Regional Catalytic Economic Impacts and Noise-Damage Costs of Aviation Growth

by

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Abstract

There is growing recognition that transportation or infrastructure improvements can have longer-term *catalytic* impacts economic productivity, which are in addition to the direct, indirect, or induced household spending impacts. These economic catalytic effects are fundamentally different from traditional measures of the impacts from spending in the air transport sector. In contrast to the generally positive regional economic benefits of aviation, however, aircraft noise has emerged as a major negative externality of the air transportation system and continues to be a controversial issue in communities around airports.

In this analysis, I develop a methodology to highlight interrelationships between airport flight operations and noise impacts on surrounding communities, and between air transport industry and regional economic growth. I calculate the noise-damage costs under different airport growth scenarios at London Heathrow and the East Midlands airport, and then apply an econometric input-output model to estimate the regional catalytic economic impacts associated with the growth of the air transport industry under these same scenarios. I find that the local airport noise damages are very small compared to the regional economic impacts from aviation. Furthermore, I find that the wider catalytic economic impacts due to increased productivity and accessibility are greater than the economic impacts from aviation sector itself at the regional level.

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List of Abbreviations

ACARS Aircraft Communication Addressing and Reporting System

AIM Aviation Integrated Modeling Project

ANASE Attitudes to Noise from Aviation Sources in England

ANCON 2 UK Aircraft Noise Contour Model

ANIS UK Aircraft Noise Index Study

APMT Aviation Environmental Portfolio Management Tool

ATM air transport movement

BAA BAA Heathrow

BEA US Bureau of Economic Analysis

CAA UK Civil Aviation Authority

CDA Continuous Descent Approach

CE Cambridge Econometrics

CEBR Centre for Economic and Business Research

CGE Computable General Equilibrium

CMI Cambridge-MIT Institute

CONSAVE European Constrained Scenarios on Aviation and Emissions

dB decibel

dBA A-weighted decibel

UK DfT UK Department for Transport

DNL Day-Night Level

EBS Experian Business Strategies

ECOTEC ECOTEC Research & Consulting

EDR Group Economic Development Research Group

EMA East Midlands Airport

EPNdB Effective Perceived Noise Level in A-weighted Decibels

EPNL Effective Perceived Noise Level

ESA 95 European System of Accounts 1995

FAA Federal Aviation Administration

FOE Friends of the Earth

GAO Government Accountability Office

GIS Geographical Information System

GLA Greater London Authority

GDP Gross Domestic Product

GRP Gross Regional Product

GVA Gross Value Added

HACAN ClearSkies Heathrow Association for the Control of Aircraft Noise

IATA International Air Transport Association

ICAO International Civil Aviation Organization

ICT information and communications technologies

IMPLAN Impact Planning Model

INM Integrated Noise Model

I-O input-output

L_{den} Day-Evening-Night

L_{Aeq} Equivalent Continuous Noise Level

MDM Multisectoral Dynamic Model

MIT Massachusetts Institute of Technology

NDI Noise Depreciation Index

NEF Noise Exposure Forecast

NNI Noise and Number Index

NPD Noise-Power-Distance

OECD Organisation for Economic Co-Operation and Development

ONS UK Office of National Statistics

OEF Oxford Economic Forecasting

RDAs Regional Development Agencies

REMI-ECOTEC Regional Economic Modeling, Inc. (Amherst, Massachusetts) and ECOTEC (Birmingham, United Kingdom)

REMI Regional Economic Modeling, Inc.

REDYN Regional Dynamics

RIMS II Regional Input-Output Modeling System

RPK revenue passenger-kilometer

RPM revenue passenger-mile

SAI Silent Aircraft Initiative

SASIG Strategic Aviation Special Interest Group of the Local Government Association

SAX-40 Silent Aircraft

SEL Sound Exposure Level

SCAQMD South Coast Air Quality Management District

STPR Social Time Preference Rate

TFP total factor productivity

VHT vehicle-hours traveled

VMT vehicle-miles traveled

WGS World Geodetic System

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Chapter 1

Introduction

Over 2.1 billion airline passengers flew 3.9 trillion revenue passenger-kilometers (RPKs) in 2006, generating $452 billion in revenue for the world's commercial airlines (International Air Transport Association, 2007a, p. 4). The airlines also carried another 39.5 million tonnes of freight across the globe—accounting for around 35% of global merchandise trade ($4.2 trillion) by value (International Air Transport Association, 2007b). Since 1960, the number of tonne-kilometers flown by the global commercial airlines has increased by a factor of nearly 30, while global Gross Domestic Product (GDP) increased by a factor of four (International Civil Aviation Organization, 2005, p. 1-1). In the United Kingdom alone, overall air mobility has increased nearly fourfold over the last three decades, with RPKs increasing from 60 million in 1975 to 290 million RPKs in 2005 (UK Civil Aviation Authority, 1995, 2006b). The world's leading commercial aircraft manufacturers, Boeing and Airbus, are predicting growth rates of about 4.8% in passenger traffic and about 6.0% in freight traffic over the next twenty years (Boeing, 2006a,b; Airbus, 2006).

The rapid growth of aviation has enhanced mobility and created global supply chains throughout the world, but has also exposed over 20 million people around the world to high levels of aircraft noise (IATA, 2004, p. 5). Dempsey (2000, p. 249) notes that aircraft noise has been one of the most prominent of environmental concerns affecting aviation since the advent of the jet aircraft, and airport development, expansion, or even airspace reconfiguration projects continue to attract vehement political opposition to this day (McKie et al., 2008; Milmo, 2007; Ritea, 2007).

The responses to aircraft noise conflicts include airport-specific operating restrictions, aircraft-technology policy mandates, and limits to aviation expansion. Howard (1974, p. 569) suggests that community reaction to the roar and whine of the jet engine irreversibly changed the course of aviation growth in the 1970s. He attributes the ending of the U.S. supersonic transport and the abandonment of airport expansion programs as concrete results of community action and national ecological movements of the era. Indeed, noise conflicts in the United States have been partially responsible for the paucity of new airport and runway projects over the past 20 years (Baliles, 2001, p. 1).

Such airport noise conflicts can be generalized as what the Organisation for Economic Co-Operation and Development (OECD) refers to as a “Pressure-State-Response” system (2006, p. 15). Economic pressures affect the state of the environment, and eventually lead to environmental policy responses. Economic theory suggests that these noise conflicts exist because the aviation community has not been able to capture the full externalities that they create. To this end, the UK government is promoting the use of economic instruments, such as taxes or other price mechanisms, to help encourage industries to adapt, innovate, and foster sustainable development (UK Department for Transport, 2003a). Under such *polluter-pays principles*, air-transport users may bear additional environmentally related taxes as a means of handling the damage costs of noise and emissions on airport-area residents (UK Department for Transport, 2000b, p. 2).

In its own strategy to support more efficient, sustainable resource use, the OECD Secretariat (2002, pp. 9-13) has identified the need to "decouple" economic growth from environmental degradation. To support this, the OECD is developing decoupling indicators to compare changes in environmental pressure with changes in causally linked economic variables (OECD, 2006, p. 15-18). The full environmental costs of transport are very difficult to estimate, and decoupling indicators such as emissions of carbon dioxide (CO_2) per unit of GDP can help policy stakeholders analyze the links between the environment and the economy. While the OECD focuses on areas such climate, air and water quality, and natural resources, similar types of decoupling indicators could be developed for other policy arenas such as community livability or transportation noise.

Here, I consider how the economic benefits or positive externalities of aviation relate to the noise damage costs or negative externalities which it creates. Howard (1974, p. 569) recognized that although many costs of airport noise need to be internalized within the air transportation system, the benefits of aviation also need to be identified and quantified as best as possible. Cooper (1990, p. 125) found evidence to suggest that airports had a significant impact on local and regional economies, but that these impacts were not yet fully understood. Furthermore, there is a growing body of literature on the *catalytic* impacts of transportation on increasing economic output, which have not been considered within the context of airport environmental damages. Analysts use the concept of catalytic impacts to describe the longer-term effects of transportation on underlying economic productivity (Oxford Economic Forecasting, 1999, 2006a;

InterVISTAS-ga2, 2006) that are different from the traditional direct, indirect, and induced impacts associated with spending in the aviation industry.

1.1 Research Questions and Hypothesis

In this analysis, I explore the externalities of local airport noise and regional growth in order to highlight key sensitivities within the air transportation system and generate some insights into the long-term sustainability of aviation and the economy. Analyzing economic benefit and noise externalities in terms of a common (monetary) reference unit allows analysts to compare them with other costs and benefits that are expressed in monetary terms (Schipper et al., 2001, p. 173), and gives local and regional stakeholders additional opportunities for dialogue and policy innovation.

Although aircraft noise impacts are mostly limited to the neighborhoods around an airport, the economic impacts of air services extend far beyond those affected by airport noise. The air transport sector itself is a large industry, and accounted for about £6.1 billion in value-added in 2004—about 0.6% of the total value-added throughout the United Kingdom (Office for National Statistics, 2006). The air transport sector can play a more significant economic role at the regional level and accounts for about 1.5% of the Greater London economy, or £3.2 billion in value-added (REMI, 2004a). As such, I have designed my study to look at both the local communities around the airport as well as their surrounding regions.

My primary research questions are: (1) what are the regional impacts associated with the catalytic relationships between air transportation services and economic growth; (2) how do the economic values of aircraft noise relate to changes in airport operations;

and (3) how do these regional benefits from aviation growth compare to the localized environmental damage costs of airport noise. My hypothesis is that the local community noise damage costs are very small compared to the direct, indirect, induced, and catalytic regional economic impacts from aviation services. A better understanding of this relationship could inform the dialogue between policymakers and other aviation community stakeholders, especially as environmental pressures, increasing fuel prices, and the airline industry restructuring continues to threaten the long-term growth and sustainability of the air transportation system.

1.2 Methodology

To test this hypothesis, I integrate a series of aircraft noise and socio-economic impact models and analyze the impacts under a series of aviation growth scenarios for two airports and their surrounding regions in the United Kingdom: London Heathrow Airport and the East Midlands Airport. My objective is to analyze the relationships between aviation activity, airport noise, local housing prices, and regional economic growth. I differentiate the cases of the London Heathrow and East Midlands airports in terms of airport size, projected air-traffic growth, urban context, and regional economic activity, which provides a good contrast in looking at the potential range of impacts associated with aviation. I also introduce a number of scenarios that incorporate an advanced technology, low-noise aircraft to look at the sensitivity of these relationships to future changes in technology.

Figure 1-1 shows my overall framework for linking aviation growth scenarios with local airport noise and regional economic performance using environmental and economic impact models. My analysis starts with a set of long-term aviation growth scenarios that are based on airport capacities and mobility projections. I use a regional econometric input-output model jointly developed by Regional Economic Modeling, Inc. (REMI) and ECOTEC Research & Consulting (ECOTEC) to analyze the wider sensitivity of the economy to growth in the air-transport sector and related industries. I considered other economic modeling strategies, such as input-output, econometric-only, or system dynamics, but for this analysis, the REMI-ECOTEC system provided the best combination of industry detail from the input-output portion of the model and long-term dynamic forecasting from the econometric portion of the model. I also investigate the wider, long-term catalytic impacts of aviation on investment and productivity. I then look at the local impacts of this aviation growth by using the Federal Aviation Administration (FAA)'s Integrated Noise Model (INM) to identify the community noise levels under the different airport activity scenarios. I apply a hedonic-price model to estimate the aggregate monetary impacts of the noise damages on housing values–or inversely, the benefits of silence (Schipper et al., 1998).

I jointly consider the results of these economic and noise impact models to illustrate the interrelationships of noise and economic growth within the air transportation system. Given the long-term uncertainty of socioeconomic conditions and air-travel demand, my analysis focuses on the differences between the model scenarios rather than the absolute values of the various summary metrics that I present. My aim is not to create a single index that captures the full complexity of the relationship between aircraft noise, aviation growth, and regional economic performance. Instead, I establish a set of plausible relationships and sensitivities that could be further explored by others with alternative modeling strategies.

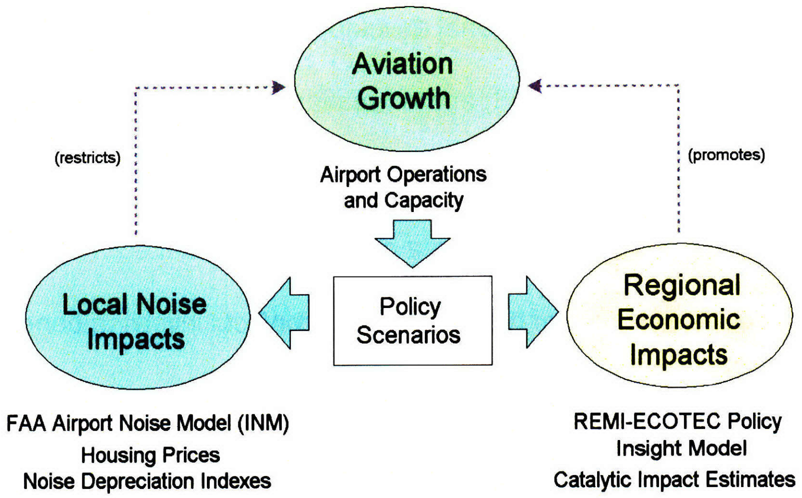

Figure 1-1: Concept diagram showing relationship between aviation growth, local noise, and regional economic growth

1.3 Contribution

My major contribution will be to link airport flight activity directly with community noise damages and regional economic growth within a single analysis. Although many economists, such as Nelson (1980) and Schipper et al. (1998), have developed and applied community Noise Depreciation Index (NDI) estimates, there have been few applications of NDIs under different airport-specific operational scenarios. My study of the noise impacts within the context of regional economic growth highlights some of the more critical interrelationships between the air transportation system, local communities, and regions. One of my major aims is to provide policymakers and researchers with a framework to consider the long-term effects of aviation and other transportation access on regional economic growth. By applying an analysis of the catalytic economic effects of aviation at the regional level, I also demonstrate the importance of considering such non-traditional economic impacts when assessing transportation impacts.

This analysis of aviation and regional development will also help to fill a gap in the urban studies literature. Taaffe (1956) and other planners and geographers have long observed the relationship between air transportation and the geography of economic activity, yet, the overall research in this area remains rather limited. Furthermore, airport noise issues are representative of typical planning conflicts involving benefits to a wider community at the expense of negative externalities affecting a small population, and this research is thus relevant to other planning issues and at different scales of analysis.

Finally, I note that this research was conducted as part of the Cambridge-MIT Institute (CMI) Silent Aircraft Initiative (SAI), a multi-disciplinary program to design conceptually an advanced-technology, low-noise aircraft. By analyzing some of the tradeoffs between the regional economic benefits of airport expansion along with the local community damage costs of airport noise, I demonstrate why such an aerospace technology research program is relevant to a wider audience—including public policy, transport economics, and regional development.

Chapter 2

Regional and Local Impacts of Aviation Growth

Air transportation is a critical enabling factor in economic development and is vital in unlocking global tourism as a development strategy (Graham, 1995, p. 102). In 2001, over 680 million international tourists spent about $472 billion throughout the world—with a large proportion of these (39%) traveling by air (International Civil Aviation Organization, 2005, p. 1-5). Air transport has also facilitated international trade by providing major travel times savings, overcoming physical geography, and provided reliable economic access in politically sensitive areas (Graham, 1995, p. 88). In addition to these tourism and regional trade benefits, airports generate jobs, tax payments, and generally help to create wealth (Banister and Berechman, 2000, p. 299). Indeed, one of the economic benefits of air transportation is that it connects areas of high and low economic wealth (International Civil Aviation Organization, 2005, p. 1-5). Figure 2-1 shows the relationship between increasing GDP per capita and the propensity to fly, measured in terms of RPKs per capita.

The close relationship between the air transportation and the economy is also reflected in the historical growth of GDP and passenger air traffic (RPK) in the United

Kingdom (Figure 2-2). Given the concurrent success of the global airline industry and the rise of globalism, the relationship between aviation and economic growth has almost become dogma. Airport development is often widely viewed as necessary to support the economy or to expand essential transport links, yet these wider regional, national, or international economic benefits may conflict with the negative environmental impacts on surrounding local communities (Caves and Gosling, 1999, p. 101).[1]

Like Caves and Gosling (1999) and others, I consider the balance between the benefits and costs of aviation growth. Here, I apply and extend this notion by quantifying and contrasting regional economic growth and local airport noise-damage costs under different growth scenarios for two specific airport-regions. I begin by presenting some background on the techniques that analysts typically use to identify the relationships between aviation and economic growth. In addition, I discuss the metrics that are used to analyze and monetize the damage costs of airport noise, and how airport noise conflicts have resulted in changes to the aviation system.

