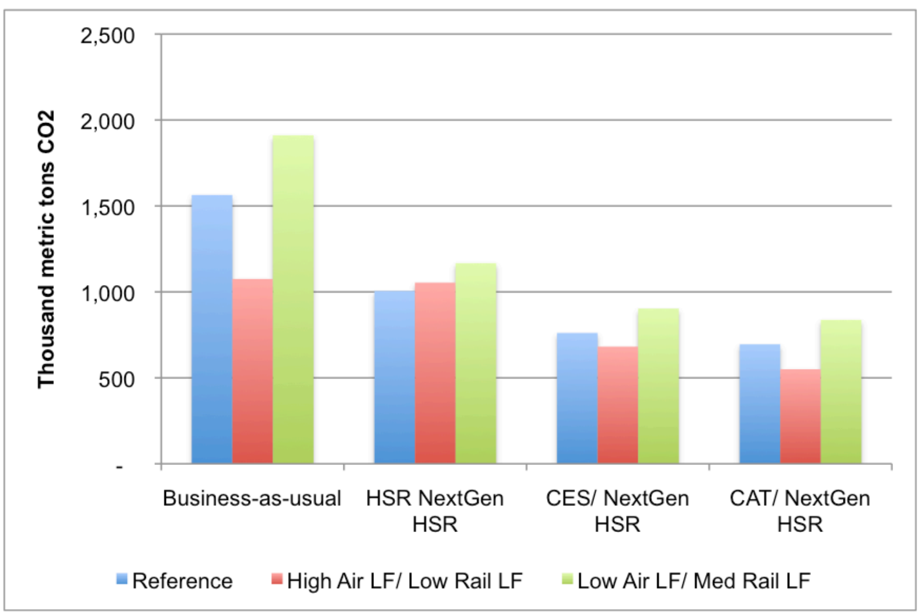

Figure 5.10 Total annual CO_2 emissions of aviation and HSR in the Northeast Corridor under different load factor assumptions (in 2035)

5.7.2. Energy consumption of high-speed rail

The second critical issue that we explore in this sensitivity analysis is the assumption of energy use for high-speed rail system introduced in California and the Northeast Corridor. In our reference case, the energy consumption was assumed to be 74.2 kilowatt-hour per train-mile. Through our sensitivity analysis, we examine a low energy use scenario (50 kWh per train-mile) and a high energy use scenario (100 kWh per train-mile). Results for the California and Northeast Corridor total CO_2 emission estimation results are presented in Figure 5.11 and Figure 5.12.

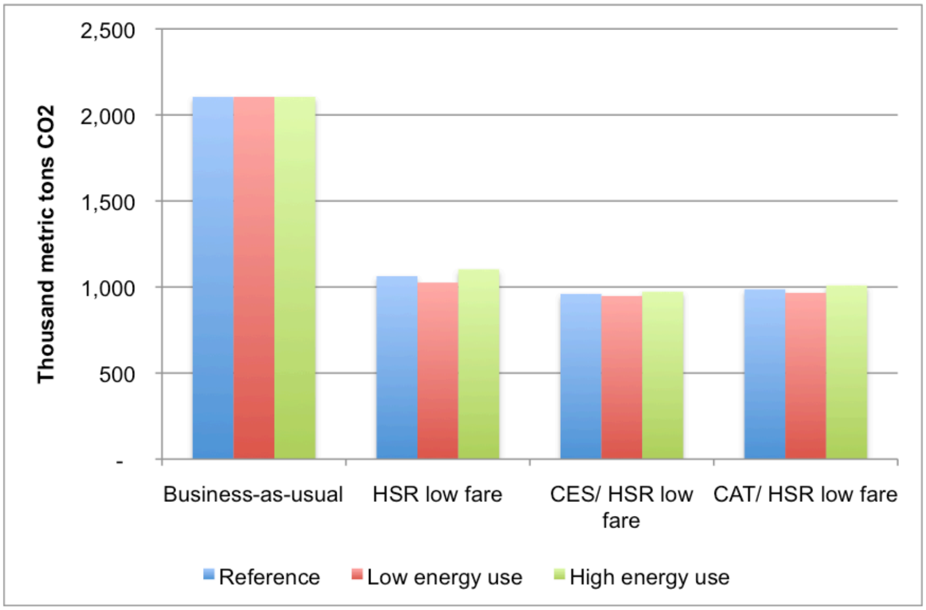

Figure 5.11 Total annual CO_2 emissions of aviation and HSR in California under different energy use assumptions (in 2035)

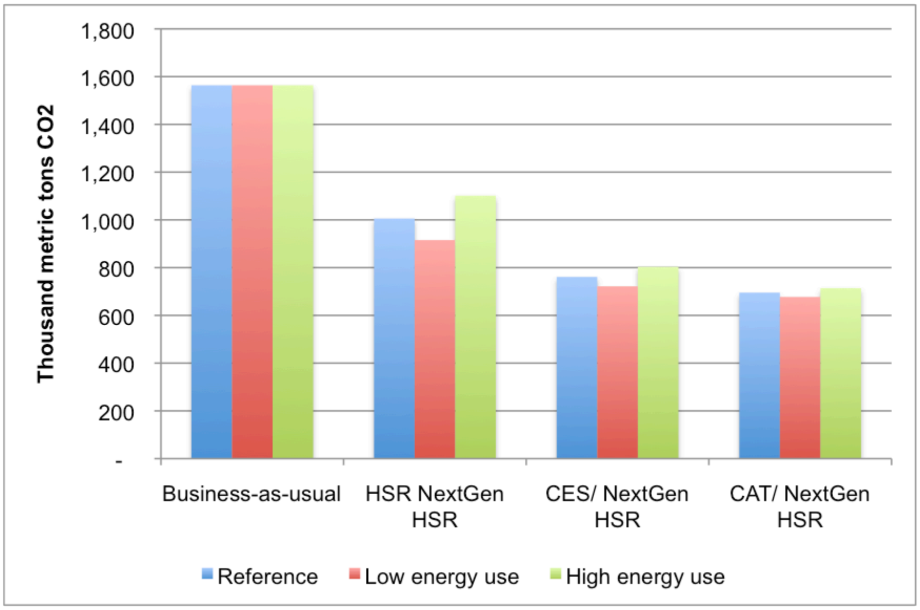

Figure 5.12 Total annual CO2 emissions of aviation and HSR in the Northeast Corridor under different energy use assumptions

Sensitivity analysis results for California indicate that the total CO_2 emission estimates from our model are fairly robust, with minimal differences between the low, reference, and high energy use scenarios. These results are largely driven by the relatively low-carbon intensity of California's electricity generation.

Estimated results for the Northeast Corridor are also fairly robust; however, there are slightly greater differences between the low, reference, and high energy use scenarios. As might be expected, the higher CO_2 emission rates of electricity generation in the Northeast states result in slightly different total emission estimates in the scenario with high-speed rail absent of energy policy.

5.7.3. CO_2 emissions per passenger-mile

Throughout this analysis, we have primarily focused on total CO2 emissions of the high-speed rail and aviation sector as our primary metric. Another common metric utilized to examine the carbon intensity of transportation systems is CO_2 emissions per passenger-mile, which we examine in this section. Table 5.6 and Table 5.7 present summary results of CO_2 emissions per passenger-mile for California and the Northeast Corridor under different load factor assumptions.

Table 5.6 Kilograms of CO_2 per passenger-mile for California under different load factor assumptions (in 2035)

	Aviation			High-Speed Rail	
	Reference	**High**	**Low**	**Reference**	**Low**
Business-as-usual	0.261	0.215	0.344		
Energy policy/ no HSR	0.261	0.215	0.344		
HSR med fare	0.259	0.213	0.341	0.047	0.047
HSR low fare	0.258	0.213	0.341	0.024	0.047
CES/ HSR med fare	0.259	0.213	0.341	0.016	0.016
CES/ HSR low fare	0.258	0.213	0.341	0.008	0.016
CAT/ HSR med fare	0.259	0.213	0.341	0.027	0.027
CAT/ HSR low fare	0.258	0.213	0.341	0.014	0.027

In the case of California, aviation load factors range from as low as 0.213 kg per passenger-mile (in the high load factor scenario) to 0.344 kg per passenger-mile (with low LF). High-speed rail emissions are lower in general, but vary substantially over the range of policy scenarios due to their relationship to electricity generation, ranging from 0.008 kg (in the CES/ low fare case) to 0.047 kg (no energy policy/ HSR medium fare case).

Similar results are obtained for the Northeast Corridor, where assumptions about aviation load factors result in a CO_2 per passenger-mile range of 0.234 to 0.446 kg per passenger mile. High-speed rail emissions vary even more substantially in the Northeast Corridor case, due to the range of electricity generation projections. In the most carbon efficient case, CO_2 emissions per passenger-mile for high-speed rail are 0.019 kg (with NextGen HSR and a cap-and-trade policy). In the least carbon efficient case, they are projected to be 0.221 kg per passenger-mile (with the NEC Master Plan and current generation mix).

Table 5.7 Kilograms of CO_2 emissions per passenger-mile for the Northeast Corridor under different load factor assumptions (in 2035)

	Aviation			High-Speed Rail	
	Reference	**High**	**Low**	**Reference**	**Low**
Business-as-usual	0.356	0.245	0.435		
Energy policy/ no HSR	0.356	0.245	0.435		
HSR NEC Master Plan	0.353	0.243	0.431	0.221	0.221
HSR NextGen HSR	0.340	0.234	0.415	0.110	0.221
CES/ NEC Master Plan	0.365	0.251	0.446	0.082	0.082
CES/ NextGen HSR	0.364	0.250	0.445	0.041	0.082
CAT/ NEC Master Plan	0.365	0.251	0.446	0.037	0.037
CAT/ NextGen HSR	0.364	0.250	0.445	0.019	0.037

Our final analysis presents CO_2 emissions per passenger-mile for high-speed rail based on alternative energy use assumptions (see Table 5.8). Similar to previous analyses, the California results are more robust than those in the Northeast corridor, due to the significant variation in possible electricity generation scenarios. In California, CO_2 emissions per passenger-mile range from 0.005 to 0.064 kg. In the Northeast corridor, they range from 0.013 kg in the best case scenario to 0.298 kg in the worst case scenario for high-speed rail.