2.1 Regional Economic Impacts of Aviation

Generally, transportation investments reduce the cost of intermediate inputs for production—either through decreased direct trip costs or shortened travel times and reduced outlays (Flyvbjerg et al., 2003, pp. 65-66). Bennathan and Johnson (1990, p. 104) find that total transportation costs account for about 2% of the total output value of industries. Reductions in price, time, inconvenience, or other factors all translate into lower general transportation costs for travelers and shippers alike. Under neoclassical

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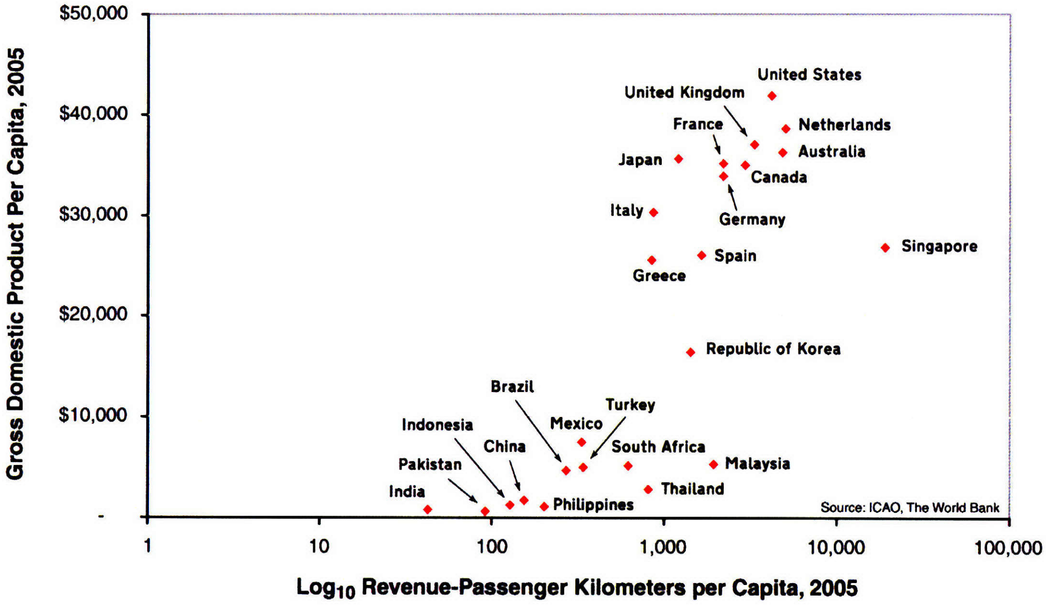
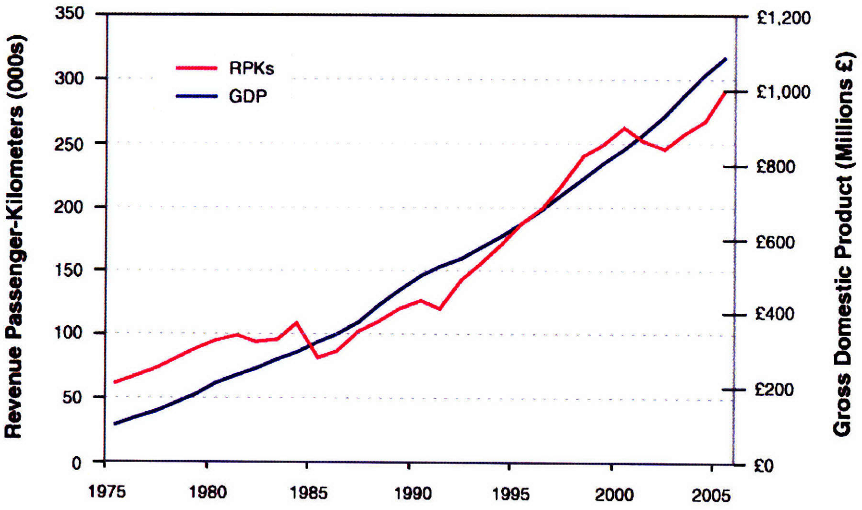
[1] In many parts of the world, however, the economic benefits of aviation are seen to outweigh the costs at any price (Caves and Gosling, 1999, p. 109).



Source: ICAO and The World Bank

Figure 2-1: Relationship between air travel and wealth per capita for selected countries, 2005



Source: Author's calculations from UK ONS and CAA data

Figure 2-2: Association between UK Gross Domestic Product and air passenger traffic, 1975-1980 economic theory, reductions in transportation costs should lead to increased productivity and output. Post-keynesian regional economic growth theory suggests that increased price competitiveness due to reductions in transportation costs leads to increases in regional exports and inward investment, migration, and overall growth (Malizia and Feser, 1999, pp. 130-131). Regional competitiveness is thus extremely critical from an economic growth standpoint.

Another analytical perspective, however, is the derived-demand hypothesis . This core concept in transport and economic geography states that transportation itself has no intrinsic value without the activities at either end (Rodrigue, 2006, p. 1449). As such, Schipper et al. (2001) and Rothengatter (1993) argue that transport externalities are pecuniary (pseudo) rather than technological (real) because they redistribute income rather than creating a change in output. In a globalized environment, though, these externalities can provide a major strategic competitive advantage—especially at the regional level (Porter, 2001b). Caves and Gosling (1999, p. 103) suggest that given the derived nature of transportation demand, using expenditures to measure economic impacts is a fallacy.

Nevertheless, transportation analysts have traditionally focused on the activity, employment, and payroll that can be attributed to the airport itself (Butler and Kiernan, 1992, p. 2). In the United Kingdom alone, for example, aviation industries directly create about 200,000 jobs, and indirectly support another 600,000 jobs (UK Department for Transport, 2003e). In addition, about 17 million foreign tourists arrive in the United Kingdom by air each year, helping to support about two million jobs in the tourism industry. Here, I discuss several common economic assessment techniques used by aviation analysts, as well as some emerging state-of-the-art methods that test the derived-demand hypothesis.

2.1.1 Measuring Economic Impacts

Airports often commission economic impacts studies to justify the high levels of public and private investments necessary to sustain the air transportation system. A typical methodology involves applying local or regional economic multipliers to spending or jobs data. Analysts use economic data or surveys of business activity to generate the wages, sales, and spending data, which are used along with input-output multiplier models, such as the US Bureau of Economic Analysis (BEA) Regional Input-Output Modeling System (RIMS II), or the Impact Planning Model (IMPLAN), in order to approximate the direct, indirect, and induced impacts of the airport and related sectors (Crihfield and Campbell Jr., 1991). Analysts also typically incorporate these methods within cost-benefit or cost-effectiveness studies to compare the relative impacts of different airport traffic levels or different project investments.

In order to look at the regional economy-wide socioeconomic impacts over time, analysts use integrated econometric input-output or Computable General Equilibrium (CGE) models to compare the impacts of a counterfactual scenario relative to a baseline forecast (Loveridge, 2004, p. 10). At the national level, analysts also use macro-economic models to identify the larger-scale impacts of aviation. One of the more recent studies in the United States, for example, found that civil aviation accounted for 9% of the US GDP in 2000, or about $900 billion dollars and 11 million jobs (DRI-WEFA, 2002). Transportation economic impact studies can also be framed in terms of user travel-time savings or congestion by converting these costs into monetary units and setting them as a cost to the economy (Delcan Corporation and Economic Development Research Group, 2003).

Weisbrod (2000a) contrasts these types of impact studies with comprehensive economic development studies that focus on broad impacts of regional growth or strategic infrastructure. Airport operators often desire to make the nexus between air service and firm location, supply-chain integration, or market access, but this often involves more intangible impacts, which are often not measured under traditional economic impact analysis methods. Analysts must often rely on anecdotal evidence and other qualitative methods in order to illustrate the potential business-side impacts which could occur. Weisbrod's Economic Development Research Group (EDR Group), for example, use case-study interviews to describe how Boston-area firms rely on air travel to support their core businesses Economic Development Research Group (2001). Although such qualitative studies can be useful for policymakers, they do not lend themselves to detailed economic-impact assessments and policy modeling.

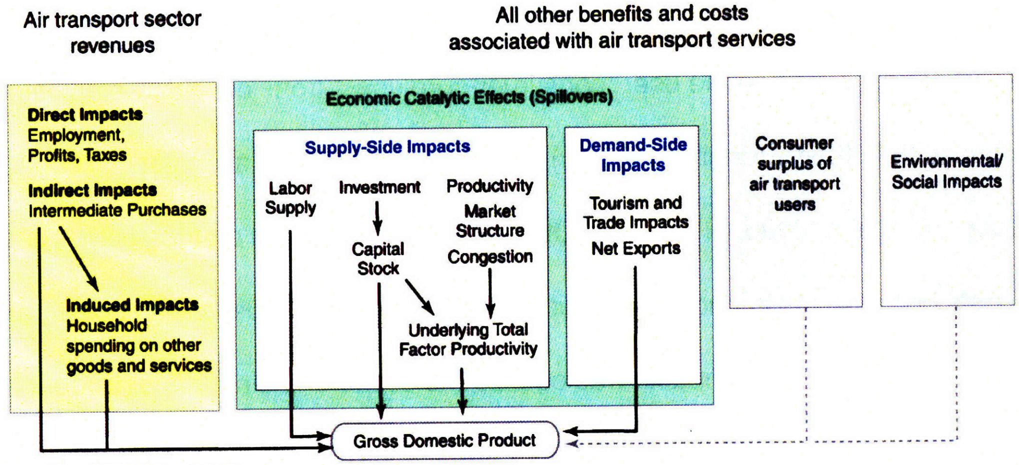
2.1.2 Regional Catalytic Impacts of Aviation

Aviation analysts traditionally focus on industry spending and employment impacts rather than the wider regional productivity benefits associated with air service-enabled accessibility. Yet, even the US Federal Aviation Administration recognizes that there are regional productivity gains and other logistical benefits from aviation that are not measured in traditional input-output analyses (Federal Aviation Administration, Office of Aviation Policy and Plans, 1999, p. 61). Air service creates access to suppliers, markets, capital, and ideas (Tam and Hansman, 2002), and thus potentially has wide regional impacts on economic productivity and geography. The availability and reliability of fast air travel in recent years, for example, has contributed to the growth of global supply chains and has shaped where and how goods are produced.

These impacts on the underlying structure of a regional economy may be a fundamentally different type of economic impact than the supply-chain relationships reflected in traditional economic accounts. Air transportation costs may only be a minor percentage of the total value of the overall inputs that feed into the production of a final good, for example, but may indeed be the most important factor in determining the potential of where or how a good is produced. An emerging method of applied analysis, however, focuses on these longer-term effects of transportation connectivity on economic productivity. Analysts use these *"economic catalytic effects"* to account for the way in which air transport "contributes to a country or economy beyond any effects that are directly or indirectly associated with the air transport industry itself (Cooper and Smith, 2005, p. 12). Such methodologies are useful when analyzing the wider benefits and costs associated with air transport service, because traditional methods may undervalue the importance of air transportation.

Long before the concept of "economic catalytic effects" came into widespread use, analysts in the regional planning, geography, and urban economics fields began using econometric models to investigate the association between transportation and economic growth—although they generally stopped short of applying these models to forecast the impacts of transportation growth. In these models, the analysts typically used independent variables, such as professional employment (Ivy et al., 1995), administrative employment (Debbage and Delk, 2001), and service-related employment (Brueckner, 2003), in order to explain the differences in the use of air transportation. As with most econometric methods, simultaneity and causality remain major methodological issues, but analysts overcome some of these limitations using simple correlation coefficients (Debbage and Delk, 2001), two-stage least squares regression models (Brueckner, 2003), lead-lag analyses (Goetz, 1992), simultaneous equation models (Ivy et al., 1995), and other methods. In general, these analysts have found positive associations between various metrics of air-transportation activity and economic growth. Brueckner, for example, found that a 10% increase in passenger enplanements is associated with a 1% increase in service-related employment (Brueckner, 2003, p. 1467).

More recently, other analysts have also begun to use the term *catalytic effects* to describe various types of economic impacts other than direct, indirect, and induced impacts. In a recent study on air-service liberalization, for example, InterVISTAS-ga2 (2006, p. 5) described the catalytic economic impacts as "the investment made by organizations in plants and facilities, and the increased trade flows driven by increased capacity of the air transport system." The International Civil Aviation Organization (2005, pp. 2-5) defines the catalytic impacts as the off-airport expenditures directly related to the use of air travel and shipment of freight—such as tourism and other freight activities. Although these uses of the term *catalytic* capture some of the benefits and costs of air transportation services, they do not fully describe the long-term, regionally differentiating impacts on economic productivity that may result from enhanced access to air-transport services.



Adapted from OEF (2005, pp. 15-20)

Figure 2-3: Traditional and catalytic impacts of air transportation services

Figure 2-3 shows a methodological framework developed by Oxford Economic Forecasting (OEF). This methodology goes beyond the traditional measures of employment and spending, intermediate purchases, and household spending by workers directly and indirectly employed by the air-transport sector. The economic spillovers of households and other companies in the wider economy are called the *economic catalytic effects* (Cooper and Smith, 2005, p. 13). These supply-side impacts of air transport are based on empirical econometric relationships between economic productivity, investment, and air-transport usage. OEF further distinguishes between supply-side and demand-side catalytic effects. Supply-side catalytic effects refer to the performance of the economy and long-run productivity and livability, while demand-side effects include the use of air services to transport goods, business travelers, and tourists (Cooper and Smith, 2005, p. 16). The supply-side impacts include the long-term impacts on labor supply and investment, as well as the impacts of market structure and congestion on productivity. All of these economic impacts can be measured through the long-run effects on GDP.

In addition to these impacts, the other benefits and costs associated with air-transport services include the user "consumer-surpluses" from low airfares (travelers paying less than their willingness to pay) and other environmental and social impacts (Cooper and Smith, 2005, p. 14). The OEF studies do not focus on these other benefits and costs because the economic benefits from consumer surpluses are unclear, and an analysis of environmental impacts was outside the scope of their studies (Cooper and Smith, 2005, p. 16). Although the consumer surplus impacts of aviation development may be very large, such as what Norris and Golaszewski (1990) found at Dallas-Ft. Worth and another unnamed island airport, such benefits should eventually be captured by long-term economic equilibrium models as consumers change their spending patterns over time. Other noise-related externalities, such as reduced educational performance of children in schools near airports (Shield and Vilatarsana, 2004; Welchman, 1999), may also incur real long-term economic costs. Such costs, however, may be difficult to isolate from other geographic and socio-economic factors.

2.2 Local Impacts of Aviation Growth: Airport Noise

In contrast to the generally positive regional economic benefits of aviation,[2] airport noise has emerged as a major negative externality of the air transportation system. Airports are also major sources of air and ground pollution, and aviation generally contributes to global climate change. From a community perspective, however, noise is often the most urgent and obvious environmental problem (Andre, 2004, p. 36). The growth of aviation

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[2] Caves and Gosling note that given the preponderance of UK holidaymakers among UK regional airport passengers, the net effect of air accessibility on the local UK economy may well be negative, even though most of the holiday spending goes to UK airlines, airports, and tour operators rather than to foreign economies (Caves and Gosling, 1999, p. 103).

has exposed over 20 million people around the world to high levels of aircraft noise (IATA, 2004). Personal annoyance and property depreciation have long been identified as key factors behind airport noise conflicts (Stevenson Jr., 1972, p. 14). Stevenson Jr. noted that property-value assessments in 1961 were reduced by as much as 20% near Los Angeles International Airport after the introduction of jet aircraft; similar reductions occurred near New York's John F. Kennedy International Airport and the Toronto Pearson International Airport.

Despite major declines in the number of residents exposed to noise due to changes in aircraft technology, operations, and aviation policy, noise issues continue to generate substantial opposition to airport and aviation expansion projects (US GAO, 2001). In a 2000 survey of 50 of the busiest commercial airports in the United States, the US GAO (2000c, p. 11) identified noise as the most critical environmental issue, although air quality was seen as becoming more serious in the future. Problems with noise have limited airport expansion projects throughout the United States and elsewhere. In this section, I discuss the methods which policy analysts use to measure and evaluate airport noise impacts.

2.2.1 Quantifying Noise Impacts

The aviation and scientific communities use a range of different metrics in order to describe general sound levels, certify aircraft, and identify the noise impacts around airports. In general, sound energy is measured in a unit of sound pressure level called a decibel (dB). These units are measured logarithmically—i.e., an increase of 10 decibels doubles the sound that people hear (US GAO, 2000b, p. 39). A-weighted decibels (dBA)

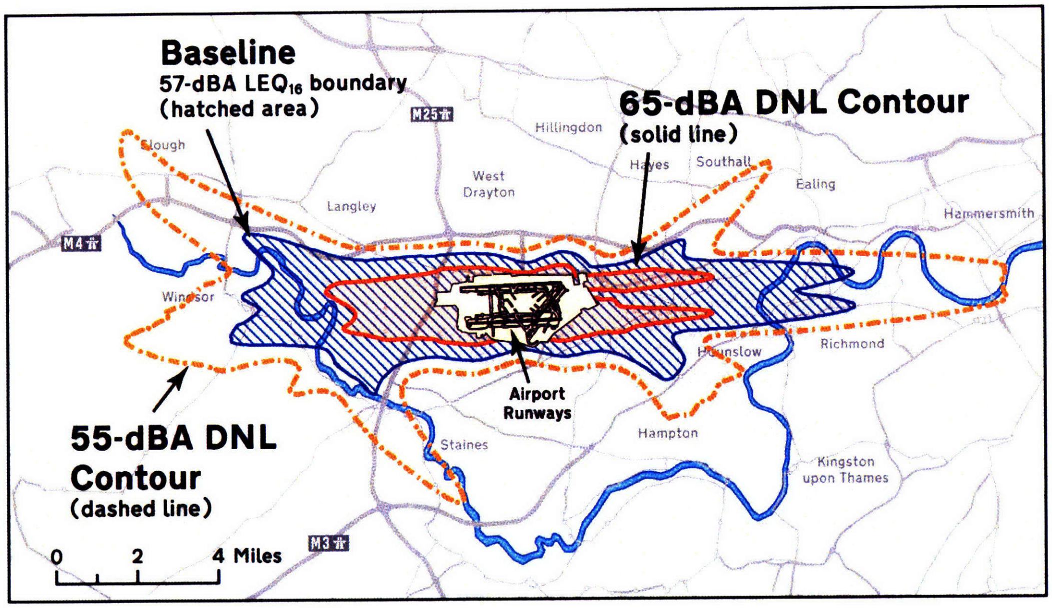
Table 2.1: Typical sound levels of common occurrences

Event	Sound level in A-weighted Decibels
Rock band (indoors)	108–114
Food blender	88
Vacuum cleaner	70
Conversation (indoors)	60
Dishwasher on rinse cycle at 10 feet	60
Bird calls (outdoors)	44

Source: US GAO (2000b, p. 40) from Federal Interagency Committee on Noise (1992)

discount the very high and low frequencies that are outside the perceptible range of the human ear. An alternative measure, "C"-weighted decibels may better reflect the type of noise generated by aircraft due to the way it weights the different frequencies of noise, but it is not typically used in environmental analyses. Sound levels for single events, such as those shown in Table 2.1, are called SELs and are typically measured in dBAs.

Airport noise exposure is generally measured in terms of the average sound levels generated by the total number of aircraft operations over a period of time such as a day or night, and are measured in dBA. The Equivalent Continuous Noise Level (L_{Aeq}) metric used in the United Kingdom, for example, averages the noise levels over a 16-hour period (0700-2300) during an average summer day (BAA, 2002). In the United States, FAA uses the Day-Night Level (DNL) metric, which places a higher weight on nighttime operations (10pm to 7am) in order to reflect the greater noise sensitivity of residential communities at night. DNLs levels above 65 dBA are considered to be incompatible with residential uses (US GAO, 2000b, p. 46). Figure 2-4 compares key L_{Aeq} and DNL metrics at London Heathrow Airport. An additional metric, Day-Evening-Night (L_{den}), is now used in the European Union as the standard metric for airport studies and incorporates different

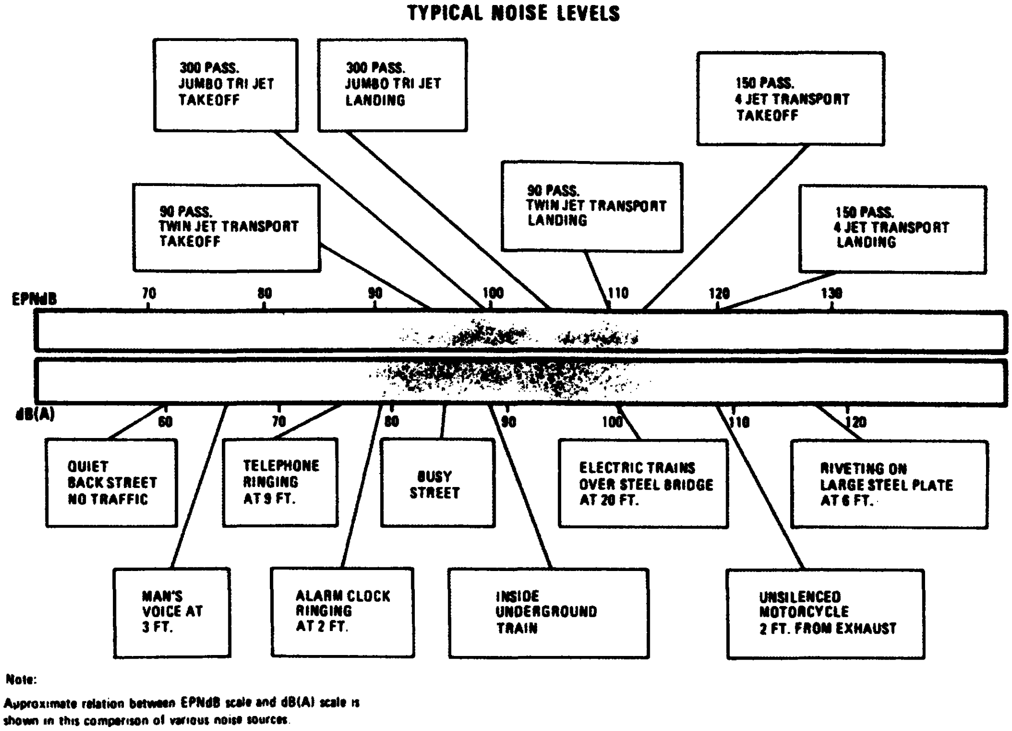


Source: Author's calculations using INM 6.2, ArcMap 9.1 and data from UK DfT and CAA

Figure 2-4: DNL- and LEQ-based noise contours at London Heathrow Airport, 2005

weightings for day, evening (7pm to 10pm), and night-time operations (UK Department for Transport, 2003e, p. 35).

The UK Department for Transport (UK DfT) uses the 57-dBA L_{Aeq} level to mark the approximate onset of significant community annoyance (UK Department for Transport, 2003e, p. 34). Noise annoyance can occur at levels lower than 57-dBA L_{Aeq}, however, and the World Health Organization has noted that moderate and serious noise annoyance occurs at the 50- and 55-dBA levels, respectively. In their recent Attitudes to Noise from Aviation Sources in England (ANASE) study, MVA Consultancy (2007) implies that a 50 dBA L_{Aeq} level may better reflect changes in community sensitivity to noise, especially since the UK DfT selection of the 57-dBA L_{Aeq} level was based on a 1982 study. The UK DfT uses the 63-dBA L_{Aeq} level to designate areas exposed to medium to high levels of noise, and airport operators are required to offer acoustic insulation to



Source: Ashford and Wright (1992, p. 490)

Figure 2-5: Comparison between dBA and EPNL

homes and community buildings in these areas (UK Department for Transport, 2003e, p. 36). Airport operators are also expected to relocate households and purchase properties within the 69-dBA L_{Aeq} level, including those that experience large (3-dBA) increases in noise (UK Department for Transport, 2003e, pp. 34-36).

Finally, aircraft are certified using a third type of noise metric. The Effective Perceived Noise Level (EPNL) metric is a special scale (measured in Effective Perceived Noise Level in A-weighted Decibels (EPNdB)) which correlates the annoying properties of jet aircraft noise as well as subjective responses to pure tones in the noise spectrum (Ashford and Wright, 1992, p. 489). EPNL levels are measured at specific locations relative to a typical takeoff and landing, as specified by government regulations, such

Table 2.2: Typical aircraft noise levels in dBA and EPNdB

Aircraft	Take-Off Weight (000 lbs.)	dBA		EPNdB		
		Takeoff	Approach	Takeoff	Sideline	Approach
EMB-145	49	68	83	79	85	93
CRJ-700	75	69	83	83	89	93
B737-700	155	71	88	84	94	96
MD-80	160	82	85	91	97	94
A320-200	162	73	85	87	93	97
B757-200	220	73	90	86	94	100
B767-300	351	80	89	91	97	102
A330-300	507	n/a	n/a	94	98	98
B777-200	545	72	89	86	95	98
A340-300	595	n/a	n/a	96	95	97
MD-11	631	n/a	n/a	95	96	105
B747-400	875	91	93	99	98	104

Source: FAA AC-36-1H

as the FAAs 14 CFR Part 36. Figure 2-5 compares the EPNL and dBA scales, while Table 2.2 compares the noise levels for typical commercial airliners at typical airport measurement points using the two different metrics. Noise from landing aircraft can be louder than that from aircraft on takeoff, due to the added airframe noise from landing gear, flaps, slats, and other sources.

2.2.2 Noise-Damage Costs

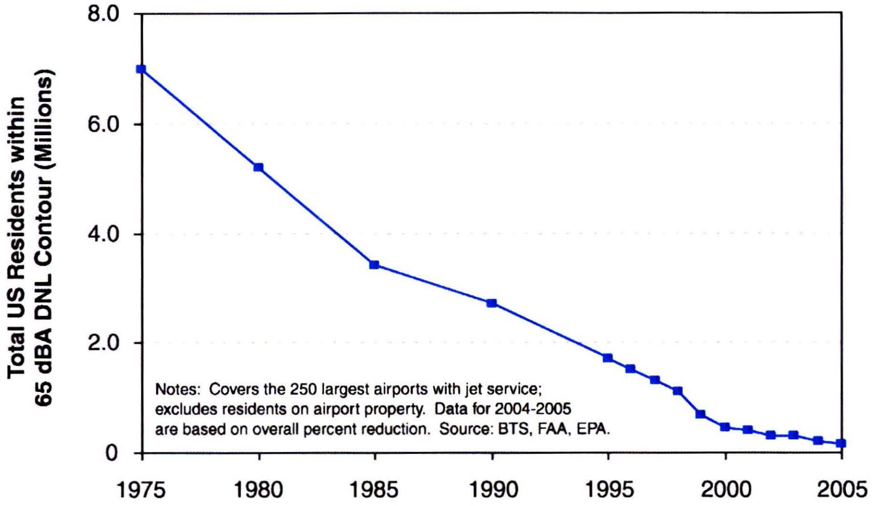
The nuisance caused by aircraft noise has a major impact in the affected communities, but monetizing these impacts is a challenging exercise. Welchman (1999) has qualitatively documented the impacts of airport noise at Heathrow on the learning environment, and Haines et al. (2002) and Shield and Vilatarsana (2004) have found impacts of aircraft noise on educational performance. While recognizing the critical importance of noise in community livability and overall socio-economic environment, many analysts nevertheless use economic instruments, such as housing values, as the primary proxy to explore the damage costs of noise. Hedonic price methods are the most widely used technique for evaluating the social costs associated with noise (Lu and Morrell, 2001), with analysts using the variation in average housing sale prices to reveal the implicit value of an attribute such as noise. Analysts have also used contingent-valuation surveys to reveal how much people are willing to pay for silence, and Feitelson et al. (1996) found that it revealed higher noise-damage costs relative to hedonic price studies. There have been very few contingent valuation studies on noise due to the difficulties of developing good survey methodologies (Navrud, 2002), although the UK DfT recently included a contingent valuation analysis as part of the ANASE study. In the ANASE study, the MVA Consultancy (2007) found an implied willingness to pay of about £3.80 to £11.50 per annum per decibel reduction in noise (L_{Aeq}).

Urban economists, such as Schipper et al. (1998) and Nelson (2004), have presented the results of hedonic price studies in terms of an Noise Depreciation Index (NDI) that describes the percentage change in housing prices associated with a change in noise level, as measured in decibels or some other metric. These NDIs can vary widely, due to the ways in which analysts setup their empirical models, as well as the type of data which are available. I discuss some of the differences between these different NDIs in Chapter 6. In a survey of thirty different hedonic price studies between 1969 and 1996, Schipper et al. (1998) found NDI estimates ranging from 0.10% to 3.47%, with a mean value of 0.83%. In other words, every decibel increase in noise levels around an airport is associated with a 0.83% decrease in housing prices on average. Nelson (2004), in another meta-analysis of studies in Canada and the United States, found an average noise discount of 0.58% per decibel of noise. Both Schipper et al. (1998) and Nelson

(2004) used a meta-analysis to reconcile the wide differences in NDIs found in previous studies: using a statistical regression model to control for the variations and minimize the effects of outlying data (Schipper et al., 1998; Lazic and Golaszewski, 2006). This permits NDIs to be more useful for benefit transfer applications, such as in the calculation of the monetary value of noise-damage costs around specific airports.

Around the Chicago O'Hare airport, for example, McMillen (2004) found that home values were about 9% lower within a 65-dBA DNL noise level, and he estimated that the current runway reconfiguration program could increase housing values by as much as $300 million. Cohen and Coughlin (2007) used a spatial hedonic price model to find that homes affected by noise around the Atlanta Hartsfield-Jackson International Airport (70-75 dBA DNL) sold for about 21% less than other homes (below 65 dBA DNL). Using a 1% per dBA NDI, Morrison et al. (1999, p. 733-735) calculated that a 5-dBA reduction in aircraft noise would increase housing values by about $6,000 per home and have a total value of $5 billion in the United States.

Other analysts have applied NDIs in other aviation-related policy studies. Pearce and Pearce (2000) used noise-damage values to set environmental charging schemes, while Lukachko (2002) and Morimoto and Hope (2005) applied the values using cost-benefit analyses to evaluate the implementation of advanced-technology, low-noise aircraft. Although this notion of damage costs indirectly reveals the sensitivity between noise and airport-area communities, aircraft noise conflicts also imposes direct costs on the air transport system. In the next section, I discuss the responses of the air transportation system and communities to aircraft noise.



Notes: Covers the 250 largest airports with jet service; excludes residents on airport property. Data for 2004-2005 are based on overall percent reduction. Source: BTS, FAA, EPA.

Source: US BTS, FAA

Figure 2-6: Decline in US population exposed to airport noise

2.3 A Coupled System

In the United States, noise issues continue to generate substantial opposition to airport-expansion projects, despite major declines in the number of residents exposed to noise (US GAO, 2001, p. 3). As Figure 2-6 shows, there has been a 95% reduction in the number of residents near airports who are exposed to high noise levels over 65 dBA DNL in the United States since 1975. Quieter aircraft engine technologies and flight procedures have enabled this decline in noise exposure to occur, even as commercial passenger traffic grew almost sixfold during this same time period (Waitz et al., 2004; US Bureau of Transportation Statistics, 2006). Yet, although the transition to quieter aircraft in the United States and elsewhere has dramatically reduced the number of residents exposed to aircraft noise, the FAA and other aviation stakeholders still fear that increased flight activity may eliminate some of these gains in the future (US GAO, 2001, p. 17).

Land-use planning issues are the root of airport noise conflicts, yet the structure of the political economy and the air transportation system makes it difficult to resolve these conflicts. In the United States and elsewhere, the promotion and maintenance of air transportation infrastructure is often a national responsibility, while land-use planning and zoning is conducted by the states and local communities (US GAO, 2001, p. 19). Although airports have very little authority to control land uses outside of airport property, local communities gain from increased tax revenues and other incentives associated with land development around airports (Ming Li et al., 2007, p. 51).[3] These conflicts are a long-recognized problem. In his early study of the political economy of airport noise conflicts, Stevenson Jr. (1972, p. 33) suggested that land developers had unchecked power in creating airport noise conflicts and bore the least consequences. Stevenson Jr. observed that developers were motivated by housing shortages, high profits, while the FAA had little influence on local zoning boards to stop them. Development pressures have not decreased in the thirty years since then, and FAA land-use guidelines have only had mixed results in deterring residential development around airports (US GAO, 2007, p. 2).

In addition to nuisance and depreciation, there may be other sociological factors that affect the response of communities to airport noise (Horonjeff and McKelvey, 1983, p. 575). Airport noise conflicts, for example, may be related to historical antecedents or airport-community relationships (Andre, 2004; Stevenson Jr., 1972). In a survey of the 50 busiest airports in the United States, the US GAO (2007, p. 26) found that over half of the noise complaints come from people in areas where airport noise levels are deemed to

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[3] In the United States, the FAA has the power to evaluate tall buildings and other airway obstructions within an area up to 3.8 miles (6.1 kilometers) from public-use or military airport runways, but this is not a specific land-use power (FAA Southern Region, 1998, p. III-15-17).

be compatible with residential land use (less than 65-dBA DNL). BAA Heathrow (2007a)[4] notes that 36% of the 5,800 noise complaints at Heathrow airport in 2006-2007 came from five callers.[5] While the Government Accountability Office (GAO) and FAA have explored the adequacy of the DNL metric in reflecting community expectations of noise sensitivity, it nevertheless remains the primary noise metric in the United States (US GAO, 2000b, p. 52). Another possibility is that airport-area communities can become more sensitive over time, as MVA Consultancy (2007) has hypothesized after a recent noise study for Heathrow Airport. Finally, the reconfiguration of aircraft flight paths–such as is currently underway in the New York-New Jersey-Philadelphia metropolitan area—can also trigger concerns over equity and environmental justice issues, especially when such actions relieve the burden of noise impacts on some communities at the expense of others (Ritea, 2007; US GAO, 2007).