Table 5.8 Kilograms of CO_2 emissios per passenger-mile under different rail energy use assumptions (in 2035)

California				**Northeast Corridor**			
	Ref.	**Low**	**High**		**Ref.**	**Low**	**High**
HSR med fare	0.047	0.032	0.064	**HSR Master Plan**	0.221	0.149	0.298
HSR low fare	0.024	0.016	0.032	**HSR NextGen**	0.110	0.074	0.149
CES/ HSR med fare	0.016	0.011	0.022	**CES/ Master Plan**	0.082	0.055	0.111
CES/ HSR low fare	0.008	0.005	0.011	**CES/ NextGen**	0.041	0.028	0.055
CAT/ HSR med fare	0.027	0.018	0.037	**CAT/ Master Plan**	0.037	0.025	0.050
CAT/ HSR low fare	0.014	0.009	0.018	**CAT/ NextGen**	0.019	0.013	0.025

5.8. CONCLUSIONS

This analysis has presented a new method for examining future demand and CO_2 emissions from the high-speed rail and aviation sector by developing an integrated model to analyze different combinations of high-speed transportation policy and energy policies. Current analyses of high-speed rail and aviation demand and their environmental impacts in the literature (and in practice) rely on either static assumptions about electricity generation, assumptions of electricity generation that are aggregated at a national level, or both. By coupling a regional, economy-wide CGE model of the United States with a technical bottom-up model that we develop for this analysis, we offer several new capabilities for examining long-range impacts of the high-speed transportation sector: 1) regional-level analysis of the climate impacts of high-speed rail and aviation based on regional electricity generation; 2) regional assessment of HSR and aviation demand under alternative climate and energy policies through 2050; and 3) integrated transportation and energy policy analysis that explores alternative transportation policies combined with alternative climate and energy policies.

5.8.1. Key findings

Although the introduction of high-speed rail as an alternative mode for intercity travel itself results in substantial reductions of projected CO_2 emissions from the aviation sector, these environmental savings are significantly increased when combined with energy or climate policies. These emissions savings are primarily due to the shift from carbon-intensive electricity generation to less carbon-intensive sources that would be required of major utilities in the U.S. under either a cap-and-trade system or clean energy standard. Finally, we find that due to the regional variation in electricity generation across the United States, the CO_2 emissions savings from developing high-speed rail are likely to vary substantially on a regional basis.

- In California, annual CO_2 emissions from the combined aviation and HSR sector are estimated to be 31% lower than business-as usual with the introduction of competitive high-speed rail in 2035. With energy policy, these emissions are estimated to be 54% lower than the reference case. The alternative scenario without high-speed rail is projected to result in a modest 3% reduction in annual CO_2 emissions.
- In the Northeast Corridor region, annual CO2 emissions in 2035 are estimated to be 36% lower with the introduction of competitive NextGen high-speed rail service. If energy policies are also enacted, these annual savings are estimated to be 56%.
- Total emission estimates for both regions are fairly robust for alternative assumptions regarding aviation and high-speed rail load factors and energy use assumptions for high-speed rail. However, due to the range of alternative electricity generation scenarios for the Northeast Corridor region, the per passenger-mile metrics vary somewhat based on load factor and energy use assumptions associated with high-speed rail.

5.8.2. Implications for policy and practice

A key finding of this study is the wide range of future CO_2 emission savings projections associated with high-speed rail, based on future electricity generation. Current cost-benefit analyses associated with high-speed rail typically rely on assumptions about energy use, electricity generation, and load factors that are often derived from national averages, rather than the more accurate figures that can be ascertained from examining regional data. Secondly, these analyses often base emissions projections on current electricity generation rather than future electricity generation, although most proposed high-speed rail systems will be utilized from 2020 to 2070 (and likely beyond). This study presents several methods for improved integrated analysis of future transportation alternatives combined with possible energy and climate policies.

This chapter has explored the potential future of high-speed rail and aviation demand, and the environmental impacts of these systems in the United States, examining alternative policies that may shape their future. In the next chapter, we will shift our attention to the influence of individual attitudes on travel mode choice between high-speed rail and aviation, and the potential impact of environmental orientation on these decisions.

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Chapter 6: Examining tradeoffs between environment and safety for intercity travel choice

Much of the analysis presented in previous chapters has relied on the premise that individuals make rational decisions about mode choice – decisions that are dominated by consideration of price and travel time. However, new research in the area of travel demand modeling suggests that these level-of-service factors and basic demographics are insufficient to completely explain travel behavior. In order to improve our understanding of human demand for transportation and energy systems, new methods have focused on how perceptions, identity, and social norms influence our choices. In this chapter, we present an analysis of perceptions of environment and safety and their potential influence on travel choice in China – a nation that has developed considerable high-speed rail infrastructure (today, the most HSR track in the world), and where issues of environment and safety are of particular concern.

6.1. INTRODUCTION

Demand for all modes of transportation in China has grown at a rapid rate since 1979, following economic reform and significant economic growth. Air passenger travel increased at an average rate of 16% per year between 1978 and 2009, and is projected to continue to increase at a rate of 12% per year over the next decade. The substantial growth of demand in China's transportation sector has significant implications for local air quality and global climate impacts. For the first time in 2007, China overtook the United States as the world's largest emitter of CO_2 emissions. The introduction of high-speed rail in China could enable lower-carbon expansion of mobility, as it previously has in Europe (and potentially could have in the U.S.). High-speed rail investment in China has been quite substantial; the Chinese government is expected to invest \$300 billion USD in high-speed rail development between 2008 and 2020. China already has developed more high-speed rail track than any other nation, with over 10,000 kilometers of high-speed rail track in operation as of 2012 (China Daily, 2012).

Although the expansion of China's high-speed rail infrastructure has been significant, there have been growing concerns about the rate at which it has been constructed, as well as corruption at the Ministry of Railways. In February 2011, China's Minister of Railways was dismissed from his position due to allegations of corruption. In April 2011, the new minister announced that in order to increase margins of safety, the top speeds of all trains would be reduced to 300 kilometers per hour (km/h); officials previously promoted the Beijing-Shanghai railway line as having been designed to reach speeds of 380 km/h. Construction on the Beijing-Shanghai high-speed rail line began in April 18, 2008 and was opened for service on June 30, 2011 – just in time to commemorate the Communist Party of China's 90th anniversary as planned. On July 23, 2011, a fatal high-speed rail accident occurred on the Yongtaiwen railway line, the line just south of the Beijing-Shanghai railway. One high-speed train collided into the back of another on a viaduct, derailing both trains and causing four rail cars to fall off the viaduct. 43 people were killed in the accident over 200 were injured (Railway Gazette, 2011). The public outcry about this accident was exceptional by the standards of China.

The goal of this study is to examine how attitudes towards safety and environment influence passenger decisions for travel choice. We developed and administered a travel intercept survey conducted at airports and rail stations among passengers traveling on the Beijing-Shanghai intercity corridor. The survey gathered demographic information about travelers, choice data based on traditional level-of-service variables (e.g., price, time), and attitudinal data related to time, price, environment, and safety. Although of course not part of the research plan, the survey was administered in China during the days immediately preceding and following the high-speed rail accident that occurred on July 23, 2011, thus resulting in pre- and post-accident survey responses. This created both opportunities and challenges for this research.

This chapter contains the following sections. Section 6.2 provides further background on recent research focused on how attitudes and social norms affect travel behavior. In Section 6.3 we present an overview of the methodology and data collection. Survey analysis is presented in Section 6.4. Section 6.5 summarizes the key findings of this study and opportunities for future work.

6.2. BACKGROUND

The bulk of literature on travel mode choice focuses on using modal attributes (e.g., price, travel time, accessibility, etc.) and individual specific demographic attributes (e.g., income, education, etc.). However, in recent years a growing body of research has explored the notion that attitudes, identity, and social norms also play a significant role in explaining energy use and travel behavior. Much of the previous work in this area has focused on examining how environmental or safety preferences influence urban mode choice and vehicle purchase. In this chapter, we extend these methods to examine intercity mode choice in the context of China.

A substantial body of travel demand research focuses on building an improved understanding of mode choice in urban environments. Given growing demand for private automobile use and its environmental implications, several studies have attempted to examine attitudes towards the environment and/or safety and the potential impact of these attitudes on mode switching (Stradling et al., 2000; Bamberg and Schmidt, 2001; Steg et al., 2001; Anable, 2005). In Steg et al., it was found that motives such as pleasure and social comparisons are as useful in predictions of mode choice as traditional variables (i.e. time and cost). In Sweden, environmental attitudes were positively correlated with willingness to reduce private automobile use or support travel reduction measures (Nilsson and Kueller, 2000). Similarly, another study found that attitudes towards environment and technology contributed to more accurate assessments of potential alternative vehicle purchase (Ewing and Sarigöllü, 2000). More recently, research aimed at disentangling neighborhood and travel choices has found that travel behavior differences between suburban and traditional neighborhoods can partially be explained by attitudes (Handy, 2005).

This study aims to build on previous work focused on transportation choices in urban contexts, by utilizing similar survey methods in an intercity context. In this study, we aim to explore the potential impact of attitudes towards safety, environment, time sensitivity, and price insensitivity, and their influence on travel choice between high-speed rail and air transportation.

6.3. DATA COLLECTION

An intercept survey of passengers traveling between Beijing and Shanghai was conducted from July to August 2011. Given the significant distance between the two cities (roughly 800 miles), the two dominant modes for intercity travel are rail and aviation. Student volunteers were recruited to administer a written questionnaire at domestic airports and rail stations in Beijing and Shanghai. Passengers who were traveling to Shanghai (from Beijing) and to Beijing (from Shanghai) were randomly selected to complete the survey. A total of 565 surveys were collected.

The 8-page written survey included four primary question sections in the following order: 1) current trip information; 2) demographic information; 3) four hypothetical mode choice questions; and 4) attitudinal questions. The attitudinal questions were included at the end of the survey in order to avoid introducing potential bias in the respondents' answers to the hypothetical mode choice questions.

We examined mode choice among the following four options described in detail below: 1) conventional rail; 2) high-speed rail (at 250 km/h); 3) high-speed rail (at 300 km/h); and 4) air transportation. The Beijing-Shanghai intercity corridor was (and continues to be served) by conventional rail service; the fastest travel time on the conventional route is 9h 49m. On June 30, 2011, the Beijing-Shanghai high-speed rail line began operations, providing passenger rail service with travel times as low as 4h 48m (at speeds of up to 300 km/h). Due to concerns about the affordability of the high-speed rail service, a slower class of trains was introduced, providing service at 250 km/h at a lower ticket price. The slower "D" trains make the journey between 7h 52m and 9 hours, whereas the faster "G" trains make the trip between 4h 48m and 5h 30m. Flights between Beijing and Shanghai are 2h 10m.

The demographic background of the sample is presented in Table 6.1 and income distribution in Figure 6.1.