With the limited success and formidable political challenges associated with airport noise conflicts, policymakers have focused their attention in four main areas: (1) modified flight operations, (2) aircraft noise abatement, (3) insulating/removing affected parties, and (4) reducing the demand for air transportation. Although Nelkin (1974, p. 37) noted that vertical take-off and landing aircraft and high-speed rail could provide alternatives to conventional air transportation and thus airport noise problems, such solutions have proved to be either technically or politically infeasible in the United States. Here, I discuss some of the costs associated with aircraft operational changes, noise-reduction technologies, and community mitigation. These costs provide further context

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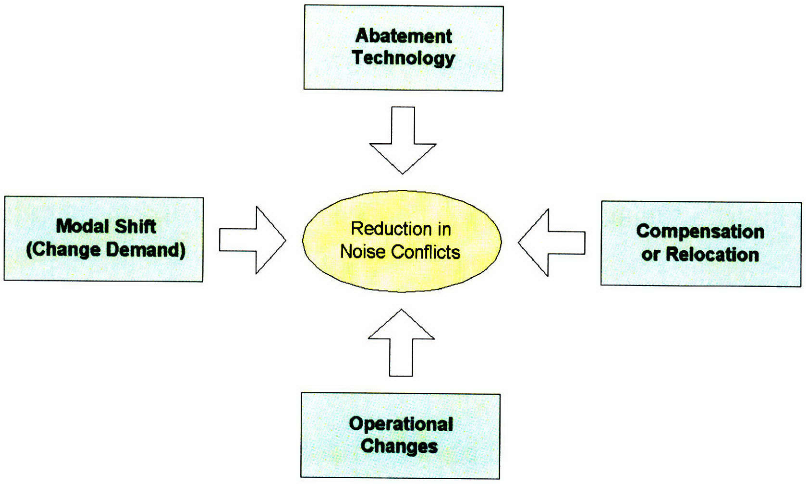
[4] BAA is a private company which owns and operates the three major London airports (Heathrow, Gatwick, and Stansted) as well as four other airports in the United Kingdom. It is now owned by consortium led by Ferrovial.

[5] 14% came from one person, and 26% came from two people. The top 20 callers accounted for 49% of the complaints.



Based on Nelkin (1974)

Figure 2-7: Major strategies to resolve airport noise conflicts

for understanding the relationship between regional economic growth and local noise-damage costs.

2.3.1 Airport Operational Restrictions

Airport-specific modifications to standard flight-operating procedures have been used for decades to lessen the noise impacts around specific communities. They may incur some direct costs to the airports and also limit the flexibility of air-traffic controllers—reducing the overall airport capacity and contributing to congestion during peak periods or inclement weather. Typical operating restrictions include special flight paths to avoid overflying specific communities. At London's Heathrow airport, for example, a longstanding (since 1952) community agreement with the town of Cranford prevents the northern runway from being used for easterly departures. Heathrow's air-traffic controllers send departures and arrivals over less-densely populated areas to the west of the airport whenever possible, but also attempt to balance the noise burden between communities on both sides (BAA Heathrow, 2007b, pp. 4-5). Burn et al. (1996) found that the more circuitous routings from such noise abatement flight tracks costed up to $25.3 million a year in extra fuel burn at Boston Logan Airport and $61 million at Los Angeles International Airport.

In addition, a more unusual strategy is that the airport uses a published 4-week rotation schedule for alternating the use of the northern and southern runways for landings and arrivals, so that residents can plan their activities accordingly. The BAA Heathrow (BAA) also enforces financial penalties for aircraft that deviate from normal flight tracks and exceed noise limits, and it reinvests these funds into community projects (BAA Heathrow Planning and Environment, 2001, p. 3). Other types of noise-abatement policies, such as steeper takeoffs with reduced-power climb or managed Continuous Descent Approachs (CDAs), may further limit the flexibility of air-traffic controllers and pilots, but may, in some cases, achieve other environmental benefits, such as reduced fuel consumption and emissions (Clarke et al., 2004; Reynolds et al., 2007).

Airports may also impose nighttime curfews or restrictions on specific aircraft types as part of an overall noise-reduction strategy. Heathrow airport uses a quota system to promote the use of quieter aircraft at night and also restricts operations based on aircraft noise levels (94 dBA daytime max). The airport also uses strict aircraft noise limits (87 dBA) for the period between 11:30pm and 6:00am (BAA Heathrow, 2004a, pp. 39-42). In the United States, the FAA Part 161 program provides a national process for communities to restrict certain types of aircraft operations, but demands detailed studies to show the benefits of flight restrictions (US GAO, 2007, p. 26). As such, US airports tend to favor informal agreements rather than mandatory restrictions.

Finally, other types of capacity restrictions may be imposed as part of environmental clearances or other legal processes. The construction of a fifth passenger terminal at Heathrow Airport was only granted under the condition that total airport operations be limited to 480,000 air transport movements (ATMs) per year, and that the land area affected by aircraft noise does not grow (BAA Heathrow, 2005b, p. 2). As part of a 1985 settlement agreement, the John Wayne Orange County Airport was originally bound to strict limits on average daily flights, annual passengers, terminal size, automobile parking spaces, and even the number of aircraft loading bridges (John Wayne Airport, 2008).[6]

Globally, such local noise-related restrictions on aviation continues to spread—increasing the constraints on the air transportation system. Over 500 airports throughout the world have implemented special flight procedures, nighttime curfews, or other measures in order to reduce the operational impacts of aircraft noise (Boeing, 2007). Figure 2-8 shows the rapid growth of airport noise restrictions over the last 35 years, and indicates the increasing sensitivity and communities to noise.

2.3.2 Community Noise Damage Mitigation

In addition to modifying aircraft flight operations, airports often attempt to mitigate the noise damages by funding community sound insulation or relocation programs. These programs incur direct costs to the aviation system, and they also indicate the magnitude of airport noise issues. In the United States, a voluntary FAA noise compatibility program

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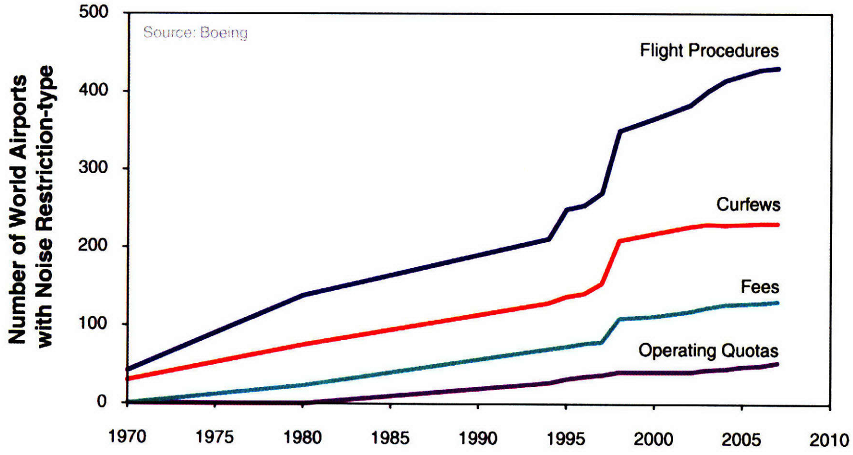
[6] The agreement has since been amended to focus on daily flight and annual passenger limits.



Source: (Boeing, 2007)

Figure 2-8: Growth in worldwide airport noise restrictions

distributes federal funds to over 300 airports for soundproofing, property acquisition, and relocation (US GAO, 2007, p. 3).[7] Airports in the United States spent $4.4 billion dollars in noise-related projects between 1982 and 1999, representing 9.1% of the total federal airport improvement program and passenger facility charge-funded projects (US GAO, 2000b, p. 35). In a 2004 survey of 39 airports in the United States, Landrum and Brown (2008) found that airports spent an average of $27,500 per home and $1.5 million per school for sound insulation. Over half of these airports were located in dense urban environments and another 30% were in suburban residential areas. Altogether, the reporting airports have insulated over 65,000 homes and 250 schools, with have another 33,000 homes and 90 schools planned for the near future (Landrum and Brown, 2004).

At Heathrow, the BAA has spent over £10 million since 1996 to insulate about 8,500 homes around the airport within the 69 dBA L_{Aeq} contour (BAA Heathrow, 2008a). This daytime noise scheme included free secondary glazing on existing windows and/or partial

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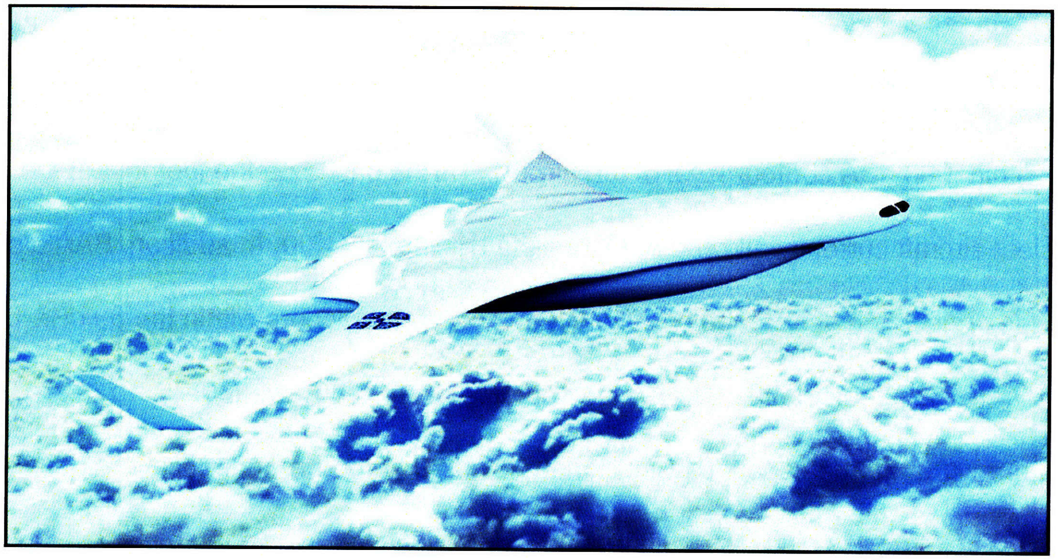
[7] It should be noted that 14 of the nation's busiest airports do not participate in the FAA Part 150 Program, leaving over 320,000 people living around these airports ineligible for federal funding (US GAO, 2000a, pp. 79-80).

grants for special double-glazed windows. BAA Heathrow (2008b) has introduced a new nighttime scheme to insulate bedrooms in about 41,000 homes around Heathrow that are within a 90 dBA contour level of the airport. This is based on the footprint of the noisiest aircraft currently allowed at night—the Boeing 747-400. In addition, BAA also provides relocation assistance of up to £12,500 for homeowners within the 69 dBA L_{Aeq} contour to move outside the 63 dBA leq contour (BAA Heathrow, 2005b). To date, BAA Heathrow (2007a) has spent £1.3 million to help 230 homeowners relocate to quieter areas. The airport is also distributing up to £25 million over five years to insulate noise-sensitive schools, hospitals, nursing homes, and other community buildings within the 2002 standard 63-dBA L_{Aeq} noise level (BAA Heathrow, 2005a).

2.3.3 Technological Changes

To overcome local noise concerns, international and national policymakers have traditionally focused on controlling aircraft noise at its source. Quiet high-bypass turbofan engines and other technological improvements have reduced aircraft noise by about 20 decibels since the 1950s (IATA, 2004, p. 6). Yet these improvements also incur costs to the air transportation system. The US GAO (2001, p. 3) estimated that US airlines spent up to $4.9 billion dollars in order to upgrade their aircraft fleets to the quieter “Stage 3” (International Civil Aviation Organization (ICAO) Chapter 3) noise standards. The ICAO and FAA have also recently implemented a new noise standard, called Chapter 4 or Stage 4, which requires new aircraft to be 1/3 quieter than Chapter 3 aircraft (IATA, 2004, p. 9).

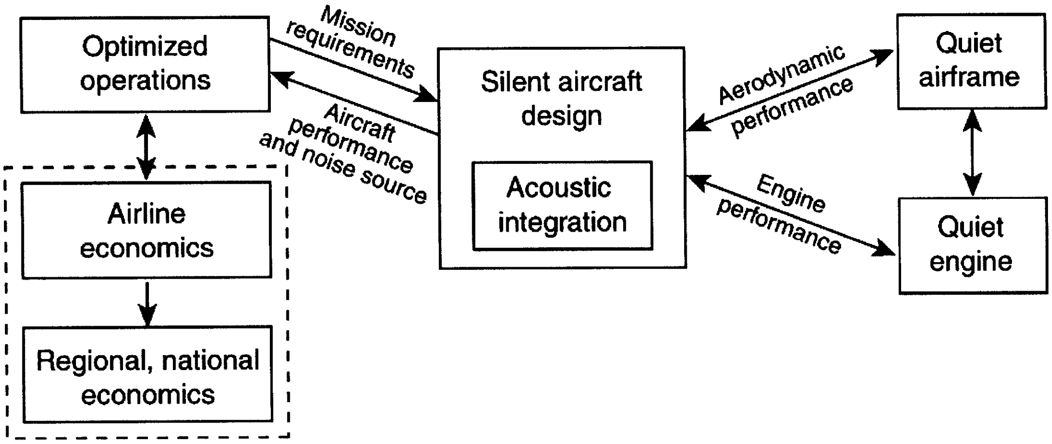


Source: SAI team

Figure 2-9: The SAX-40 is a conceptual design for an advanced technology, low-noise aircraft

For aircraft manufacturers and operators, noise reduction goals also often create conflicting design requirements, and they may negatively affect emissions, flight performance, and operating costs (ICCAIA, 2004, p. 27). Researchers at the Massachusetts Institute of Technology (MIT) and the University of Cambridge, among others, have considered the conceptual design of a commercial aircraft that may reduce the airport noise footprint to near-ambient urban noise levels (Hileman et al., 2007). Between 2003 and 2006, the Cambridge-MIT Institute (CMI) Silent Aircraft Initiative (SAI) engaged over 40 student, post-doc, and faculty researchers at both institutions to use noise reduction as the primary goal in an integrated airframe-engine design. In the end, the researchers developed a concept design for a commercial airliner called the SAX-40, which would achieve a single-event noise-contour of about 61-dBA at the perimeter fence of a typical international airport, such as at London Heathrow Airport (Hileman et al., 2007). Because there are significant technological challenges associated with developing such an advanced-technology, low-noise aircraft to meet all airline market-demand segments, the SAX-40 is designed as a 215-seat airliner with a range of 5,000 nautical miles. A low-noise aircraft designed for short-haul operations (e.g., 130-seats at 2,000 nautical miles) or high-capacity, long-haul flights (650 seats at 9,000 nautical miles) would have a different configuration than the SAX-40 design depicted in Figure 2-9.

In addition to conceptual design integration, short-term operational enhancements and the application of incremental technologies, such as noise-minimizing CDA procedures, were also integral parts of the SAI project (Hileman et al., 2007). A schematic of the project organizational structure is shown in Figure 2-10, and shows that one component of the project was to assess the regional and national economic impacts of aviation to the United Kingdom. This task included evaluating the extent to which low-noise aircraft technology could be used to alleviate the external costs or enable the growth of air transportation in the United Kingdom (Dowling and Greitzer, 2003, p. 17). Based on this research objective and as a key member of the SAI Economics team, I focused the regional economic and noise impact modeling on two case studies located in the United Kingdom. In the next chapter, I discuss the methodology adopted for this analysis.



Source: SAI team

Figure 2-10: Structure of the Silent Aircraft Initiative

Chapter 3

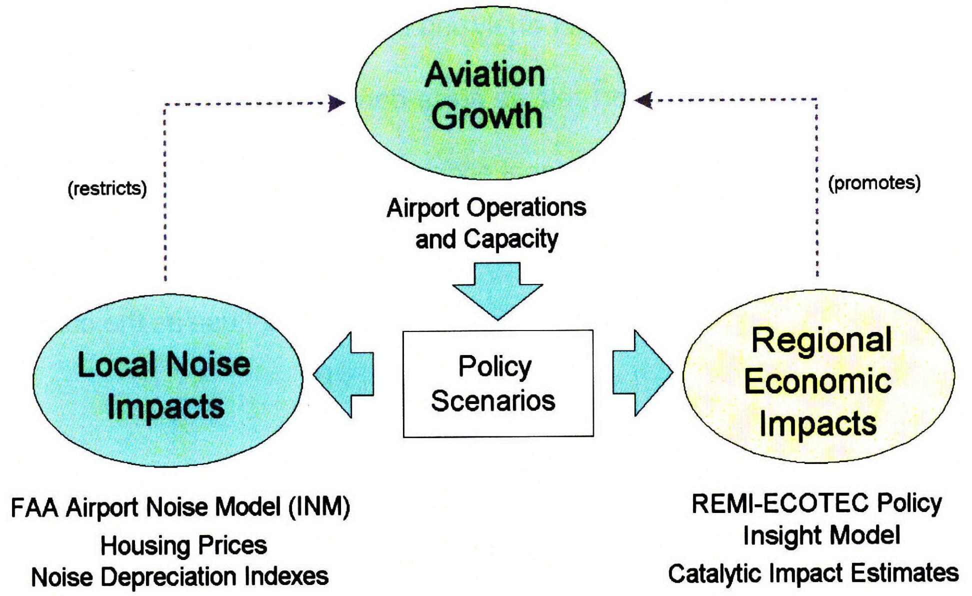
A Methodology for Analyzing Aviation Growth

As discussed in Chapter 2, the tension between aviation impacts on local communities and the accessibility demands of wider regions underlies much of the social, political, and environmental conflicts involving the air transportation system. While aircraft noise, air pollution, and congestion generally affect a limited area immediately around an airport, the jobs and longer-term economic impacts associated with that airport are spread across a much wider geographical area.

Having identified aviation as a major factor affecting both regional economic development and local community livability (noise), I now set forth a methodology for modeling and analyzing the impacts of aviation growth on these areas. I jointly consider the impacts of aviation growth on regional economic growth and community noise. Although these two thematic areas have very different scales of impact, they are inherently related as parts of a politically linked socio-economic system. As an example of a Pressure-State-Response system (OECD Secretariat, 2002), economic growth could slow as environmental policies (for noise or other effects such as climate change) increase the price of air travel and as airports reach capacity limits. I hypothesize that the long-term economic growth and regional restructuring associated with aviation growth is much larger than the localized airport noise-damage costs associated with that growth. My underlying assumption is that aviation growth enables global trade and facilitates the economic development of high-value and service-related industries.

I test this hypothesis within a regional economic modeling system by using various exogenous changes to air transportation-related sectors that will simulate aviation-enabled catalytic economic growth. These economy-wide simulations are based on empirical relationships observed in the literature, consultation with industry experts, and through my own analysis of two airports in the United Kingdom. I also use applications of new economic geography theories to analyze these complex, long-term regional interactions between regional accessibility and productivity. New economic geography theory is the latest attempt in economics to account for the increasing productivity or returns to scale associated with agglomeration (Fujita et al., 1999, pp. 1-3). Along with improvements in information and communications technologies (ICT), access to air transportation creates “virtual agglomeration” by enabling global supply chains—thus creating the potential to reshape regional and local economies.

Figure 3-1 illustrates my general methodology. Starting from a set of long-term aviation growth scenarios, I identify the impacts of additional air transport industry output on the long-term performance of the regional economy. I frame these impacts against an analysis of the noise-damage costs associated with increased flight activity at two airports. I also include an example of an advanced technology, low-noise aircraft to look at the sensitivity of these relationships between airport operations and the damage costs.



Source: Author

Figure 3-1: Concept diagram showing methodology for analyzing relationships between aviation growth, local noise impacts, and regional economic growth

I use a set of consistent growth scenarios as a common framework to explore the interrelationships between aviation, regional economic growth, and local community noise-damage costs. I analyze the impacts of these scenarios while recognizing the limitations of forecasting over long time horizons as well as potentially large uncertainties in the empirical data used to model these relationships. Overall, I use these different types and scales of economic and environmental impacts to identify some of the *externalities* of air transportation beyond the impacts of the sector itself. Analyzing the noise and economic benefit externalities in terms of a common (monetary) reference unit also allows for a comparison with other costs and benefits that are expressed in monetary terms (Schipper et al., 2001, p. 173). This also provides a useful means of applying and communicating these results to policymakers and other stakeholders.

First, I discuss my methodology for analyzing the regional economic impacts of aviation growth and the local airport-related noise-damage costs. Then, I describe the models that I apply for the specific regional economic and local noise impacts, as well as the particular economic indicators of interest. I also discuss the two airport-region case studies and the long-term aviation growth scenarios that I use as the context for this analysis.

3.1 Methodology Development

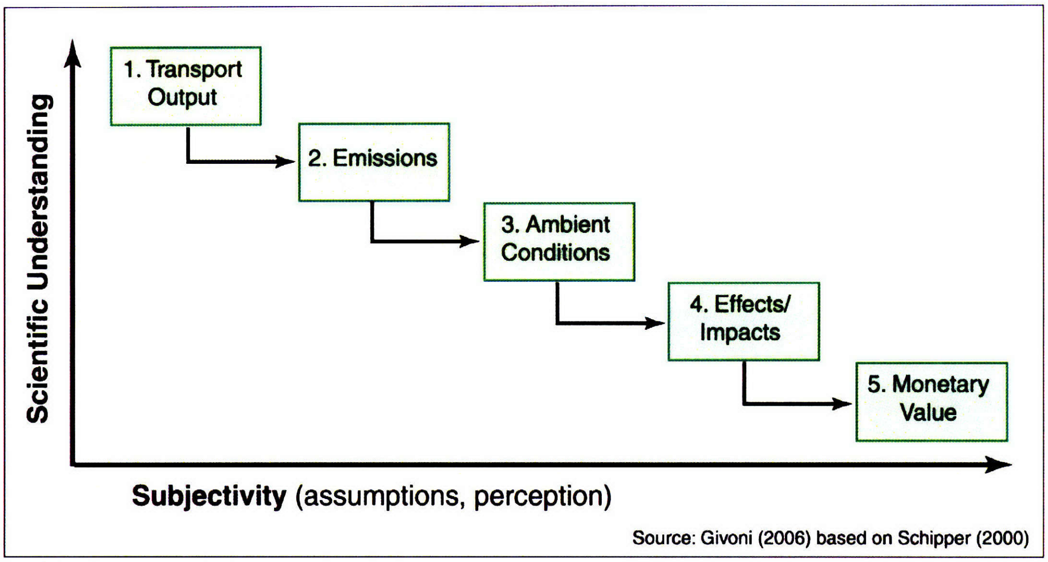
From the outset, the SAI Economics team chose to use a set of models linked under common growth scenarios in order to illustrate the complex interdependencies and relationships between air transportation policy, technology, and the economy. The nature of this research domain (airport noise and regional economic growth impacts) lends itself to such a coupled modeling approach. Indeed, models are widely used in the design of public policy in order to identify how a policy change or project may affect a particular economy or region (Pindyck and Rubinfeld, 1998, p. 279). In addition to enabling appropriate resource planning and informed policy decisions, models help analysts identify the dynamics and sensitivities of complex systems that may not be readily evident. In utilizing this methodology, however, I remain cognizant of the subjectivity embedded within models.

3.1.1 Modeling and Subjectivity

One of the analytical challenges in interpreting long-range economic and environmental policy models is that the underlying baseline scenario—often called "No-Build" or

"Business as Usual"—is itself a forecast. Policymakers commonly use these baseline forecasts as a reference from which to identify the positive and negative consequences of different counterfactual policy options (Pindyck and Rubinfeld, 1998; Mills, 1993). The baseline forecast incorporates trends that are expected to occur if no changes are made to the structure of the regional economy. The counterfactual scenario involves introducing a change to the economic system, and then identifying the differences in the resulting forecast (Loveridge, 2004, p. 10). Analysts can then use the differences in the *ex-ante* forecasts to identify the major characteristics of the change and affected areas. Many economic models are based either on historical trends or static input-output accounting relationships. Although these techniques may be suitable for short-term economic forecasts, they may be subject to errors over longer time horizons.

Analysts also often introduce additional subjectivity into their models as they convert transportation productivity metrics (such as available passenger-miles) into emissions units (such as CO_2) and monetary values. Schipper et al. (2001) describe this emission-exposure-effect value chain as a *pathway* of transport externalities. Figure 3-2 illustrates this generalized methodology for environmental studies (Givoni, 2006) . Note that as changes in transport output (Step 1) are converted to environmental impacts (Steps 2-4) and monetized (Step 5), the level of scientific understanding of the problem decreases and the subjectivity of the analysis increases. Similarly, the conversion of transportation measures into parameters suitable for use in economic models might involve the calculation of spending impacts or the exposition of policy links (Pereira and Polenske, 1996, p. 128).



Source: Givoni (2006) based on Schipper (2000)

Figure 3-2: Methodology for environmental analysis of transportation

Although the physical propagation of sound energy is a very well-understood phenomena from a scientific point-of-view (Steps 1–4 in Figure 3-2), much less is known about the socio-political ramifications of noise in each community. Thus, attempts to monetize these impacts (Step 5) are extremely subjective. A similar challenge exists with representing the relationship between air transportation and economic growth, except that the complexity of regional development makes it difficult to isolate the effects or impacts associated with aviation itself (Step 4). Nevertheless, monetary units provide the most useful information for policymakers, even though the corresponding reduction in scientific understanding decreases the robustness of the analysis (Givoni, 2006).

3.1.2 Open versus Closed System Modeling Approach

Given the goal of analyzing very long-term impacts of regional development and aviation growth, one of the analytical challenges was how to manage the subjectivity and uncertainty in the modeling process. Greenberger et al. (1976, pp. 63-70) note that modelers often must balance the trade-offs among theory, data, and methodology when representing a given reference system as a model. Theory refers to the underlying hypotheses in the model, while methodology includes the tools that are used to transform the mental conception of the reference system into a formal model (Greenberger et al., 1976, pp. 66-74). Data links the model to its reference system and are used to gain confidence in it and its results.

One of the early methodological questions was whether to approach the airport economics-noise modeling either as a single, closed system integrating feedbacks between aviation, the economy, and community noise responses, or to use open models with distinct, separate pathways. For the integrated, closed-system modeling approach, I considered developing a system dynamics model, such as Ishuktina's (2008) analysis of the global economic impacts of aviation. System dynamics is a simulation methodology that is based on feedback control theory (Ford, 1999, p. 5); dynamic, causal relationships that are represented by differential equations and designed to highlight questions and observations about the world (Meadows and Robinson, 1985, p. 28). The underlying assumption of system dynamics is that the dynamic tendencies of any complex system arise from its internal causal structure (Meadows and Robinson, 1985, p. 34). Yet because system dynamics makes minimal use of data and theories from social science, it is frequently a target of criticism (Greenberger et al., 1976, p. 187). An integrated system dynamics approach would focus on representing the causal interactions between aircraft noise, community socio-political pressure, and airport noise restrictions within one single system. The model would also have to include causal relationships between airport flight activity and economic growth in order to balance the local pressure that constrains the airport with the increased regional demands for aviation. Firm-level surveys and historical data on regional business patterns could be used to estimate some of these relationships.

Due to lack of data, time, and resource limitations, however, I decided not to adopt a closed-system model.[1] Instead, I use an open-system approach to model the regional economic and noise impacts as separate pathways that are conceptually linked under a set of consistent growth scenarios. I also chose to structure the analysis around pre-built, regional economic- and noise-impact models—again, partially due to limited time and budget resources. One of the major advantages of this approach is that it enabled me to build upon state-of-the-art, industry-standard methods of analysis. This has the additional benefit of allowing this methodology to be more immediately relevant to transportation and environmental planning practitioners. Using two separate open systems also limits the propagation of forecasting errors through the analysis; a mis-specified noise-damage cost index will not necessarily affect the calculation of regional economic growth. Finally, the causal feedbacks between aviation noise and the resulting constraints on the aviation system are very much a function of the regional political economy, and they would be difficult to quantify at a global level. Indeed, Ming Li et al. (2007, p. 52) were unable to find consistent relationships between population characteristics and noise complaints in a study of several major US airports.

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[1] Such an approach that captures the major relationships between aviation and the environment, however, is currently being undertaken by researchers at MIT and Cambridge University (Committee on Aviation Environmental Protection, 2007; Reynolds et al., 2007). The large-scale Aviation Environmental Portfolio Management Tool (APMT) and Aviation Integrated Modeling Project (AIM) projects generally use economic growth to drive the demand for air transportation and predict the resulting emissions—a different focus than the analysis presented here.

3.1.3 Pathway Methodologies

Having established the decision to model the economics and noise impact pathways separately, the next major decision was to identify the specific methodologies for each pathway. Due to the time and resource limitations of the SAI project, I focused on pre-built models. The selection of the noise impact model was relatively straightforward, since the only publicly available airport noise model was the FAAs Integrated Noise Model software. The selection of the regional economic model, however, was a much more complex process due to the wide range of methodologies and models used in regional economic-impact analysis. In developing the economic-impact methodology, several key model requirements emerged, including a regional scale of analysis and the ability to provide detailed long-term forecasts. As such, I did not consider simple multiplier or static input-output techniques—such as the Regional Input-Output Modeling System (RIMS II) or Impact Planning Model (IMPLAN) models in the United States. Budget constraints also played a role in the model selection process.

The SAI Economics team investigated several leading econometric input-output and CGE models in the United Kingdom, including those made by Experian Business Strategies (EBS), Cambridge Econometrics (CE), Centre for Economic and Business Research (CEBR), and OEF. Table 3.1 summarizes the differences between these models. The long forecasting horizon and multi-regional capability of the CE Multisectoral Dynamic Model (MDM) initially emerged as the most suitable for this analysis, and the SAI Economics team procured an initial set of baseline forecasts through 2030, as well as historical economic data from 1971 through 2003. After this initial forecast was acquired, however, the SAI Economics team learned that ECOTEC had developed a partnership

Table 3.1: Comparison of the four main UK economic forecasting models with the REMI-ECOTEC model

Model Vendor	Cambridge Econometrics (CE)	Experian Business Services (EBS)	Oxford Economics Forecasting (OEF)	Centre for Economics & Business Research (CEBR)	ECOTEC UK, Ltd. (REMI-ECOTEC)
Forecasting Horizon	2015[a]	+ 10-15 years[c]	+ 10 years	+ 5 years	2040
Regions	12[b]	12	13	5+[d]	any[c]
Sectors	49	30-57	over 70	8	53[e]
User License[f]	No	n/a	n/a	n/a	Yes

Notes: [a] Possible to do until 2020. [b] 20 years and beyond for demographic and supply-side scenarios. [c] Any area for which data are available. [d] A 12-region study has also been done. [e] The input-output model has 123 sectors. [f] Original survey conducted in 2004. Most forecasters subsequently developed user license-based models. Source: Adapted from Morimoto and Hope (2004)

with REMI to create a regional model for the United Kingdom. Also, we would not have been able to do the CE runs ourselves, and the cost of doing runs with the CE model was large. For budget and user-operability reasons, the team switched to the REMI-ECOTEC model for the remainder of the project. In the next section, I discuss the use of the REMI-ECOTEC model as well as the other economic and noise submodels in more detail.

3.2 Impact Models

In this section, I discuss the major models and empirical relationships which I apply within each of the regional economic and noise-damage cost pathways. For the regional economic impact analysis, I use the REMI-ECOTEC model along with studies of the catalytic effects of enhanced productivity and accessibility. For the noise-damage cost pathway, I use the FAA Integrated Noise Model to identify the noise levels around an airport and then apply hedonic price studies to monetize these impacts.

3.2.1 Regional Economic Analysis Framework

The REMI-ECOTEC Policy Insight model (UK Version 6.0) was developed jointly by REMI and ECOTEC for the United Kingdom, but it is based on the US version of the REMI model. The US version of the REMI model is the most commonly used regional forecasting and simulation model in the United States (Weisbrod, 2000b, p. 19), and is tailored for the types of studies that are conducted by policy analysts. REMI focuses on a few select economic phenomena that are of particular interest to policymakers, including employment, productivity, taxes, and production costs (Treyz and Treyz, 2004b, p. 167). One of the key strengths of the REMI-ECOTEC model is that it enables analysts to analyze the relative performance of different regions as compared to the nation and the rest-of-world.