Table 6.1 Demographic background of the sample

Gender	
Male	0.68
Female	0.32
Age	
Under 17	0.03
18 to 24	0.17
25 to 34	0.42
35 to 44	0.23
45 to 59	0.11
60 and above	0.03
Profession	
Government & military	0.03
Professional	0.20
Professional (management)	0.19
Self-employed	0.07
Staff/ worker	0.17
Student	0.15
Unemployed	0.01
Other	0.08

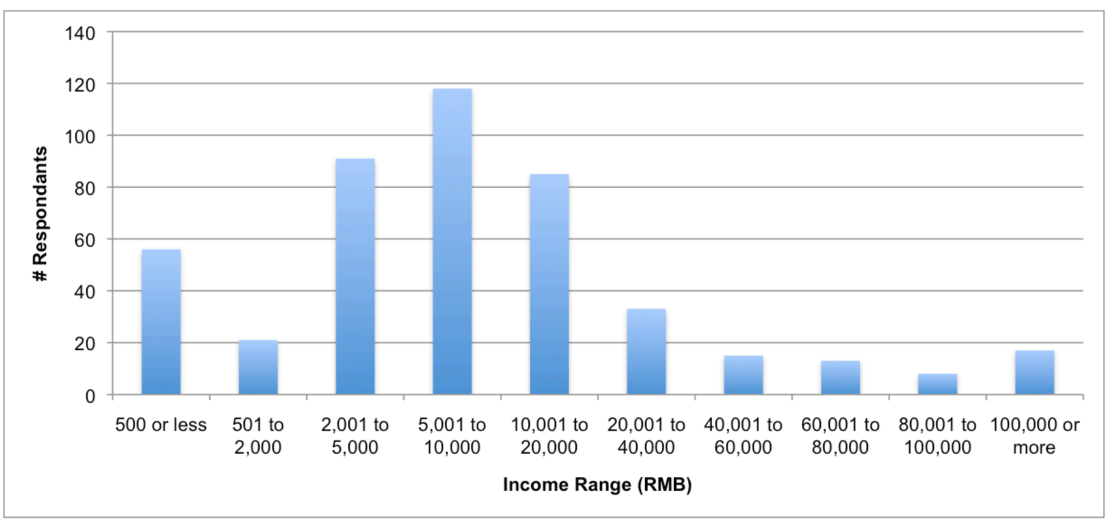

Figure 6.1 Income distribution of sample

The sample consists of 68% men; similar to previous studies of intercity travel in China, men are more highly represented in these travel markets. Income distribution follows a nearly normal distribution. The large number of those reporting their income as "500 RMB or less" is partially overrepresented due to the relatively large number of students who travel to/ from their universities (i.e. 15% of our sample). In the following section, we discuss data analysis and results of the trip-based questions included in the survey, mode choice selections for future trips, and attitudinal questions.

6.4. DATA ANALYSIS AND RESULTS

As is common in travel mode choice research, data was collected through an intercept survey (in this case, collected at train stations and airports). The survey respondents completed written questions associated with the current trip that they were in the process of making, and were then asked to complete hypothetical mode choice questions in the context of their current trip. Based on the literature, the primary trip factors that are typically found to have the greatest influence on intercity mode choice (outside of price and travel time) are trip purpose, size of travel party, and accessibility of the airport (or rail station). The results of the survey on these factors are discussed in detail below.

6.4.1. Trip purpose

Similar to previous studies of air/rail mode share for intercity travel, we find that business passengers appear more likely to travel by aviation than by rail (see Figure 6.2). Business travelers represent 65% of the passengers share among air passenger respondents, compared with 49% of rail passenger respondents. However, as compared with other developed regions, business travelers still represent a larger portion of respondents than typically found in, for example, the United States or Europe, where domestic leisure air travel markets are more mature.

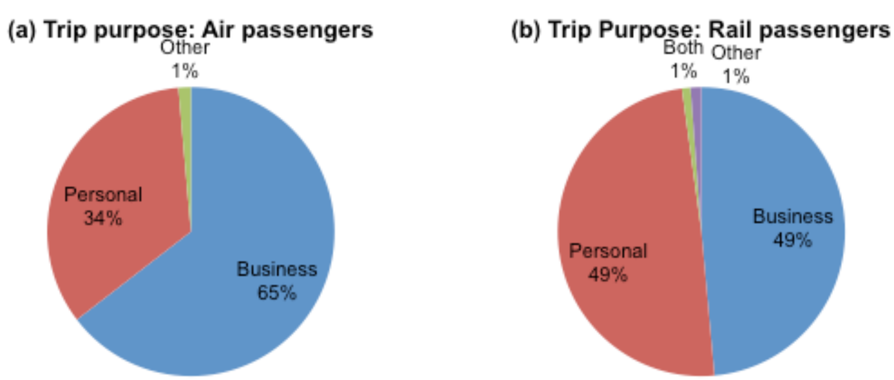

Figure 6.2 Trip purpose by current mode

6.4.2. Accessibility of airports and rail stations

Respondents were asked to indicate how they travelled to the airport (or rail station), as well as how long it took them to make that (access) trip. In the hypothetical mode choice scenario, they were then asked to indicate how long they thought it would take them to reach the alternative mode (i.e. the rail station or airport), and how they might get there. Table 6.2 summarizes the results for access trip times, and Figure 6.3 summarizes access and egress mode by intercity mode choice.

Table 6.2 Access times by current and alternative mode

Access Time	Air	Rail (alternative)	Rail	Air (alternative)
Less than 15m	5%	5%	5%	1%
15m to 30m	11%	12%	24%	8%
30m to 1h	63%	55%	51%	37%
1h to 1h30m	17%	20%	15%	30%
1h30 to 2h	5%	3%	4%	12%
Over 2h		0%	2%	3%
Don't know		5%		9%

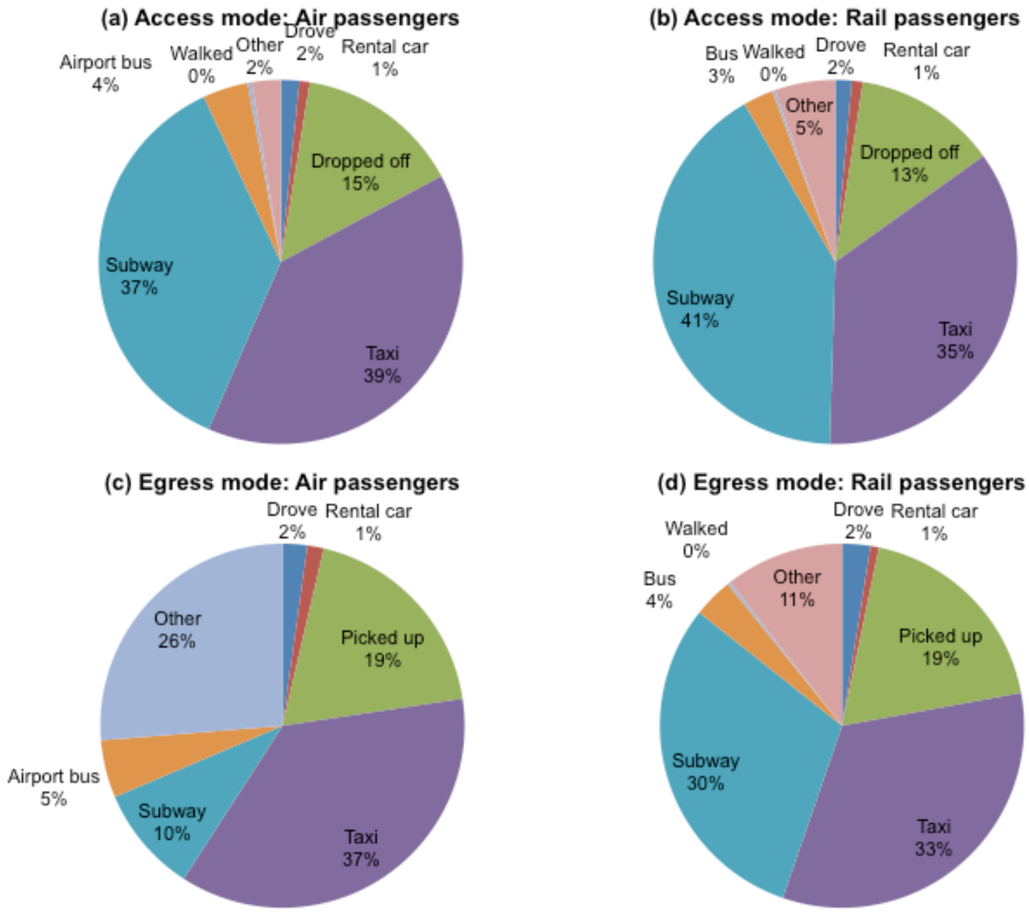

Figure 6.3 Access and egress by current mode choice

In other regions, for example, Japan and Europe, it is often argued that high-speed rail is more accessible than air transportation, making it more competitive for intercity travel where passengers are more likely to be motivated to minimize their access/ egress times. High-speed rail stations are often located within city centers and are connected by local transit and/or commuter rail systems, whereas airports are often located outside of city center where they may primarily be accessible by private automobile. In the case of China, access times appeared to be slightly shorter for rail stations than airports (see Table 6.2). However, differences in access times and access/egress modes in China were not as significant as they are typically found in other regions.

One of the likely explanations is the relative ease of accessibility to both rail stations and airports via urban transit in China. In both Beijing and Shanghai, the domestic airports and rail stations are both accessible via bus or rail. In the case of Beijing, the airport is accessible by a direct "airport bus" as well as an express link from the subway system. In Shanghai, Hongqiao International Airport (the primary domestic airport) is located adjacent to Hongqiao Rail Station; both are accessible by subway. This access/egress data highlights a fairly different scenario compared with previous studies where high-speed rail tends to dominate as the most accessible mode from the city center. In the case of Beijing and Shanghai, well-designed transit services to airports provide fairly competitive access options.

6.4.3. Attitudes towards price and travel time

In the following two sections, an analysis of attitudes towards price and time, as well as safety and environment, are presented with segmentation based on the *hypothetical* mode choices that survey respondents were asked to respond to for a hypothetical future trip. The primary question we aim to answer is: do travelers' mode choices appear to be affected by their attitudes towards time, price, environment, or safety? The English version of the attitudinal questions asked of travelers is presented in Table 6.3.[3]

Table 6.3 Attitudinal portion of survey

	Disagree				**Agree**
I would be willing to pay more when I travel if it would help the environment.	1	2	3	4	5
I consider the safety of the travel mode I choose.	1	2	3	4	5
I always take the fastest form of travel even if a cheaper alternative is available.	1	2	3	4	5
It is usually important that I arrive at my destination on schedule.	1	2	3	4	5
I sometimes worry about whether or not there might be an accident on my train (or flight).	1	2	3	4	5
Use of rail can help improve the environment.	1	2	3	4	5
I use the most convenient form of transportation regardless of cost.	1	2	3	4	5
I would switch to a different mode of transportation if it would help the environment.	1	2	3	4	5
I would change my mode of travel if it would save time.	1	2	3	4	5
I don't mind delays.	1	2	3	4	5

[3] The majority of surveys were completed in Mandarin. Only international passengers completed the English-language version of the survey.

In Figure 6.4, we display passengers' attitudes towards time and punctuality (TIME) and price (PRICE_INSENSITIVITY). Price insensitivity was measured through questions posed to elicit respondents' views on whether or not price was an important factor in their transportation decision-making (see Table 6.3). Based on the survey data, there were limited differences among the future mode choices of passengers and their sensitivity to time. Price insensitivity, however, appears to have a potentially significant impact on transportation mode choice. Respondents who selected the lower priced, moderately fast (i.e., 250 km/h) high-speed rail service were 13.1% more price sensitive than that average respondent, whereas respondents who opted for air travel were 9.3% less price sensitive than the average respondent.