The REMI Policy Insight model structure combines elements of input-output, econometric, and CGE methodologies into its single dynamic economic forecasting framework. The various feedbacks in the model affect personal income, consumer spending, population migration, prices, and market shares in each region (REMI, 2004b). At the core of the model is a set of 53-sector regional input-output accounts, which capture the inter-industry demand relationships. The model also contains detailed demographic and labor data for specific occupations. Time lags and elasticities of demand for labor and products are also included in order to simulate the dynamic properties of regional economies. In addition, the relative commodity- and labor-accessibility attributes of different regions are used to model changes in transportation and flows. Like other econometric and computable general equilibrium models, the REMI model is solved through a series of simultaneous equations that relate regional industrial-sector activity to estimated time-series relationships. Changes in one sector of the economy are allowed to affect other sectors, which feed back on the original sector in an iterative fashion until the disequilibrium caused by an initial policy stimulus significantly dampens (Polenske et al., 1992; Pereira and Polenske, 1996)

The REMI model uses economic behavioral assumptions to compare the *relative* economic performance of industries, firms, and individuals in different regions, and then accordingly adjusts the flows of activity between the regions. Industries produce output using a mix of intermediate inputs, labor, fuel, and capital that is determined by the relative cost of each input. Relative labor intensity is determined by relative costs according to a Cobb-Douglas production function (Bolton, 1985, p. 511), while a stock-adjustment process includes region-specific capital preferences and a speed of adjustment (Rickman et al., 1993, p. 206). Relative costs and accessibility affect the regional and global market shares for each industry (REMI, 2004b, p. 21), as consumers try to minimize costs and producers try to maximize profits. The inclusion of behavioral assumptions rather than just econometric trends is fundamental to the structure of the REMI model and represents a theoretical strength relative to other non-structural modeling approaches.[2]

Model Application. The REMI model is designed as a regional policy analysis tool. The general application of the REMI model includes (1) determining the direct

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[2] Nonstructural models are based on past trends (including statistical econometric methods), regional changes derived on past trends, and shifts in the local share of national industries (Treyz, 1993, p. 7). In contrast, structural models are developed using cause-and-effect relationships based on economic theories.

(exogenous) effects of a policy over time; (2) entering these effects into the model through a series of policy variables; and (3) using the model to generate the regional economic and demographic changes that occur (Treyz and Treyz, 2004a, p. 11). One of the key steps in conducting an analysis using the REMI model includes determining the correct policy variables to use.

Within the model, a large number of policy variables affect the inter-regional relationships between industry-level output, labor and capital demand, demographic trends, production costs, and market shares. These policy variables are specified for a specific region and period of time. Examples of input data might include firm sales, consumer spending, induced employment, wage rates, housing prices, or foreign imports. As industrial output changes due to an exogenous policy intervention, the various feedbacks in the model will affect personal income, consumer spending, population migration, prices, and regional market shares (REMI, 2004b, p. 13). As such, the model can show how industries and people interact due to changes in employment, inter-regional competition, investment, government spending, and other factors.

Pereira and Polenske (1996, p. 137) note that the large number of policy and population variables provides great flexibility to model users for describing a particular policy within the modeling framework. The explicit structure of the REMI model also makes it easier to track the policy effects on all the variables in the model (Treyz et al., 1992, p. 222). Although this theoretical structure limits the ability of REMI modelers to specify ad hoc equations that reduce the model's prediction errors, it provides more accurate economic explanatory power (Cassing and Giarratani, 1992, p. 1554).

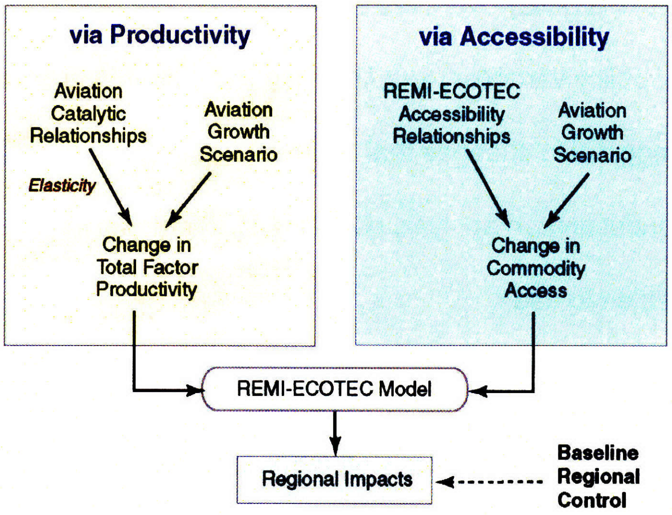


Figure 3-3: Economic catalytic effect methodology

3.2.2 Catalytic Effects

As Figure 3-3 shows, I use changes in total factor productivity (TFP) and commodity accessibility within the REMI-ECOTEC model to identify the catalytic impacts associated with different levels of aviation growth. The productivity-based analyses rely on the latest OEF elasticities (0.06), while the accessibility-based analyses are based on the commodity-access relationships within the REMI-ECOTEC model.

Productivity-Based Model. To examine the magnitude of these catalytic effects of aviation at the regional level, I test several increases in TFP in the East Midlands, and then analyze the resulting changes in regional Gross Value Added (GVA). I use an economy-wide increase in TFP to frame the upper range of the catalytic impact estimates, and an increase in selected private non-farm industries (manufacturing, retail/hotels/catering, transport, telecom, and basic regional export-related services) to frame the lower range of the estimates. My underlying assumption is that air transport is inherently related to the viability of regional supply chains in manufacturing, services, and tourism—thus enabling such industrial activities to locate in a given region such as the East Midlands. I test changes in overall TFP in the East Midlands that are proportional to the assumed growth rate scenarios and the OEF elasticity of 0.06, thus assuming a constant linear relationship between growth and TFP.

Accessibility-Based Model. I simulate the effect of increased air services by modifying the commodity-access coefficients for the air transportation sector within the model. In the REMI-ECOTEC model, the Commodity Access Index measures the relative change in access to specialized inputs for production in order to predict the change in the productivity of intermediate inputs (Regional Economic Models, 2007). The commodity-access index affects the intermediate inputs and productivity (and output), as well as migration/population. Ultimately, it affects both the composite cost of production by industry and the consumption-access index in the economic-migration equation (Lee and Zohir, 2006, p. 6).

3.2.3 Airport-Communities and Noise

I apply an airport noise model to identify the neighborhoods affected by airport noise, and then use a hedonic price model to calculate the total value of these damage costs. Within the airport noise model, I focus on the higher-level relationships between aggregate fleet mixes and total operation levels on community noise impacts. Understanding this relationship is important because although larger, heavier airplanes generate more noise than smaller, lighter ones, the frequency of total operations is a major factor in airport noise contours and nuisance in general. I use the monetary value of aircraft noise-

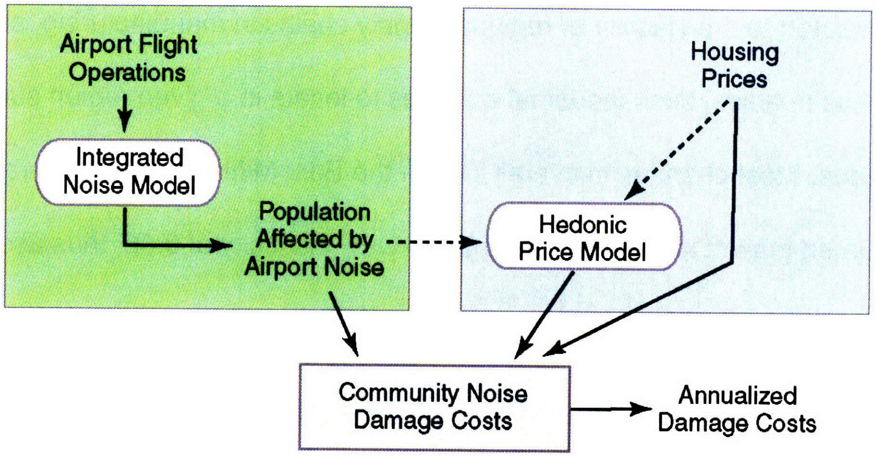


Figure 3-4: Airport noise analysis methodology

damage costs on housing sales prices in order to study the impacts of aviation growth on local airport-communities. This general methodology is shown in Figure 3-4.

Modeling Airport Noise. Although the number of aircraft operations per day and their time of occurrence can strongly influence the degree of annoyance experienced by those residing near airports (Ashford and Wright, 1992, p. 488), other factors such as the magnitude of aircraft sound levels, flight paths, and runway operations can also affect how airport noise is perceived by a community (Horonjeff and McKelvey, 1983, p. 575). One of the major factors that contribute to airport noise levels, for example, is the mix of aircraft at an airport. Although large wide-body jets generate more noise than smaller aircraft, they may only account for a small fraction of total operations and thus have a relatively small effect on overall averaged noise levels. I apply an airport noise model to calculate the average daily noise levels around London Heathrow and East Midlands airport under various scenarios based on different distributions of aircraft types by flight track, runway use, and time of day.

To model the airport noise impacts, I use the Federal Aviation Administration Integrated Noise Model Version 6.2. The FAA has used the INM model to determine and plot community noise levels for use in environmental-impact assessments and other airport operational assessments since the 1970s (Horonjeff and McKelvey, 1983, p. 590). It is also used by over 700 organizations in over 60 countries throughout the world (FAA and ATAC, 2002, p. 1). I use this industry-standard model in order to model different airport flight operational scenarios and take advantage of its detailed population- and noise-output data. I note that the UK Civil Aviation Authority (CAA) uses the UK Aircraft Noise Contour Model (ANCON 2) system instead of INM. Because this model contains more UK-specific aircraft, population, and operational data, it generates contours that are 20-30% different in size than INM (Monkman et al., 2005). Although I do not use the ANCON 2 model due to its proprietary nature, I consider the published CAA noise contours in evaluating my INM model inputs. In Appendix C, I directly compare the INM and ANCON 2 noise contours for the London Heathrow airport. Moreover, I focus my analysis more on the sensitivity of the changes due to traffic growth, rather than the absolute noise levels under each scenario.

Noise-Damage Costs. I use housing values to understand the economic value of community damages from aircraft noise. For each of the different airport operational scenarios, I calculate the theoretical appreciation in residential property values due to reductions in noise exposure levels. I use a Geographical Information System (GIS) to calculate the number of housing units and the average housing sales price within each band. For each of the airport growth scenarios, I use a range of NDI values to identify the effect of aircraft noise on housing values. I apply NDI values of 0.51% to 0.67% per decibel in noise change, as Nelson (2004) recently found in a meta-analysis of previous

Table 3.2: Summary of previous meta-analyses: noise-depreciation indices per decibel

Study	NDI (per dB)	Metric	Notes
Schipper et al. (1998)	0.9	meta	LL/SS; 1.30 for Box-Cox
Nelson (2004)	0.51-0.67	meta	US/Canadian airports
Nelson (1980)	0.58	meta	In NEF; 0.29 to 1.10
Johnson and Button (1997)	0.37	meta	R^2 of 0.13

NEF = Noise Exposure Forecast.

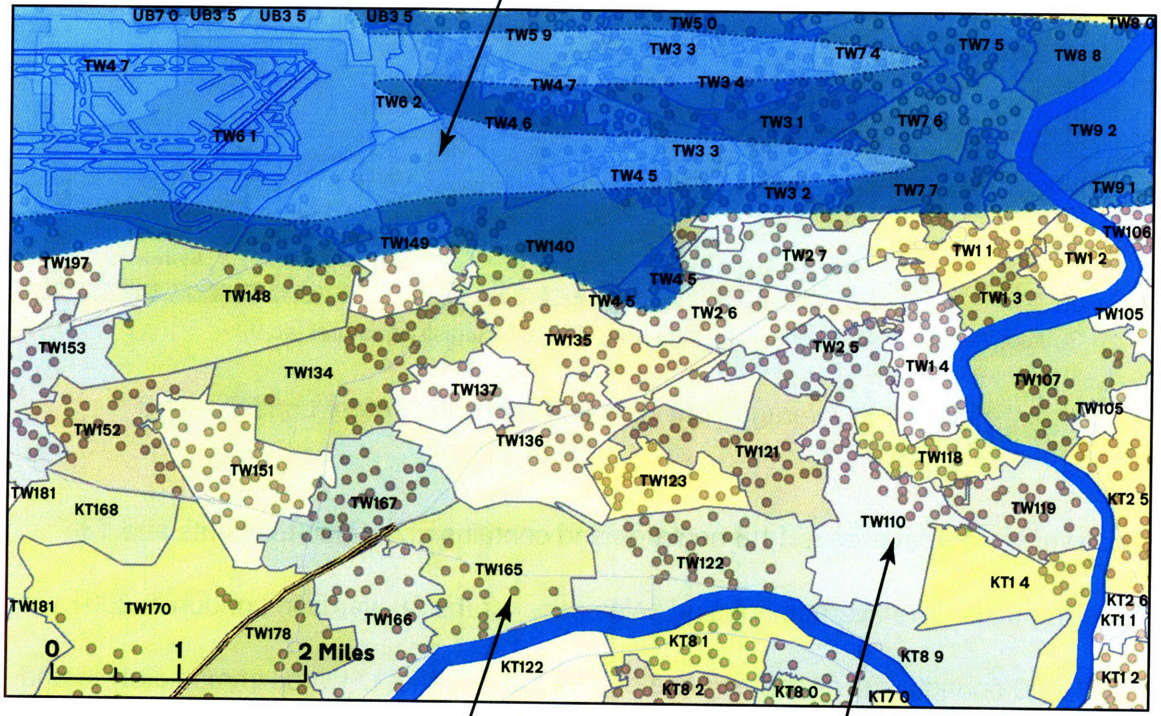
noise studies in the United States. Table 3.2 compares the results of several recent meta-analyses.

I identify the affected population and dwelling units using UK Office of National Statistics shapefiles and census data at the output-area level. I used the population-weighted centroids (reprojected to World Geodetic System 84 coordinates) as the basis to identify whether or not a particular output area was affected at a given noise contour level. I use average housing sales price data from the UK Land Registry Department at the postcode-sector level. In the study area around London Heathrow, there were 628 postcode sectors, each with an average of about 6,600 residents and 2,900 dwelling units. The census output-area data provided much more detailed data, however, and was about 11.6 hectares in size and contains about 300 residents and 130 dwelling units on average. Figure 3-5 compares the different output-area and postcode-sector geographies around the London Heathrow Airport, and Figure 3-6 shows the average housing sales prices in London at the postcode-district level (about 22,100 persons and 9,600 dwelling units in each district) from 2005.

I also use other data at the at the larger administrative ward level. Although the average ward in London is about 400 hectares in size and contains about 8,200 persons,

Airport Noise Contour (Polygon)

63-dBA contour, 2005



Census Output-Area (Centroid)

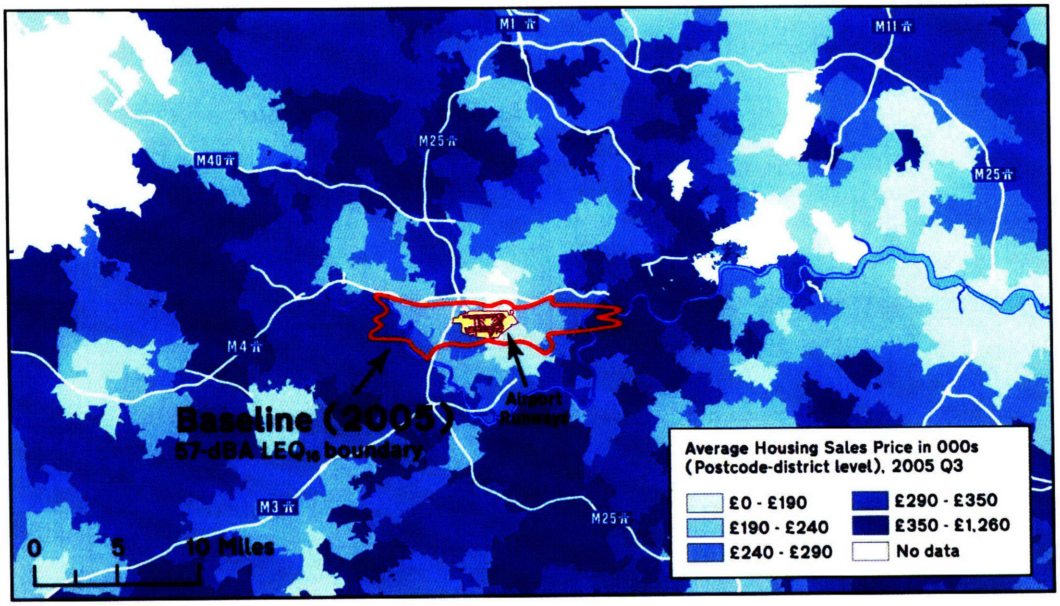
Population and number of housing units

Postcode Sector (Polygon)

Average housing sales prices i.e.:

123 transactions in 2005 at an average sales price of £112,000

Figure 3-5: Data sources and geography



Source: Author's calculations using data from UK Land Registry and ArcMap 9.1

Figure 3-6: Average housing sales prices in Greater London, 2005

the average output area is 11.6 hectares and contains about 300 residents and 130 dwelling units. The average housing sales price for the 38 wards in London in 2001 was £231,000 pounds with a median price of £182,000. In the 17 wards immediately in and around the East Midlands airport, the average sales prices was about £90,000 pounds, with an median price of £73,000.

Because the INM software identifies the precise noise level at each of the centroid locations, I use the difference in noise relative to the 57-dBA baseline in order to calculate the associated damage costs. This approach differs from many hedonic noise studies, which assign housing and population within 3- or 5-dBA contour bands rather using than the more precise noise level data upon which these contours are derived.[3] Some analysts then convert the band-level data into continuous variables by using the noise at the midpoint of the band (McMillen, 2004, p. 630).

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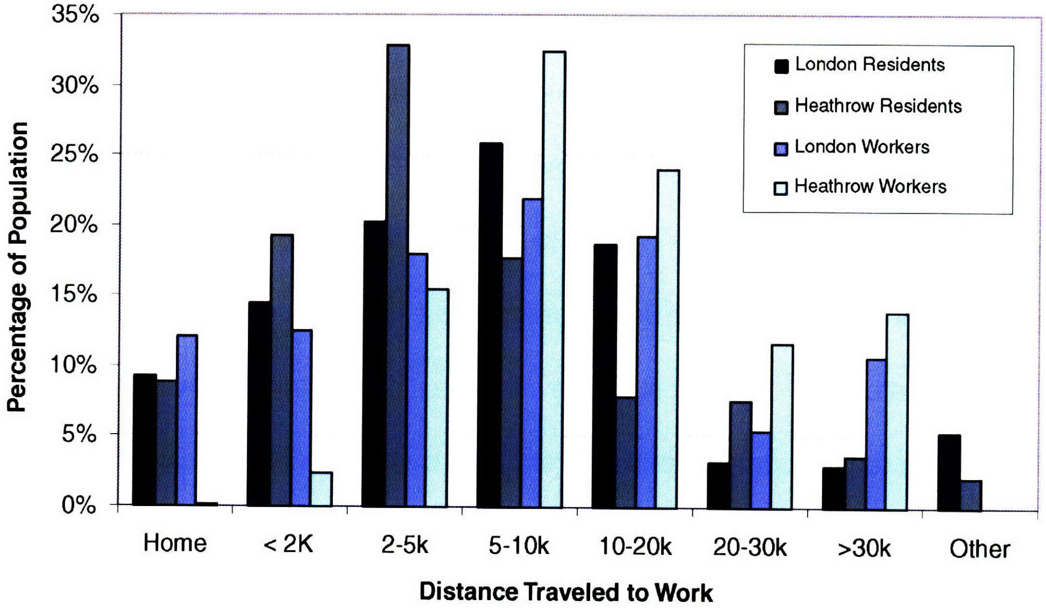
[3] This is presumably due to the type of noise impact studies that are typically available to most economists.

My damage cost calculations assume that the 57-dBA L_{Aeq} noise contour contracts inwards to the airport boundary, and thus that no residential dwellings around the airport would experience noise levels above 57-dBA. Dwellings within the existing 72-dBA contour, for example, would experience noise reductions of up to 15 dBA, while dwellings inside the existing 60-dBA contour would experience reductions of only 3 dBA on average. Note that I do not assume any changes in population growth nor housing values in order to focus on the sensitivity of the noise contours themselves rather than the effects of socioeconomic growth. This is relatively consistent with the REMI-ECOTEC baseline control forecasts, which predict a relatively low population growth for these regions (0.3% per year for Greater London and about 0.9% for the East Midlands).

3.3 Aviation Growth in Two Airport-Regions

As discussed at the end of Chapter 2, this analysis is based on research conducted under the SAI project. For this reason, I focus my analyses on two cases in the United Kingdom. Good data availability, a mature aviation system, and strong reliance on air transportation also make this a highly suitable national context for analysis. As an island nation of almost 60 million people with only a single fixed rail link to the rest of the European continent, the United Kingdom depends heavily on air transportation. In 2006, about 238 million passengers and 2.6 million metric tonnes of freight on 3.7 million flights passed through one of 67 airports in the United Kingdom (UK Civil Aviation Authority, 2006a). One-third of the exports by value are moved by air, while services–which rely on air travel–account for another eight percent of the economy.

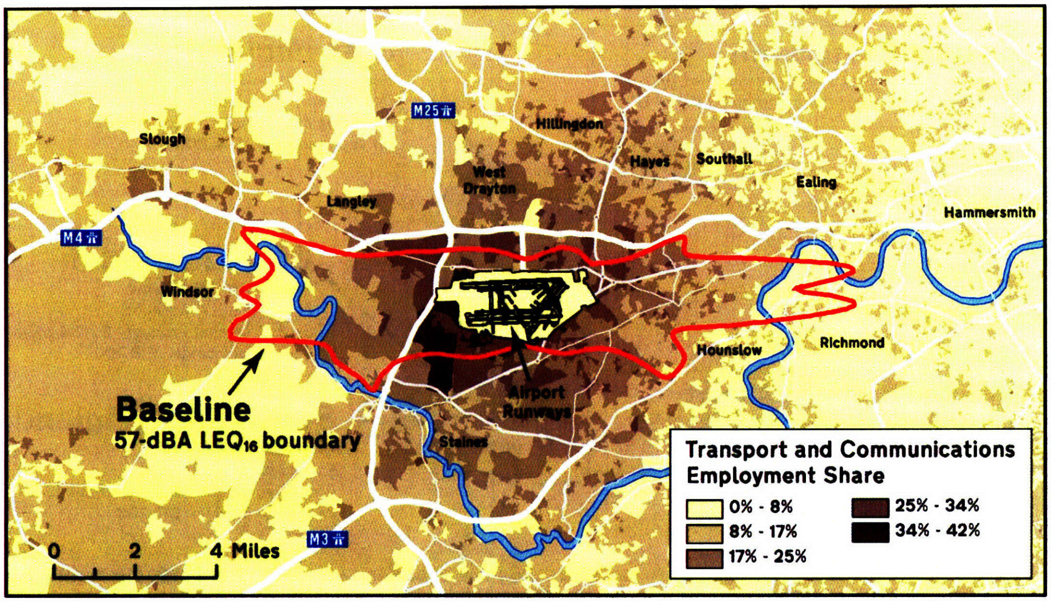


Other includes no fixed location, foreign, and offshore workers. Heathrow data includes 2001 UK census output areas 00ASGP0006 and 00ASGP0020.

Figure 3-7: Average distance traveled to work

I use regions as the unit of analysis for studying the economic impacts of aviation growth. Airports are well-known to have major economic impacts in their localities (up to 15 miles), and more widely across regional and international contexts (Banister and Berechman, 2000, p. 288). Figure 3-7 shows that about 56% of all workers and residents in London commute over 5-km to work. Workers at Heathrow airport tend to travel further than typical Londoners, with over 82% commuting over 5-km. The 300-odd residents in the two census tracts immediately adjacent to Heathrow Airport have somewhat shorter commutes, with about 19% employed within 2-km of their homes. This could reflect the large economic opportunities at the airport (almost 30,000 employees were recorded in the two Heathrow census tracts), as well as the socio-economic status of these residents.

Although specific employment data for the air transport industry were not available, Figure 3-8 shows that there is a large cluster of employment in the overall transport

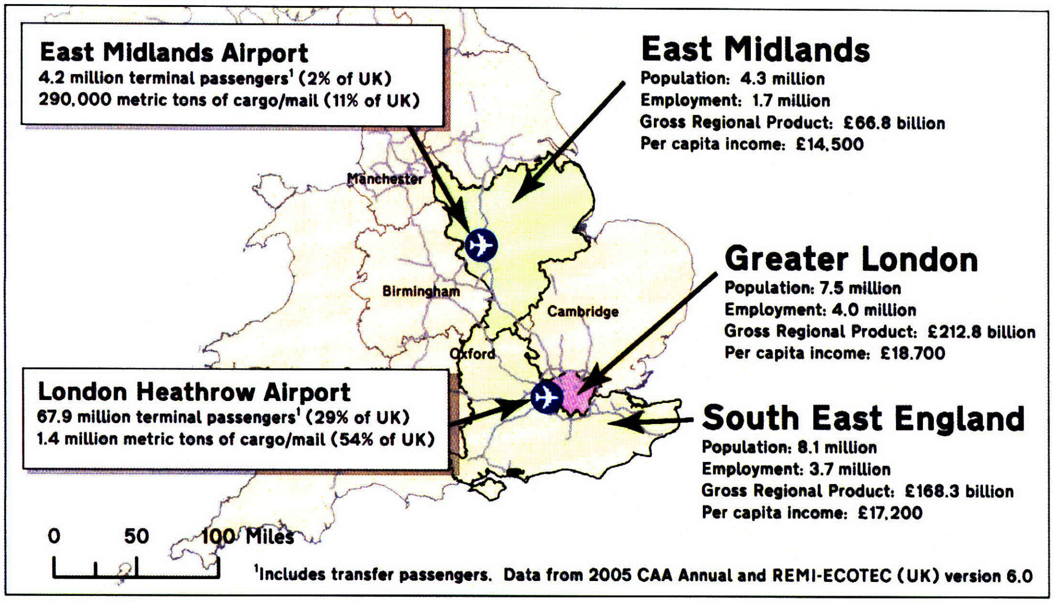


Source: Author's calculations from UK ONS data (UV34 dataset) using ArcMap 9.1

Figure 3-8: Share of residents employed in transport and communications industries around London Heathrow airport, 2001

sector around London Heathrow airport. Banister and Berechman (2000, p. 288) estimate that economic impacts associated with airport-related jobs extends as much as 15 miles from an airport. Other analysts suggest an economic catchment area of a 90-minute commute time to an airport.

Moreover, policymakers in the United Kingdom have remained focused on regional issues since the discovery of structural regional disparities in the 1930s (Hall, 2007, p. 10). Regional post-war policies focused on steering the manufacturing industry from the South East to the North of England, South Wales, and Central Scotland, but this ended with the overall decline of manufacturing in the United Kingdom. With the re-emergence of the Labour Party in the 1990s and European Union incentives, policymakers created new institutions, such as Regional Development Agencies (RDAs), to enhance competitiveness and bolster economic growth at the regional level.



¹Includes transfer passengers. Data from 2005 CAA Annual and REMI-ECOTEC (UK) version 6.0

Figure 3-9: Map of Central England showing the London Heathrow and East Midlands airport-regions

These RDAs have a wide authority to further economic development, competitiveness, employment, sustainability, and skills (Twedwr-Jones and Allmendinger, 2007, p. 21-28).

3.3.1 Case Selection

One of my research objectives is to contrast the impacts of aviation growth in an urban, global international hub and a rural, regional airport. Although traffic increases at the regional airport could potentially result in very large changes to both noise and economic growth, such impacts might have less of an economic value than at the large international airport. This could affect the stakeholder relationships and present some policy ramifications. Here, I analyze the impacts of projected aviation growth for two specific airports and their surrounding regions: London Heathrow and East Midlands. The key characteristics of the two cases are shown in Figure 3-9.

As the world's busiest international passenger gateway with significant growth pressures and a long history of community noise conflicts, London Heathrow airport provides a strong case for analysis. London Heathrow Airport handled about 67.9 million terminal and transit passengers in 2005. This accounted for about 49% of all air traffic to/from/through London.[4] There were a total of 477,000 flight operations, of which 99% were operated by commercial airliners. Heathrow handled about 1.3 million metric tonnes of cargo–about 53% of the cargo moved through all UK airports. Operations at Heathrow have been growing about 1.0% per year on average since 1996.

To identify the second airport case, the SAI team developed a number of screening criteria which included regional socio-economic indicators, airport traffic characteristics, and the built urban form of the communities around the airport. The team considered several UK regional airports, including Birmingham, East Midlands, Leeds/Bradford, Luton, Manchester, Newcastle, and Stansted airport. The 2003 Aviation White Paper identified noise issues as potentially constraining growth at Birmingham, Manchester, and Stansted (UK Department for Transport, 2003e)—making these airports attractive candidates for an in-depth study. The large size of these city-regions, however, made them too similar to the case of Heathrow airport. While Newcastle and Leeds have good development potential, these markets are too small to support substantial levels of international traffic service—even given the expected growth through 2025.

The East Midlands Airport handled about 4.7 million passengers in 2006. There were a total of 88,600 flight operations. Only 64% of these flights were for commercial passenger, cargo, or air taxi services; the remainder were general aviation or training flights. Total operations have grown on average by about 5.4% per year since 1996. East

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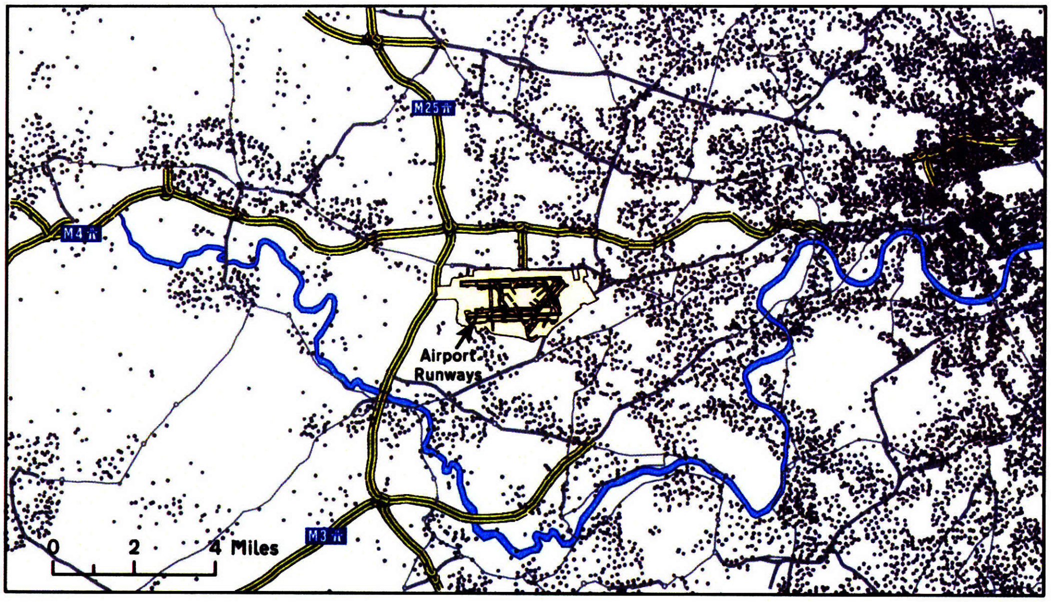
[4] Gatwick had 25%, Stansted 17%, and Luton had 7% of all passenger traffic.

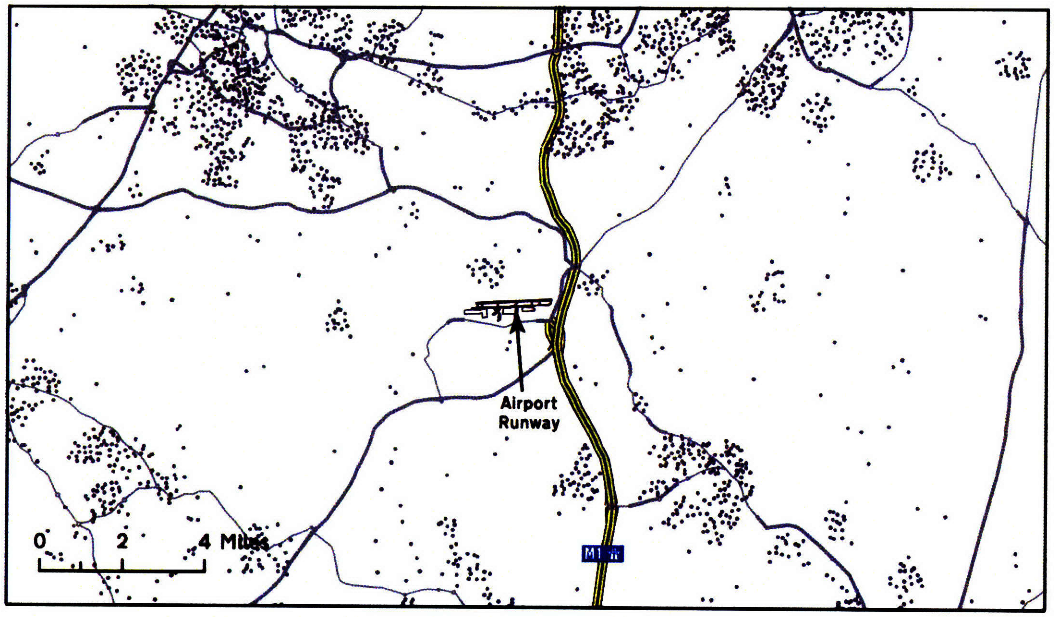
Midlands Airport also handled almost 300,000 metric tonnes of cargo and mail–about 12% of the UK total. It is the largest pure-freight airport in the United Kingdom. Situated within a three-hour drive of most of England's major cities, the airport has become a major base for key cargo carriers such as DHL, TNT, UPS, and the Royal Mail. Most of these freight operations occur at night, when noise issues are most critical. The large presence of nighttime freight operations and logistics handling in the East Midlands was one of the major criteria for its selection as the regional case. Oxford Economic Forecasting estimates that 18% of all firm sales are dependent on air services of one form or another. About one-third of all express packages at the East Midlands Airport are originating or destined to local companies based in the East or West Midlands (Oxford Economic Forecasting, 2006b, p. 8).