Figure 6.4 Attitudes towards time and price by mode

6.4.4. Attitudes towards safety and environment

One of the primary hypotheses explored in this study is that individuals are influenced at a meaningful level by considerations other than travel time and price when making travel choices, in particular, safety and environment. Figure 6.5 summarizes attitudinal data segmented by mode choice response.

Figure 6.5 Attitudes towards safety and environment by mode

Based on our survey results, those respondents who selected air transportation for their hypothetical future trip rated safety more highly than the average respondent, and rated environmental concerns lower than the average respondent. The opposite was true for those that opted for high-speed rail. Results from this analysis indicate that travelers who are more likely to choose air transportation over rail in China place a greater weight on safety concerns, and a lower weight on environmental issues.

6.4.5. The impact of a major accident on mode choice

As described in Section 6.1, a major high-speed rail accident occurred on July 23, 2011. The accident occurred following two days of data collection at high-speed rail stations; airport intercept data collection had been schedule for the days following the accident. Results for hypothetical mode choice are presented in Figure 6.6, segmented by current air and rail passengers.

Prior to the accident, 80% of future trip choices by current high-speed rail passengers would have been made with high-speed rail, with 62% of the total mode share on the ("G" train) service and 18% on the ("D" train) service (see Figure 6.6a). Following the accident, the high-speed rail share dropped to 70% of hypothetical mode choice, with 45% opting for the fastest service and 25% opting for the slower service (see Figure 6.6b). Passengers appear to have shifted from the 300 km/h service to the 250 km/h service in fairly large numbers. We hypothesize that they view the slower train as safer, although the accident that occurred on July 23, 2011 involved the collision of two of the slower "D" service. The results suggest that intercity travelers in China may view the "D" service as an alternative, safer mode, although they are quite similar to the "G" service in terms of trainset technology and signaling.

Based on our survey, among passengers intercepted at airports (all post-accident), 66% of hypothetical mode share went to air travel (see Figure 6.6c). Amongst current air travelers, 32% of future trips went to high-speed rail, with the majority (25%) opting for the fastest service. The results appear to confirm previous indications that air travelers are often more time sensitive and less price sensitive.

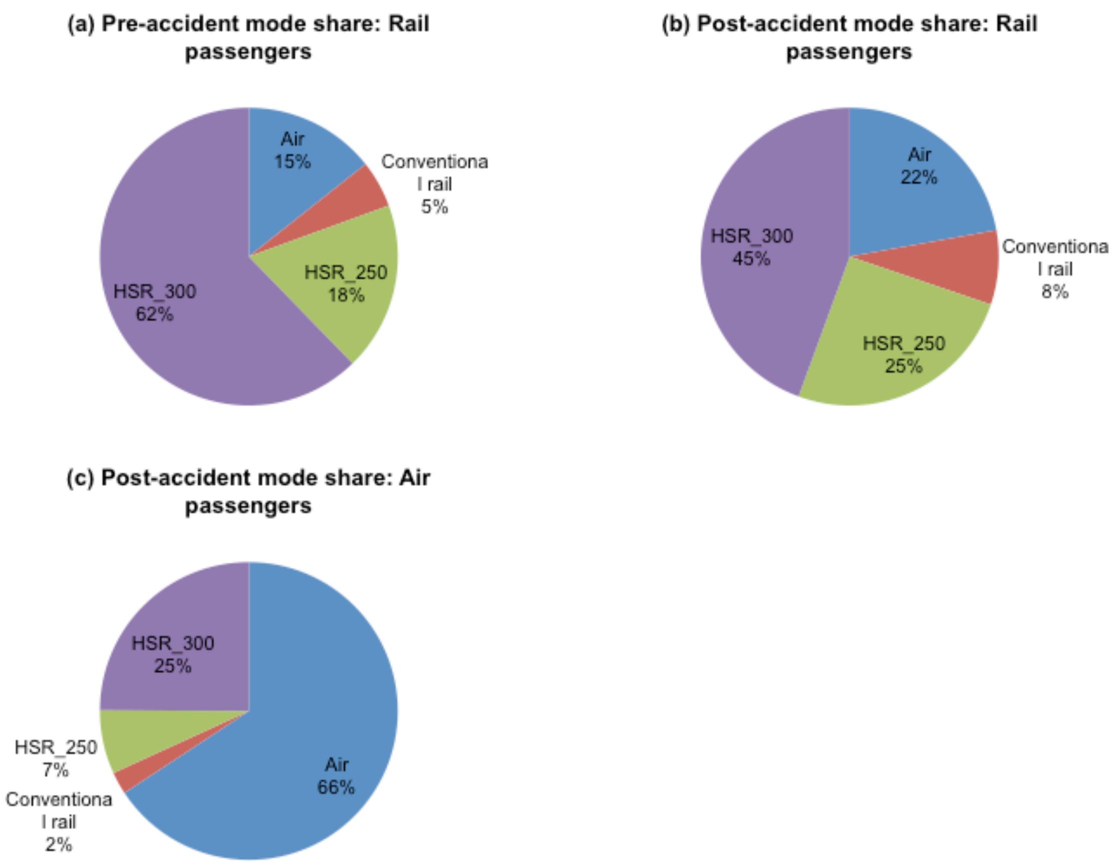

Figure 6.6 Pre- and post-accident hypothetical mode choice

The hypothetical choice results from our pre- and post-accident data indicate a fairly substantial shift in mode choice following the deadly high-speed rail collision in China.

According to the data collected through this intercept survey, high-speed rail lost 10% of the mode share for future trips among current rail passengers; in addition, 7% of passengers shifted from the faster service to the slower service. Given the timing of our data collection, it is unclear what the loss of high-speed rail share would have been among current air travelers. Reports from Chinese new agencies suggest that since the accident, high-speed rail mode share has in fact declined over the past year.

6.5. CONCLUSIONS AND FUTURE WORK

6.5.1. Key findings

This study aimed to build an improved understanding of passenger choice between air travel and high-speed rail in China, and in particular, to explore the attitudinal factors that were hypothesized to influence travel decisions. We conclude by summarizing the following key findings:

1) High-speed rail stations and airports in Beijing and Shanghai are similarly accessible as compared with most international experiences with high-speed rail; thus, access/egress decisions are likely to have a smaller affect on intercity travel choice between air and rail.

2) A fairly large segment of travelers between Beijing and Shanghai travel for business purposes (65% of air passengers, 49% of rail passengers).

3) Individuals who opt to travel by aviation tend to be less price sensitive, more safety conscious, and less environmentally conscious than the average traveler.

4) Individuals who opt to travel by the 250 km/h ("D" train) service are significantly more price sensitive than those traveling by high-speed rail ("G" train) service or air travel.

5) The occurrence of a high-profile high-speed rail accident had a substantial immediate impact on future mode share among high-speed rail passengers. However, lack of specific information about the causes and details of the accident led passengers to switch from the faster high-speed rail service to the slower service, when in fact, the accident occurred on the slower service.

6.5.2. Limitations and future work

As is clear from the results presented in this study, the accident that occurred on July 23, 2011 had a significant impact on the survey data collected. Immediately following the accident, there were significant differences in perceptions about safety as well as in mode choice decisions. A critical question is how long these perceptions and mode choice shifts persist over time. Conducting another survey a year or more after the accident and comparing those results to this data could improve our understanding of the short- versus long-term affects of safety incidents on travel decisions.

This preliminary analysis of how attitudes influence passenger travel decisions demonstrates that although price and travel time are significant factors affecting mode choice, individuals consider other issues as well (e.g., such as safety and environment). However, the majority of policy and practical interventions in the transportation sector focus primarily on issues of cost and travel time.

In the following chapter, we will summarize the research results from throughout this dissertation and their implications for policy and practice.

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Chapter 7: Implications for policy and practice

The goal of this dissertation has been to explore the impacts of climate and transportation policy on high-speed rail and aviation systems, with a focus on travel demand and associated CO_2 emissions. By examining the history of high-speed rail and air transportation in Europe and present-day challenges in China, we have gained insights about demand for these systems, potential levers for shaping future travel demand, and their environmental impacts. In this chapter, we summarize key findings from the international experience and potential implications for the future of high-speed rail in the United States. Section 7.1. summarizes international lessons learned; the remainder of the chapter discusses the current policy and programs for high-speed rail in the United States, potential challenges, and recommendations for policy and practical applications.

7.1. KEY FINDINGS FROM INTERNATIONAL EXPERIENCE

In this section, we summarize key findings from our analysis on Europe and China, focusing primarily on demand and environmental considerations of high-speed rail and air transportation. A more complete overview of global high-speed rail development is also available in Chapter 2.

7.1.1. High-speed rail and intercity demand

As described in Chapter 1, a primary motivation for this analysis of passenger demand is the relationship between travel demand and climate impacts of the transport sector. The key factor driving growth in CO_2 emissions from transportation systems globally is continued growth in travel demand. In this section, we discuss the potential benefits and limitations of high-speed rail development on mitigating the projected continued growth of air travel demand and its associated emissions.

As is clear from our analysis in Chapter 3, the introduction of high-speed rail has resulted in a significant decline in short-haul air travel demand in Europe. Given the airport-market pairs considered in our analysis, average air traffic on short-haul routes in Europe has declined by ~3 percent per year. This decline in traffic has resulted in a reduction of 580 thousand metric tonnes of CO_2 emission equivalents on an annual basis from reduced air travel (see Appendix A).

However, if one broadens the scope of analysis to explore trends within the air transportation *system* (versus simply between city pairs as is often done), it is clear that air travel demand in Europe has experienced steady growth over the past two decades, and along with it annual emissions associated with the transport sector. There are several factors to consider that have likely shaped this growth:

1) Globally, including in Europe and in the United States, demand for international air travel has grown more than short-haul markets, partly driven by economic growth in emerging economies.
2) Expansion of low-cost carriers in Europe has driven significant increases in medium, intra-EU travel.
3) Reduction of domestic air travel in Europe due to the introduction of high-speed rail has eased airport capacity constraints.

Many of Europe's major airports are severely congested and are unable to meet unconstrained passenger demand. Airport capacity is limited primarily by runway and taxiway infrastructure, where capacity measured by the number aircraft landings (or takeoffs) that can be accommodated, often referred to as "slots". The shift of domestic traffic from aviation to high-speed rail has opened up slots at these constrained airports – slots that can now be used to provide more medium- and long-haul transportation service. From the perspective of mobility and economic growth, these capacity shifts represent improved use of the intercity transportation system. However, from an environmental perspective, emissions savings in the aviation sector from short-haul traffic reductions are essentially negated when one accounts for intra-EU and international air traffic growth (see Figure 7.1).

Results of this analysis highlight challenges associated with broader transportation systems planning. There appear to be promising opportunities to mitigate the environmental impacts of short-haul, intercity travel, while simultaneously alleviating congested airports and airspace. However, absent of policy instruments to mitigate the environmental impacts of travel within medium- and long-haul markets, the environmental impacts of air travel are likely to grow at a steady pace.

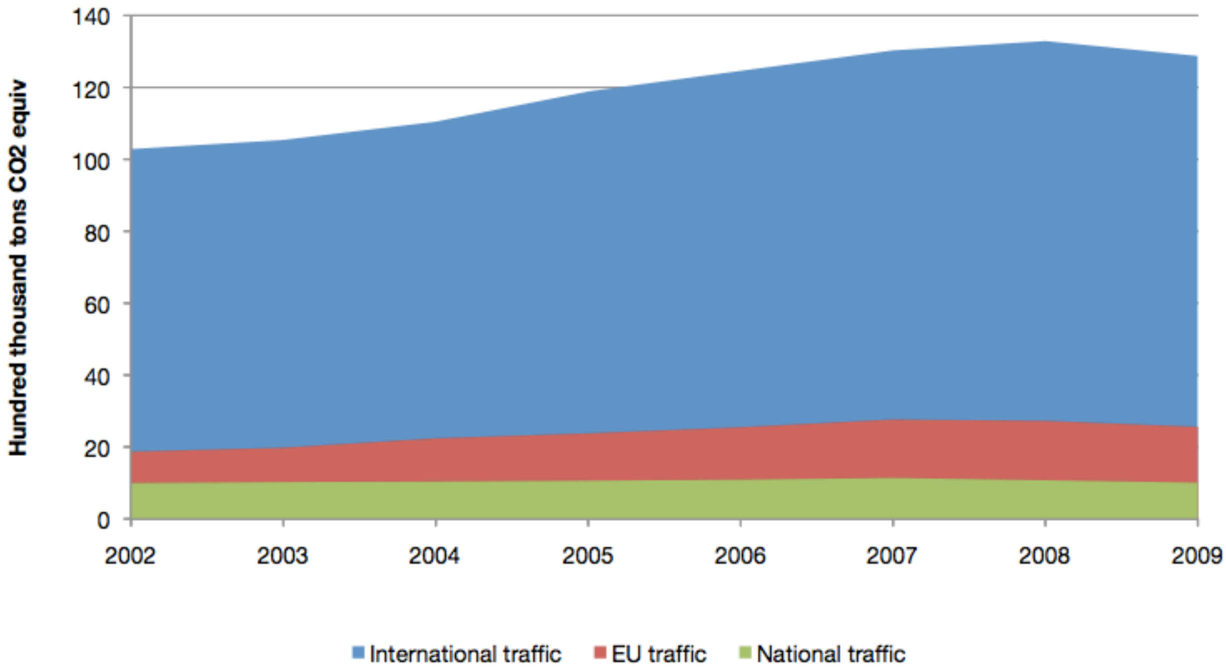

Figure 7.1 CO2 emissions of traffic from major European Airports

7.1.2. Balancing safety and the environment

Although there are significant differences between the United States and China in their approaches to energy and transportation planning, our analysis of passenger preferences between air and rail aims to enhance our understanding of traveler choice at a more fundamental level. Specifically, how do individuals prioritize various factors that influence their travel decisions? The primary factors that are typically utilized to forecast substitution between air and rail are travel time, price, frequency, and accessibility (along with demographics, e.g., income). Our analysis in China indicates that both safety and environmental considerations do influence travel choices; however, safety considerations are a higher priority for most consumers. Previous studies in the area of vehicle purchase present similar findings in different European countries (Koppel et al., 2008).

The key lesson for the United States from the China analysis presented in Chapter 6 is the importance that individuals place on safety when making transportation decisions. Along with price and fares, it is one of the top considerations that impact a travelers' mode choice. In the case of China, there was a significant change in attitude towards high-speed rail following the accident that occurred in July 2011, including among passengers who had previously chosen high-speed rail for their intercity travel. As plans to develop high-speed rail in the United States progress, it is critical to consider the high priority that consumers place on this factor when making their transportation choices.

7.2. CONSIDERATIONS FOR U.S. TRANSPORTATION AND CLIMATE POLICY

7.2.1. U.S. policy for high-speed rail development

Over the past 50 years, U.S. transportation funding has overwhelmingly been dedicated to highways and the air transportation system, accelerating decline in intercity rail passenger demand. Although there were a few efforts to explore the potential of U.S. high-speed rail after the introduction of the Japanese Shinkansen in 1964, there has been limited financial backing to support the introduction of advanced high-speed rail systems in the United States. In recent years, however, there has been renewed interest (and some substantial financial support) for high-speed rail development.

In 2008, the Passenger Rail Improvement and Investment Act (PRIIA) was signed into law, reauthorizing the National Railroad Passenger Corporation, better known as Amtrak, with \$2.6 billion a year through 2013. PRIIA authorized funds to support the only existing high-speed rail service in the United States (i.e. the Northeast Corridor) and laid the groundwork for improving intercity passenger rail service across the United States. In February 2009, the first substantial federal investment in high-speed rail was committed through the American Recovery and Reinvestment Act (ARRA) of 2009, authorizing \$8 billion to develop a U.S. high-speed rail intercity passenger system.

The ARRA required that the Federal Railroad Administration (FRA) develop a strategic plan for high-speed rail in the United States. Figure 7.2 illustrates the proposed corridors envisioned in April 2009. The strategic plan identified ten corridors as potential funding targets, as well as the existing Northeast Corridor. Through a competitive grant process, the FRA received applications from 34 states for over \$57 billion in funding requests in August and October 2009. In January 2010, 31 states and 13 corridors were announced to have received funding (see Table 7.1).

Figure 7.2 Proposed U.S. high-speed rail corridor map (FRA, 2009)

Table 7.1 Initial corridors awarded ARRA funds in 2010

Corridor	Grant received (in millions $)
Chicago Hub/Ohio Hub	2614
California	2250
Florida	1250
Southeast	620
Pacific Northwest	598
Other Corridors in NE	371
Northeast Corridor	112
South Central	4

(Source: FRA, High-Speed Rail Intercity Passenger Program, 2010)

A major challenge facing the development of U.S. high-speed rail has been ongoing criticism of proposed spending required to build these advanced transportation systems. Following the U.S. gubernatorial elections in November 2010, newly elected Republican governors of Ohio, Wisconsin, and Florida rejected federal high-speed rail funding that had been allocated to their states through the ARRA economic stimulus funds. Although the ARRA funding represents the largest federal investment in high-speed rail in the United States to date, the majority of corridors would require significant additional investment (e.g., through state bonds and private investors). The issue has become rather partisan, with Democrats largely in support of high-speed rail and most Republicans against its development.

In 2010, the 111th U.S. Congress allocated \$2.5 billion in the FY 2010 budget, which included major grants for California, Florida, and the Chicago hub. However, a proposal by Vice President Joe Biden in 2011 to build on the initial \$10.5 billion investment with an additional \$53 billion over the following six years was met with significant resistance. Since 2010, there have not been any additional federal investments in high-speed rail through the FY 2011 or FY 2012 budgets. In addition, there have been a handful of unsuccessful legislative attempts to rescind the initial federal funding committed in 2009 and 2010 (see H.R. 2811, H.R. 3143).

Although U.S. intercity passenger rail has recently received the largest commitments of funding in the past 50 years, significant sustained investment will be required in order to achieve the current FRA's vision to develop high-speed rail in the United States. The two corridors that are often regarded as having the most potential, California and the Northeast Corridor, will certainly require substantial federal funding in order to be successfully completed. The current status of these corridors will be discussed further in Section 7.3.

7.2.2. U.S. climate and energy policy

U.S. climate and energy policy is relevant to the discussion of high-speed rail and aviation infrastructure planning because, as illustrated in Chapter 5, such policy could have a significant influence on the environmental footprint of air and rail systems. In this section we discuss recent climate and energy policies that have been considered in the United States and their current status.

With the American Clean Energy and Security Act (ACES), also known as the Waxman-Markey Bill (H.R. 2454), the 111th U.S. Congress considered the establishment of a cap-and-trade system limiting national greenhouse gas emissions. Although the House of Representatives approved the bill in June 2009, it failed to receive Senate approval. This proposed bill, if passed, would have arguably been the most significant step in the U.S. towards establishing a cap on greenhouse gas emissions; however, given the economic downturn of 2008 and subsequent political shifts in the 112th U.S. Congress, the possibility that any major U.S. climate legislation will be approved in the near future is regarded as quite unlikely.

Alternative policy measures focused on energy have gained more traction in the United States, at both the state and federal level. The Energy Independence and Security Act of 2007 (Pub.L. 110-140) was passed by the 110th U.S. Congress, calling for improved automobile fuel economy, development of biofuels, and energy efficiency in buildings. More recently, regulations to mandate increased production of energy from renewable or "clean" energy sources have been passed at the state level, and are currently being considered at the federal level.

The Clean Energy Standard Act of 2012 (S.2146), introduced in March 2012, is currently under consideration in the 112th U.S. Congress. If passed, this federal clean energy standard (CES) would mandate that the largest utilities in the United States produce a certain percentage of their electricity from clean energy sources starting in 2015. As compared with a *renewable* energy standard, the CES is a more flexible framework, allowing utilities to include a wider variety of sources for "clean" electricity production (e.g., natural gas and coal with carbon capture and storage). Renewable energy standards (RES), also commonly referred to as renewable portfolio standards (RPS), are policies that require utilities to produce a certain minimum share of their electricity production from designated renewable sources. In the case of an RES, these sources typically include wind, solar, geothermal, biomass, and some types of hydroelectricity. As of January 2012, 30 states and the District of Columbia had established an enforceable RPS or other mandated renewable energy policy. Although several RPS proposals have been considered at the federal level, political analysts regard the approval of a clean energy standard more likely in the near future.

As illustrated by the study presented in Chapter 5, the implications of the above climate or energy policies on high-speed rail emissions are significant. Based on analysis of recent and current policies, it is certain that U.S. electricity generation will become cleaner, and secondly, that there is likely to be variation in the carbon intensity of electricity production from region to region.

7.3. CALIFORNIA AND THE NORTHEAST CORRIDOR

7.3.1. California

The development of a high-speed rail system to connect northern and southern California has been under consideration for two decades as part of long-range transportation plans. The first large investment in the rail system was approved by voters through Proposition 1A in November 2008, which authorized $9.95 billion in bonds for the project. In 2009, the state was awarded an additional $2.25 billion in federal funds through the American Recovery and Reinvestment Act described in Section 7.2.1. In this section, we will provide an overview of the current status of the project, with a focus on identifying the key policy issues and stakeholders.

The proposed California system would connect San Francisco and Los Angeles with 432 miles of dedicated high-speed trail passenger service. Secondary phases of the project would add extensions to Sacramento (in the north) and possibly San Diego (in the south). Figure 7.3 illustrates the proposed route and stations.

Figure 7.3 Proposed California high-speed rail route and stations (source: Metropolitan Transportation Commission, 2010).

Similar to concerns at the federal level, the primary issue of controversy surrounding the California project is its budget. The California High-Speed Rail Authority (CHSRA) originally estimated that the core San Francisco to Anaheim segment would cost $35.7 billion (in 2009 USD). However, a new business plan released in November 2011 projected a new figure of $65.4 billion (in 2010 USD), or $98.5 billion after adjusting for inflation. New board members appointed by California Governor Brown in August 2011 defended the plan as more realistic. However, the updated business plan added to opponents' existing concerns about the project's costs. After leadership changes at the California High-Speed Rail Authority in January 2012, the CHSRA released another updated plan in April 2012 that estimated the costs to be $68 billion, $30 billion less than estimated in November 2011. The primary cost savings were the result of a strategy to make better use of existing commuter-rail lines in urban areas, rather than build entirely new track for the high-speed rail system. In Table 7.2, a summary of key stakeholders, their interests and views in the development of high-speed rail is presented.

Table 7.2 Overview of key stakeholders in California high-speed rail development

Stakeholder	**Stakeholder description, interests, and views**
California High-Speed Rail Authority (CHSRA). State agency established in 1996 by the California High-Speed Rail Act (S.B. 1420).	• The agency's primary objective is to develop and implement high-speed intercity passenger rail in the state of California. • As is often the case with such agencies, the initial business plan estimating the costs and benefits may have been overly optimistic (e.g., underestimating the costs and overestimating the ridership). • New leadership of the CHSRA appointed in August 2011 and January 2012 appear to be focused on ensuring that future estimates are as realistic as possible.
California State Legislature. Consists of the California State Assembly (80 members) and California State Senate (40 members).	• Composition of State Assembly: 52 (D), 27 (R), 1 (I) from 2010-2012. Composition of State Senate: 25 (D), 15 (R). • The state of California has had a budget crisis since 2008, which has been one of the primary issues facing the State Legislature from 2008 through today. • Support for and against high-speed rail is generally split along party lines, with Democrats largely in support of the project, and Republications against.
Office of Governor. Currently Edmund Gerald "Jerry" Brown.	• Governor Jerry Brown (D) has been a very outspoken advocate of the California high-speed rail project. • His predecessor, Arnold Schwarzenegger (R), was also a strong supporter of the project.

California Senators and Congressmen	• At the federal level, support for and against high-speed rail is also split along party lines (i.e. Democrats supporting, Republicans opposing). • Democratic members of the U.S. Senate and House from California have been involved in federal legislation to either increase or ensure funding for high-speed rail development. • Republican members of the U.S. House of Representatives have made legislative attempt to rescind the federal funding allocated to the state of California (H.R. 2811, H.R. 3143).
Transportation planning agencies	• Until recently, there had been somewhat limited or strained interaction between the CHSRA and the California Metropolitan Planning Organizations (MPOs) and Regional Transportation Planning Agencies (RTPAs). Some viewed the high-speed rail system as a separate, more costly system that might detract support from local commuter rail. • The new leadership at the CHSRA has made an effort to build more strategic partnerships with these agencies. Memorandums of understanding have been signed to establish working relationships and funding from the CHSRA to upgrade local urban rail systems.
Communities affected by construction	• As is common in transportation infrastructure development projects, some of the communities that are located along the California high-speed rail route have objected to its construction. • The cities of Palo Alto, Menlo Park, and Atherton (in the Penninsula) have sued the CHSRA, alleging that its ridership and revenue forecasts were flawed. They have also challenged the project on the basis of the Environmental Impact Review (EIR).
General citizens	• General public support for and against the project is roughly 50-50. • Based on a survey conducted in March 2012 by the Public Policy Institute of California, 51 percent of adults indicated that they support the rail project. • However, 53 percent of likely voters indicated that they would oppose the rail project when told it would cost $100 billion over 20 years.
Environmental advocacy groups	• When the project was first initiated, there was general support among environmental advocacy groups due to the likely environmental benefits gained by developing high-speed rail. • However, in the past two years, support from environmental advocacy groups has diminished. There are two key issues: 1) proposed plans to ease the Environmental Impact Review (EIR) process; 2) the potential for the high-speed rail project to utilize funds from California's cap-and-trade program to be launched on January 1, 2013. • Given the significant costs associated with the high-speed rail project, environmental groups are concerned that there would be limited funding remaining from the cap-and-trade program for other environmental issues/programs if the funds are utilized for rail.

In order for the project to move forward, the California State Legislature needed to approve the selling of state bonds to raise a portion of the $9.95 billion that voters authorized in 2008. On July 6, 2012, the California State Legislature voted to approve the bond sale (by one vote), and on July 18, 2012, California Governor Jerry Brown signed the legislation authorizing $5.8 billion to start construction of the high-speed rail line. The initial funds include $2.6 billion in state rail bonds and $3.2 in federal aid. Although the approval of funds is one step towards construction of the California high-speed rail system, there is growing opposition to the project in the Central Valley, where the California High-Speed Rail Authority plans to break ground on the project in September 2012.

7.3.2. The Northeast Corridor

The Northeast Corridor is the only existing high-speed rail service in the United States, connecting cities between Boston, Massachusetts and Washington, D.C. It was originally constructed between 1830 and 1917; however, significant upgrades occurred through the Northeast Corridor Improvement Project from 1976 to 1980. There are approximately 720,000 passengers that ride some part of the corridor on a daily basis; it is the most successful rail corridor in the United States in terms of passengers and load factors.

Amtrak, which owns the majority of the Northeast Corridor, prepared a "State of Good Repair" (SOGR) plan in April 2009, in response to the Passenger Rail Investment and Improvement Act of 2008. The initial plan estimated that $38 billion between 2009 and 2030 would be required for SOGR safety, mandates, capacity and trip time improvements. Implementation of this plan would result in limited travel time improvements for the Boston-New York route (currently 3h 25m) and New York-Washington, D.C. route (currently 2h 48m). In 2010, Amtrak released a more ambitious plan, "A vision for High-Speed Rail on the Northeast corridor," that could reduce travel times for the Boston-New York trip to 84 minutes, and the New York-Washington, D.C. trip to 96 minutes. The estimated cost for Amrak's ambitious NextGen high-speed rail system is $117 billion (in 2010 dollars).

The Northeast Corridor (NEC) was awarded $450 million in federal funding in August 2011, as well as $295 million to New York for improvements on the Harold Interlocking rail junction, which would also benefit service on the Northeast Corridor. The NEC FUTURE planning effort, established by the FRA in coordination with the NEC Commission, was formed in February 2012 to define, evaluate, and prioritize future investments in the Northeast Corridor. Critical next steps in the planning process include: 1) a Service Development Plan (SDP) that outlines the costs and benefits for proposed rail alternatives; and 2) an Environmental Impact Statement (EIS) that addresses the environmental effects for the corridor.

One of the unique challenges of developing advanced high-speed rail service in the Northeast Corridor is the large number of stakeholders associated with the project, across several states. In addition to Amtrak, parts of the rail line are owned or operated on by commuter rail and freight rail companies. However, that said, the Northeast Corridor has fairly broad bipartisan and local support for infrastructure improvements, due largely to its proven record of attracting rail passenger ridership. For example, the current Republican Chairman of the influential House Transportation and Infrastructure Committee, John Mica, although critical of all other proposed high-speed rail corridor projects, has supported improvements to the Northeast Corridor. In April 2012, the National High Performance Passenger Rail Transportation-Oriented Development Act (H.R. 4361) was also proposed by a Republican Congressman; it would encourage dedicated revenue sources for urban and regional rail corridor development, including the Northeast Corridor. Although there have been many criticisms of the nationwide high-speed rail intercity passenger program, the Northeast Corridor has experienced relatively strong support at the federal level as well as within the northeast states.

7.4. RECOMMENDATIONS FOR POLICY AND PRACTICE

It is clear from the analysis presented in this dissertation that the introduction of high-speed rail passenger service would reduce the climate impacts of travel in short-haul intercity markets, and secondly, that these benefits are underestimated by current cost-benefit analyses, as discussed in Chapter 5. In this chapter, our discussion has primarily focused on the two corridors that are more likely to proceed with development in the United States, California and the Northeast Corridor. However, both projects face potential obstacles for moving forward. In this section, we present specific recommendations for policy and planning to establish high-speed rail for intercity passenger travel in the United States.

Sustain federal funding for high-speed rail

Although this is a significant challenge politically, sustained funding for high-speed rail at the federal level is critical for ensuring that other stakeholders are willing to move forward with planning and investment in high-speed rail infrastructure. Historically, no other country has successfully established high-speed rail service without significant political and financial backing from the national government. Since the $8 billion in funding through the American Recovery and Reinvestment Act of 2009 (ARRA) and the $2.5 billion allocated through the FY2010 budget, additional proposals for sustained investment have not passed.

Prioritize development of corridors with greater likelihood of success

The initial investment of $8 billion through the ARRA was divided among 13 proposed corridors in the United States, many of which, in the near term, are unlikely to be developed as international-standard high-speed rail intercity corridors. The U.S. Government Accountability Office released a study in 2009 that reviewed the historic costs of high-speed rail systems around the world, which ranged from $39 to $153 million dollars (2012$) per train mile. The California corridor alone is projected to cost $65.4 billion (i.e. within the range of historic costs elsewhere). Although beneficial to the project, the $2.25 billion that was awarded to California through ARRA falls far below the likely level of federal support to ensure the project is successful. Given opposition at the federal level to many of the proposed corridors in the United States, it would be more beneficial to utilize the limited funds available for high-speed rail development on priority corridors that have substantial local support, politically and financially (e.g., California and the Northeast Corridor).

Enable international cooperation in high-speed rail development

Outside of Japan and Europe, where innovation for high-speed rail technologies began, the majority of nations that have developed high-speed rail have relied on international partnerships and technology transfer to successfully build their own systems. Although there is interest among international firms in investing in U.S. high-speed rail corridors, limited levels of federal support, financially and politically, threaten these potential partnerships. In addition, legislation focused on protecting American jobs complicate the ability for the U.S. to develop high-speed rail systems through these partnerships. Although they were not ultimately passed, the Make it in America Act (H.R. 613) and Rebuild America Jobs Act (S.1769) both sought to impose such regulations. The development of high-speed rail is likely to revitalize jobs in the U.S.; however, the projected long-term revitalization does not stem from an increase in manufacturing. Based on experiences abroad, the majority of new job creation is likely to result from development around new high-speed rail stations, and broader regional productivity.

Develop long-range plans for regional development and economic growth

Developing long-range plans and improved estimates of economic growth that is likely to occur as a result of high-speed rail development would improve political support for high-speed rail. Literature based on recent international experiences with high-speed rail can inform planning for maximizing the potential regional benefits of HSR service, as well as developing forecasts for land use, population redistribution, job creation, and economic growth.

Ensure independent development of forecasts

Initial ridership (and thus revenue) forecasts for the proposed high-speed rail system in California have been the subject of much criticism. After communities filed lawsuits citing the forecasts as flawed, the forecasts and models were evaluated by an independent academic research institution. The independent researchers indicated that there were significant flaws in the forecasts developed by the consulting firm that the California High-Speed Rail Authority had hired. The controversy surrounding this particular case has resulted in ongoing skepticism about the budget, benefits, and ridership estimates among policymakers. Ensuring independent review and transparency of forecasts of the benefits and costs associated with such systems is essential to enable policymakers to make informed decisions about high-speed rail and other transportation infrastructure investments.

Create incentives for coordination between rail agencies

Building coordination between emerging high-speed rail agencies and local rail agencies will lay the groundwork for long-term success of high-speed rail systems. In the case of the Northeast Corridor and northern California, upgrading existing commuter rail systems will result in modest travel time and capacity improvements that will benefit high-speed rail systems that are likely to share track. Based on the European and Asian experiences with high-speed rail, a second key motivation to upgrade local transit systems in the U.S. is that their performance is likely to affect the high-speed rail ridership here. Greater accessibility to high-speed rail stations in Europe and Asia (as compared with airports, which are typically located further from the city) is a factor that shapes their high rail market shares for intercity travel. Without reliable, accessible "feeder" rail lines in the United States, high-speed rail systems may experience limited ridership levels as compared with their European counterparts.

7.5. CONCLUSIONS

It is clear that the development of high-speed rail intercity passenger rail offers one avenue for the United States to reduce its reliance on liquid fuels and limit the climate impacts of the transportation sector. This is particularly true when one considers the long timeframe over which this infrastructure will be utilized, and the cleaner sources of energy that will almost certainly power these systems. Although the upfront costs to develop technologically-advanced high-speed rail service for intercity travel in the United States are significant, these transportation investments are critical for meeting continued travel demand of growing urban populations and enabling regional economic growth. This chapter outlined the practical implications of our analysis, as well as policy recommendations related to high-speed rail development in the United States. In the next chapter, we identify the research contributions of this thesis and opportunities for future work.

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Chapter 8: Conclusions

Continued future growth for air transportation presents a significant challenge for addressing the growing climate impacts of the transportation sector, in the United States and globally. High-speed rail might serve as an effective substitute for intercity travel, potential resulting in significant energy and climate savings. In this dissertation, we aimed to build an improved understanding of demand for high-speed rail and air travel, and their resulting energy and climate impacts. We explored this issue from three perspectives: 1) the historical experience with high-speed rail and its impacts on air travel; 2) current proposals for high-speed rail in the United States and their impacts on demand and the environment; and 3) alternative factors that influence individuals' choices between high-speed rail and air transportation. In this chapter, we present a summary of key findings and contributions to the literature.

8.1. MODELING DEMAND FOR AVIATION AND HIGH-SPEED RAIL

8.1.1. The impact of high-speed rail and low-cost air carriers

It is clear that the introduction of high-speed rail has a significant impact on short-haul, intercity travel. Previous studies have suggested that there is a time threshold (e.g., 3 hours) under which high-speed rail gains the majority of market share. However, few studies have examined variation of the impact of high-speed rail on short-haul air travel, nor the broader system-wide trends in European air transportation. The first contribution of this dissertation is the econometric analysis presented in Chapter 3, where we find that, in addition to GDP and fares, the introduction of high-speed rail has had a significant impact on short-haul air travel demand. Furthermore, we found the impact of high-speed rail on reducing air traffic has been more significant where there is increased density.

The second contribution from Chapter 3 is the broader econometric analysis of air travel demand in Europe, which shows that although high-speed rail has had a significant influence reducing short-haul air travel, the introduction of low-cost air carriers has had a more significant influence on *increasing* air travel demand in Europe. From an environmental perspective, air travel trends over the past two decades in Europe has resulted in a significant net rise in total CO_2 emissions from air travel.

The analysis from Chapter 3 contributes to a large body of literature on air travel demand modeling for origin-destination and airport-level traffic.

8.1.2. Cooperation versus competition

The third contribution from our historical analysis of high-speed rail and air travel in Europe is our analysis of air-rail connectivity and its influence on demand. Although the basic introduction of high-speed rail service reduces domestic air traffic, the potential for air-rail connectivity to further mitigate anticipated airport capacity constraints has been suggested in many parts of the world. In Chapter 4 we explored experiences with air-rail connectivity in Europe, examining how airline/ rail operator/ airport partnerships were formed, and how air-rail complementarity ultimately impacts demand for these systems.

At both Paris Charles de Gaulle and Frankfurt airports, air-rail connectivity has resulted in a more significant reduction in domestic air traffic than other airports in cities that have high-speed rail stations (only in the city center). This reduction in domestic air traffic is even more significant in the case of Frankfurt airport, where flight and rail timetables have been coordinated to enable smoother transfers for air-rail passengers. A critical success factor for air-rail connectivity is the attractiveness of the airport itself for passengers. Those air-rail connections that have been successful in attracting large numbers of passengers are ones based at large, international hub airports (e.g., CDG and FRA) that serve a wide variety of destinations. Air-rail connections to non-hub airports (e.g., Paris Orly) have attracted far fewer passengers, resulting in limited capacity shifts from air to rail for domestic flights.

8.2. INTEGRATED ASSESSMENT OF CLIMATE POLICY AND TRANSPORTATION INVESTMENT

Previous transportation and environmental analysis has focused on examining tradeoffs between aviation and high-speed rail absent of climate and energy policy. A main contribution of this dissertation is the development of bottom-up, regional model of high-speed rail and air travel demand for the United States and its integration with a top-down model of the economy. The coupling of these two models enables us to perform a unique analysis of the environmental impacts of high-speed rail and air transportation under climate and energy policy on a regional basis.

The bottom-up model presented in Chapter 5 provides a detailed, regional approach to examine demand and the environmental impacts of intercity travel that could be expanded to incorporate additional modes, as well as applied to alternative regions. The disaggregation of specific origin-destination city pairs enables a more refined analysis of the potential impact of high-speed rail on the energy and climate impacts of intercity travel. The integration of this bottom-up, regional model with a top-down, regional model allows one to examine the regional environmental benefits of introduction high-speed rail under policy scenarios. Previous research in this area has often relied on an aggregate approach to model travel demand as well as aggregate approach to examine energy and climate impacts. Through the development of this model, we are able to explore the regional differences in both demand and environmental impacts of high-speed rail and air transportation.

8.3. PASSENGER PREFERENCES FOR AIR AND RAIL TRANSPORT

In Chapter 6, we extend our examination of high-speed rail and air transportation demand to explore the potential influence of safety and environment on individual passenger preferences. The majority of current policies focused on high-speed rail and air transportation are predicated on the assumption that passengers make travel decisions based primarily on income, travel time, and price. However, previous studies in the context of urban transportation modeling suggest that attitudes towards environment and safety can be as useful in predicting mode choice.

The development and implementation of an intercept survey on the Beijing-Shanghai corridor represents one of very few attempts by researchers to examine intercity mode choice between high-speed rail and air transportation in China. Previous studies of the potential influence of attitudes on travel decision-making have focused on the urban transportation context, which typically involves shorter distances and habitual behavior. In this dissertation, we build on this body of work by extending these survey methods to an intercity transportation context in China.

The results of this study suggest that individuals who opt to travel by aviation are less price sensitive, more concerned about safety (in the context of China), and less concerned about environmental issues. In addition, although not part of the original research design, pre- and post-high-speed rail accident data collected through this study presents evidence that a substantial number (10%) of high-speed rail passengers would shift their preferred mode choice following an accident.

The survey method and results presented in this study builds on existing work in the area of urban transportation modeling; results presented here indicate that environmental and safety attitudes have potentially significant impacts on traveler mode choice and demand. Implications for policy and practice are as follows: 1) interventions designed to shift travelers from energy-intensive modes to less-energy intensive modes should focus on other factors in addition to price and travel time (e.g., presenting specific information to travelers about the energy intensity of air travel as compared with intercity trail might result in greater substitution of rail for air); 2) understanding current attitudes towards transportation alternatives and factors such as safety and environment might inform development of future forecasts of demand.

8.4. DISCUSSION AND FUTURE WORK

This thesis has explored high-speed rail, aviation demand, and their environmental implications by examining historic, current, and potential systems in Europe, China, and the United States. Although high-speed travel currently represents a smaller portion of total transportation demand (and thus climate impacts), there is evidence to suggest that its share of total travel demand will grow over time. Furthermore, there are fewer technological alternatives to reduce the energy intensity and climate impacts of air transportation. In order to address the future climate implications of this transportation sector, this thesis has aimed to improved our understanding of demand, including passenger preferences, and the potential environmental impacts of these systems over the long timeframe that they will be utilized.

Future work could investigate how the introduction of high-speed rail influences aviation demand as well as automobile use, which comprises a significant portion of travel demand in the United States. Similar to the analysis presented in Chapter 5, an analysis of intercity demand that examines personal vehicle use should also consider how the personal vehicle fleet, its efficiency, and its energy use requirements might change under climate and energy policies.

A second direction to extend this research is to further examine additional factors that may influence individual mode choice for intercity transportation (i.e., in addition to price, travel time, and basic demographics). A limited number of studies examine the influence that safety and environmental attitudes have on transportation mode choice; however, there is some evidence that these attitudes, along with neighborhood choice, may play a significant role in travel decisions. Further research in this area would lead to a better understanding of travel behavior, as well as improved travel demand models for transportation planning and policy.

This thesis has contributed to an improved understanding of how high-speed rail influences aviation system demand, and the climate and energy implications of these systems over time. It is our hope that the results will inform future research and policy decisions that can lead to a more sustainable transportation future.

Appendix A. The climate impacts of European air traffic.

One of the key challenges facing the aviation community is limiting the environmental impact of air transportation. Gaining an understanding of how changing air traffic patterns have impacted CO_2 emissions from the aviation sector is a useful step towards developing strategies to reduce emissions under the EU Emissions Trading Scheme (EU-ETS). Passenger demand and traffic are the key drivers of CO_2 emissions for air transportation, given some difficulties associated with technological change in the aviation industry (due to the energy density requirements for aviation as well as slow turnover of the aircraft fleet). In this section, we examine the CO_2 emissions of short-haul air traffic and major airports within the European Union, based the air traffic trends in Chapter 3.

CO_2 Emissions of Major Airports in Europe

To estimate CO_2 emissions at the airport level, we assume an average distance of 463 km for all domestic flights and of 1108 km for all intra-EU flights based on DEFRA averages (DEFRA, 2009). Due largely to the disproportionate amount of fuel burn associated with takeoff and landing, as well as representative aircraft associated with short-haul versus medium- and long-haul travel, a separate equation is utilized to estimate CO_2 emission equivalents of intra-EU air traffic. The CO_2 emission equivalents, CE, of intra-EU, medium-haul flights are given by:

$$CE = P \times D \times 1.09 \times 0.09924 \text{ kg} \tag{A.1}$$

where P is the total passengers carried and D is the distance of the flight. Equation A.1. is used estimate emissions associated with domestic travel.

The results of our comparison of 2002 and 2009 airport-based emissions are presented in Figure 7.1 in Chapter 7. While the total annual CO_2 emission equivalents have declined or experienced limited growth for domestic flights, they have increased (and in some cases quite substantially) for intra-EU, medium-haul flights. Furthermore, because the distances for intra-EU flights are generally longer than the distances for domestic flights, the total CO_2 emissions of these flights are more substantial.

This analysis illustrates some of the challenges associated with reducing the environmental impacts of air transportation in Europe. Although high-speed rail has enabled a reduction of emissions associated with short-haul air traffic on many routes during the past decade, the growth of intra-EU air traffic has resulted in a significant net increase of CO_2 emissions from the aviation sector in Europe. The most recent forecast by EUROCONTROL estimates that European air traffic will grow at an average rate of 2.8 percent in its 'most likely' scenario (EUROCONTROL, 2010). Given continued growth, if much of the air traffic increase occurs in longer-haul markets, reducing CO_2 emissions will in the aviation sector will become increasingly difficult.

Appendix A References

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Appendix B. Developing an integrated model of high-speed rail, aviation, and climate policy: Methods, data, and alternative scenarios

This section provides additional information on the integrated modeling framework developed to examine the impacts of transportation and climate policy scenarios on the high-speed transport sector. This appendix further describes the data and methods utilized to develop the bottom-up technical model outlined in Chapter 5, as well as alternative policy scenarios and detailed regional results from the economy-wide CGE model utilized to conduct the analysis.

B.1. Origin-destination demand for California and the Northeast Corridor

As described in Chapter 5, the bottom-up technical model of aviation and high-speed rail incorporates demand origin-destination forecasts of airport market-pairs in California and the Northeast Corridor. Table B.1 and Table B.2 list the origin-destination airport-market pairs included in the California and Northeast Corridor analysis, respectively.

Air traffic forecasts utilized in the analysis of the California corridor presented in Chapter 5 are based on the most recent forecasts reported by the Bay Area Regional Airport System Planning Analysis (RASPA) 2011 Update (SH&E, 2011). Airport market-pair shares for the RASPA were determined through the process described in a technical memorandum prepared for the transportation planning agencies (Gosling, 2010). In the RASPA analysis, air traffic growth rates for airport market-pairs are estimated for the years 2020 and 2035. The average growth rate between 2020 and 2035 is extrapolated to determine demand forecasts for 2050 that are utilized in the analysis presented in Chapter 5.

Regional transportation agency forecasts are not available for the airport market-pairs considered in the Northeast Corridor. In order to determine demand in 2035 and 2050, we analyze data for the airport market-pairs listed in Table B.2 from BTS, Form 41, T-100 data for the previous 20 years (BTS, 2010). Total annual air traffic tends to fluctuate with the state of the economy. Calculating the average growth rate for these corridors over the past 20 years, our analysis assumes 1.5% annual growth for all Northeast Corridor airport market-pairs.

Table B.1 Origin-destination airport-market pairs included in California analysis

Market Pair	Origin	Destination	Distance
Burbank - Oakland	BUR	OAK	325
Burbank - San Francisco	BUR	SFO	326
Burbank - San Jose	BUR	SJC	297
Burbank - Sacramento	BUR	SMF	358
Los Angeles - Oakland	LAX	OAK	337
Los Angeles - San Francisco	LAX	SFO	337
Los Angeles - San Jose	LAX	SJC	308
Los Angeles - Sacramento	LAX	SMF	373
Long Beach - Oakland	LGB	OAK	353
Long Beach - San Francisco	LGB	SFO	354
Long Beach - San Jose	LGB	SJC	324
Long Beach - Sacramento	LGB	SMF	387
LA/ Ontario - Oakland	ONT	OAK	362
LA/ Ontario - San Francisco	ONT	SFO	363
LA/ Ontario - San Jose	ONT	SJC	334
LA/ Ontario - Sacramento	ONT	SMF	390
Palm Springs - San Francisco	PSP	SFO	421
Palm Springs - San Jose	PSP	SJC	390
Palm Springs - Sacramento	PSP	SMF	440
San Diego - Oakland	SAN	OAK	446
San Diego - San Francisco	SAN	SFO	447
San Diego - San Jose	SAN	SJC	418
San Diego - Sacramento	SAN	SMF	480
Orange County - Oakland	SNA	OAK	371
Orange County - San Francisco	SNA	SFO	372
Orange County - San Jose	SNA	SJC	342
Orange County - Sacramento	SNA	SMF	404

Table B.2 Origin-destination airport-market pairs included in Northeast Corridor analysis

	Origin	Destination	Distance
Boston - Baltimore	BOS	BWI	370
Boston - Washington DC (DCA)	BOS	DCA	399
Boston - Newark	BOS	EWR	200
Boston - Washington DC (IAD)	BOS	IAD	413
Boston - New York (JFK)	BOS	JFK	187
Boston - New York (LGA)	BOS	LGA	185
Boston - Philadelphia	BOS	PHL	280
Newark - Baltimore	EWR	BWI	169
Newark - Washington DC (DCA)	EWR	DCA	199
Newark - Washington DC (IAD)	EWR	IAD	213
Newark - Philadelphia	EWR	PHL	81
New York (JFK) - Baltimore	JFK	BWI	184
New York (JFK) - Washington DC (DCA)	JFK	DCA	213
New York (JFK) - Washington DC (IAD)	JFK	IAD	228
New York (JFK) - Philadelphia	JFK	PHL	94
New York (LGA) - Baltimore	LGA	BWI	185
New York (LGA) - Washington DC (DCA)	LGA	DCA	214
New York (LGA) - Washington DC (IAD)	LGA	IAD	229
New York (LGA) - Philadelphia	LGA	PHL	96
Philadelphia - Baltimore	PHL	BWI	90
Philadelphia - Washington DC (DCA)	PHL	DCA	119
Philadelphia - Washington DC (IAD)	PHL	IAD	134
PVD - Baltimore	PVD	BWI	328
PVD - Washington DC (DCA)	PVD	DCA	357
PVD - Newark	PVD	EWR	160
PVD - Washington DC (IAD)	PVD	IAD	372
PVD - New York (JFK)	PVD	JFK	144
PVD - New York (LGA)	PVD	LGA	143
PVD - Philadelphia	PVD	PHL	238

B.2. High-speed rail diversion rates

The bottom-up technical model of aviation and high-speed rail emissions includes three transportation policy scenarios: 1) a reference (no-build case), 2) moderately competitive high-speed rail; and 3) very competitive high-speed rail. For the latter two scenarios, the model estimates future high-speed rail passenger demand and air travel demand based on substitution forecasts reported by the California High-Speed Rail Authority. The moderately competitive high-speed rail scenario is based on the assumption that HSR fares are 83% of airfares, and the very competitive high-speed rail scenario is based on the assumption that HSR fares are 50% of airfares. Also implicit in the mode choice forecasts prepared for the California High Speed Rail Authority are various level-of-service variables that were determined to have the great influence on mode choice, including primarily travel time, price, and access/ egress times, as well as sociodemographic data of the forecasted regional populations. Table B.3 presents the forecasted substitution rates that are incorporated into our bottom-up model of aviation and high-speed rail. Forecasted substitution rates for the 83% fare scenario are available in Table 5.3 of Chapter 5.

Table B.3 Assumed diversion to high-speed rail by airport-market pair in California: HSR fares 50% of airfares (source: Gosling, 2010)

		2035		
Market		**OAK**	**SFO**	**SJC**
Los Angeles	**LAX**	56.6%	72.9%	72.9%
Orange County	**SNA**	45.8%	61.1%	61.1%
Burbank	**BUR**	56.2%	74.9%	74.9%
Ontario	**ONT**	47.3%	63.0%	63.0%
Long Beach	**LGB**	46.0%	63.0%	63.0%
Palm Springs	**PSP**	26.1%	34.8%	34.8%
San Diego	**SAN**	27.5%	36.7%	36.7%

Appendix B References

Bureau of Transportation Statistics (BTS). (2010). Air Carrier Statistics and Financial Reports, Aviation Data Library, Table T‐100. U.S. Department of Transportation, BTS, Research and Innovation Technology Administration, Washington, DC. Retrieved June 1, 2012 from http://www.transtats.bts.gov/databases.asp?Mode_ID=1

Gosling, G. (2010). "High-Speed Rail Scenario Passenger Diversion." Analysis prepared for the Bay Area Regional Airport System Plan Analysis Update, Aviation System Consulting, LLC, Berkeley, California.

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Appendix C. Intercept survey design

This appendix provides additional detail on the intercept survey conducted in Beijing and Shanghai at airports and rail stations for the research presented in Chapter 6. The following sections were included in the 8-page survey completed by passengers either traveling to Shanghai (at Beijing stations and airports) or to Beijing (at Shanghai stations and airports).

C.1. Questions about passengers' current trip.

- Destination
- Date
- Train number (or flight number)
- Departure time
- Type of ticket purchased
- Who paid for the trip
- How many times the passenger made a trip between these cities last year.
- Trip purpose
- Number in travel party
- Length of current trip
- Luggage

C.2 Access/ egress of current and hypothetical trip

- Access and egress mode
- Access and egress times
- Access and egress costs
- Amount of time prior to train/ flight that passenger arrived at station/ airport
- If the passenger were to take the alternative mode from what they are using for their current trip (flight or rail), how would they get to/ from airport/ rail station, etc?

C.3 Demographic information

- Gender
- Age
- City of residence
- Highest level of education completed
- Average monthly income
- Profession

C.4 Hypothetical mode choice

In the survey, *after* questions about the current trip and demographic data, and *before* attitudinal questions, passengers' were asked to complete four hypothetical mode choice questions as shown in Table C.1. The frequency, travel time, on-time percentage, and one-way fare were varied based on a fractional-factorial design.

Table C.1 Hypothetical mode choice

	Conventional Rail	**High-Speed Rail (250 km/h)**	**High-Speed Rail (300 km/h)**	**Air**
	Travel to and from the stations is the same as you described earlier in the survey	Travel to and from the stations is the same as you described earlier in the survey	Travel to and from the stations is the same as you described earlier in the survey	Travel to and from the airports is the same as you described earlier in the survey
	There is a train every **X11** minutes	There is a train every **X12** minutes	There is a train every **X13** minutes	There is a flight every **X14** minutes
	The scheduled travel time is: **X21** hr and min	The scheduled travel time is: **X22** hr and min	The scheduled travel time is: **X23** hr and min	The scheduled travel time is: **X24** hr and min
	X31% of trains arrive within 10 minutes of schedule	**X32**% of trains arrive within 10 minutes of schedule	**X33**% of trains arrive within 10 minutes of schedule	**X34**% of flights arrive within 10 minutes of schedule
	The one-way fare is: **X41¥**	The one-way fare is: **X42¥**	The one-way fare is: **X43¥**	The one-way fare is: **X44¥**
Please select only ***one*** option between conventional rail, high-speed rail, and air.	❑ Travel by conventional rail.	❑ Travel by high-speed rail (250).	❑ Travel by high-speed rail (300).	❑ Travel by air.