3.3.2 Aviation Growth Scenarios

In this analysis, I consider how UK regional socio-economic growth may be affected by changes in aviation. Growth in the aviation sector, for example, could slow as airports reach capacity limits or as environmental policies (for noise or other effects such as climate change) increase the price of air travel. I analyze different air transport growth rates to assess the sensitivity of other sectors in the regional economy to changes in aviation. Aviation growth enters into my analysis in two ways: (1) regional growth of the air transport sector, and (2) increased flights at specific airports. Due to the long-term nature of economic restructuring and technological change, I focus on the long-term growth trends of aviation.



(a) London Heathrow Airport



(b) East Midlands Airport

Note: Each dot represents about 300 people and 130 housing units.
Source: Author's calculations from UK ONS data using ArcMap 9.1

Figure 3-10: Comparison of population density around the London Heathrow and East Midlands airports

The world's largest air transport manufacturers, Boeing and Airbus, have forecast long-term global passenger traffic growth rates of about 4.9% and 4.8% annually through 2025—essentially maintaining the same rate of growth that has occurred over the last 20 years (Boeing, 2006a; Airbus, 2006, p. 17). Total passenger traffic would grow from 4.0 billion to 10.5 billion RPKs by 2025 (Boeing, 2006a, p. 37).

The European Commission has developed the European Constrained Scenarios on Aviation and Emissions (CONSAVE) forecasts to illustrate the range in air travel forecasts that might be expected due to variations in GDP, population growth, technology, and energy usage. These CONSAVE scenarios reflect underlying differences in globalization, travel, and even social attitudes towards the environment (Berghof and Schmitt, 2005, p. 3). The "Down-to-Earth" scenario, for example, assumes some environmental changes, modest GDP growth, and a decline in air transport due to higher costs and low profitability, while the "Regulatory Scenario" has a high increase in traffic and decrease in aviation costs tempered by capacity restrictions and environmental regulations. The average annual growth in air travel demand (passenger-kilometers) for each scenario ranges from 0.9% to 3.4% through 2020.

Figure 3-11 shows the global air traffic forecasts from the leading air transport manufacturers and ICAO along with the CONSAVE scenarios. The contrast between the industry forecasts and the CONSAVE scenarios show that slight differences in global socio-economic development could have large impacts on air traffic levels and suggests that long-term forecasts may need to consider the ramifications of such embedded assumptions.

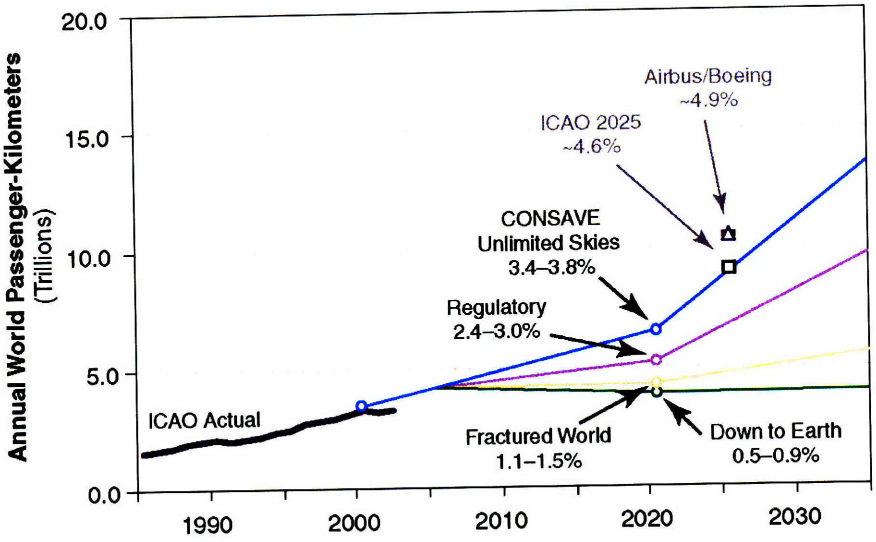


Figure 3-11: Actual global air travel demand with comparison of CONSAVE, ICAO, and Airbus/Boeing growth forecasts, 1985-2050

In the United Kingdom, the UK DfT forecasts increases in air travel demand of about two or three times the current levels. In 2006, the UK airports handled about 235 million passengers and about 2.4 million air transport movements (ATMs). The unconstrained demand at UK airports is expected to rise to 400-600 million passengers per year by 2030 (UK Department for Transport, 2003e, p. 9). Underlying this forecast is the assumption that GDP will increase by 2.25% per year in the United Kingdom and other industrialized countries, with higher growth rates in developing countries.

Air Transport Industry Growth. Economic impact models typically describe the air transportation sector in terms of the monetary value of industry output such as GVA rather than physical output in terms of RPKs or other metrics of airline passenger or freight traffic flows. As is to be expected, Figure 3-12 shows that there is generally a good correlation between RPKs and GVA. I use the latter metric while analyzing the impacts of the air transport sector on regional socio-economic growth. I adopt a relatively simple

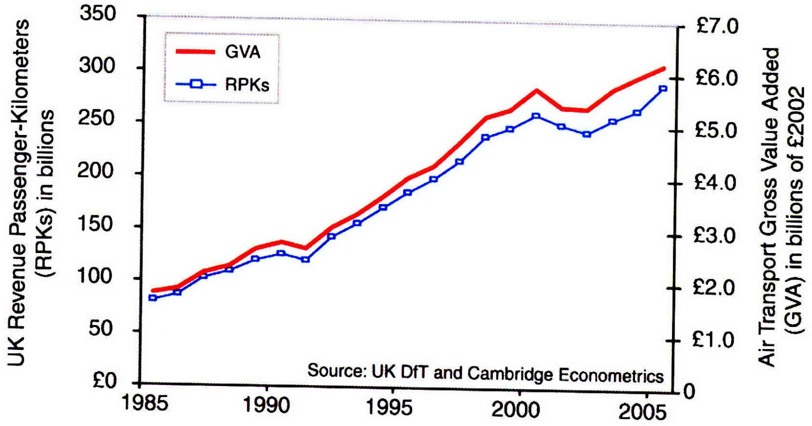
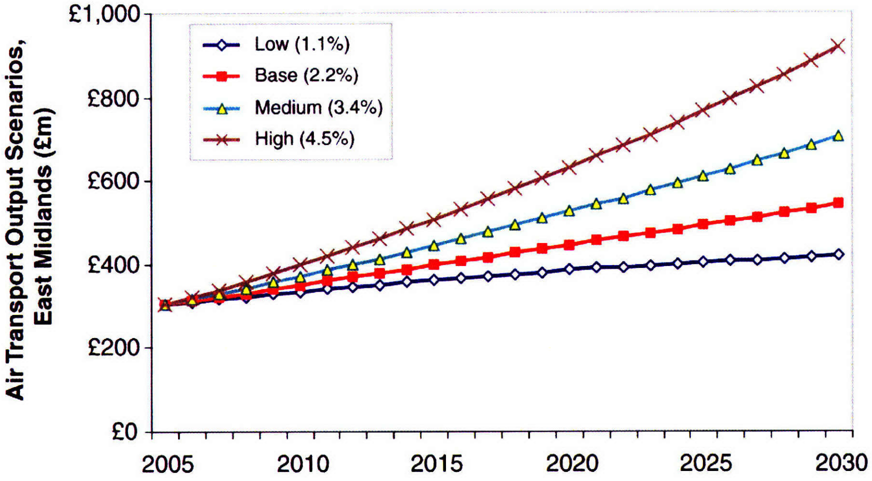


Figure 3-12: Association between air transport industry output and passenger traffic in the United Kingdom, 1985-2005.

methodology for testing a range of growth scenarios relative to a baseline forecast within the regional economic modeling system.

For my baseline reference, I use the REMI-ECOTEC forecast of about 2.2% average growth in the output of the air transport industry. Under this forecast, the air transport sector in the East Midlands will grow to about £230 million in GVA by 2030. I use a "Low Growth" scenario, which corresponds to the most conservative CONSAVE estimates of passenger growth: about 1.5% per year. Under this scenario, the air transport sector GVA in the East Midlands would reach about £176 million pounds. I also analyze the UK DfT forecast of 4.5% growth through 2020 (UK Department for Transport, 2003e) as a "High Growth" scenario—essentially tripling the size of the aviation industry over current levels. I also consider a "Medium Growth" scenario with air transport growth of 3.4% annually. I model these alternative growth scenarios in the REMI-ECOTEC model by using exogenous changes in air transport industry sales within the East Midlands in order to set the overall growth to the target scenario levels. Figure 3-13 shows these scenarios in terms of total air transport output for the East Midlands.



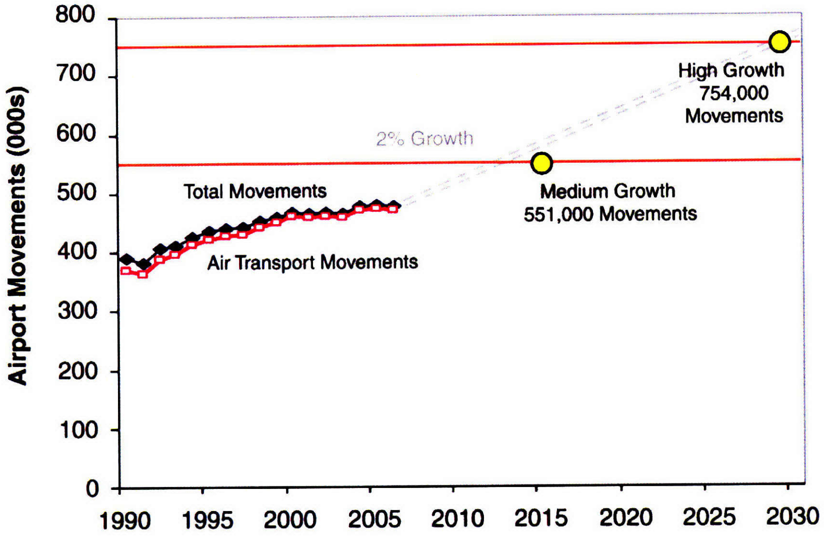
Source: Author's calculations using REMI-ECOTEC UK version 6.0

Figure 3-13: Air transport growth scenarios, East Midlands.

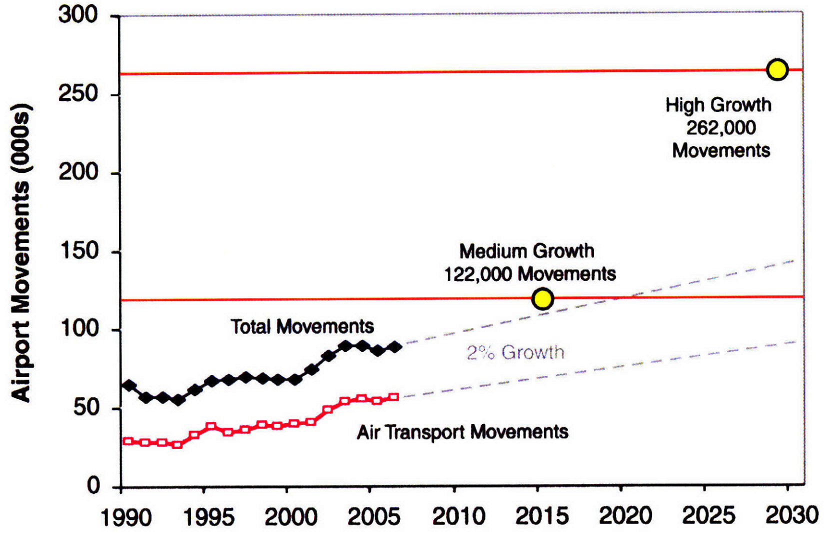
Air Traffic Growth. Changes in airline industry output or revenue passenger-miles may not necessarily correspond directly with changes in airport-specific flight operations, due to differences in the geographic distribution of traffic flows, airline route network structure, aircraft size, average flight length, or even bilateral treaty agreements. In the United States, for example, the FAA expects that by 2025, passenger traffic will grow by about 2.0 to 3.0 times current levels, while the number of flights will increase by 1.4 to 3.0 times current levels (US DOT Joint Planning and Development Office, 2004). Runway and air traffic control capacity are frequently one of the major constraints on air traffic capacity. At London Heathrow, for example, runway capacity is expected to be one of the key constraints limiting growth. In order to facilitate continued passenger traffic growth and make the most efficient use of scarce takeoff and landing slots, BAA is actively encouraging its operators to increase the capacity at Heathrow Airport by promoting the use of larger aircraft like the Airbus A380. The average aircraft size is expected to increase from 185 to 191 seats. Long-term traffic scenarios are 79 to 80 million passengers per year in 2015, and between 89 to 135 million passengers per year in 2030 (BAA Heathrow, 2004b).

The scenarios shown in Figure 3-14 are based on capacity limits and long-term traffic growth forecasts developed for the UK Aviation White Paper (UK Department for Transport, 2003b,d) and also the East Midlands Airport Draft Master Plan (Nottingham East Midlands Airport, 2006). For Heathrow, I include a medium-growth scenario that fully maximizes the use of the existing runways under mixed-mode operations and a high-growth scenario that also relies on mixed mode operations but adds a third runway. The runway alternation scheme at London Heathrow segregates the operations under a multi-week schedule so that all landings occur on one of the parallel runways and all takeoffs occur on the other in order to provide noise relief for communities living near the airport. Eliminating this operational scheme could immediately increase runway capacity by 15-20% (Webster, 2005), without the construction of any new runways. At the East Midlands airport, the UK DfT predicts that traffic will grow to about 12-14 million passengers per year and 2.5 million tonnes of freight by 2030. This would involve about 60,000 cargo flights a year (UK Department for Transport, 2003e, p. 97). There are no plans for runway expansion at the East Midlands Airport, so any traffic increases will be confined to the existing runway.

Advanced Technology, Low-Noise Aircraft Scenario. Finally, to examine how changes in aircraft technology could potentially affect the noise-damage costs, I introduce an advanced technology, low-noise aircraft into the analysis. I evaluate how the SAX-40 would affect the noise contours and associated noise-damage costs under different fleet penetration scenarios. My SAX-40 scenarios include the replacement of (a) all



(a) London Heathrow Airport



(b) East Midlands Airport

Source: DfT SERAS forecasts

Figure 3-14: Historical airport movements and growth scenarios at London Heathrow and East Midlands airports, 1990-2030 comparable aircraft such as B757s, B767s, B777s, and A330s, and (b) the replacement of all longhaul aircraft such as A340s and B747s.

3.4 Analytical Instruments

I use regional economic growth and aircraft noise-damage costs as two research instruments to analyze some of the wider positive and negative externalities, respectively, of the air transportation system. An underlying assumption of my regional economic analysis is that regional economic growth is good because it leads to increased household earnings and disposable income per capita. But accessibility is not always good: more competition for jobs and increased population in-migration could lead to increased housing prices and even decreased wages. In addition, there are questions as to whether or not nuisance values are accurately capitalized within housing values. The failure of housing consumers to understand the long-term impacts of noise might explain why airport noise continues to create socio-political conflicts. Nevertheless, both of these instruments are relatively simple to understand and well-used by analysts and other environmental and political stakeholders alike. Despite their limitations, they are useful tools to help communicate the complexity of the situation.

3.4.1 Key Economic Indicators

In order to measure the economic activity in these regions, I primarily focus on the supply-side value-added produced by the various industrial sectors. Value-added is the total monetary value of the outputs produced by a sector minus its material inputs—and thus can essentially be considered as total profit and compensation or wages (Miller and Ervin, 2004). Total value-added is also equivalent to aggregate Gross Regional Product—another commonly-used metric. Total GRP equals the total of personal consumption, investment, government expenditures, and net foreign exports.

Although I have obtained detailed UK inter-industry transaction data for up to 123 industrial sectors[5], I primarily focus on a simplified analysis framework with the following 9 key aggregated sector-groups: (1) Agriculture and Mining, (2), Manufacturing, (3) Utilities and Construction, (4) Retail Services, (5) Hotels and Restaurants, (6) Other Transport Services, and (7) Air Transport Services. In my analyses, I also divide the services sector between locally-oriented services and telecom (8), and non-local professional services and household services (9). In regional economic terminology, the local and non-local services are called the *Non-Basic* and *Basic* sectors, respectively. An example of a local or non-basic sector is Equipment Renting or Sewage Disposal, while Banking/Finance or Research and Development are examples of non-local or basic sectors, the demand for which comes from outside of the region. For the purposes of this analysis, I classify these sectors as basic or non-basic based on the share of local consumption relative to total exports.

The 2002 UK input-output regional accounting framework is based on the European System of Accounts 1995 (ESA 95) standard and defines the air transport sector as the output from scheduled and unscheduled air carriers (UK Office for National Statistics, 2002, p. 5). This rather narrow definition excludes aircraft manufacturers or supporting industries, such as travel agents or ground handlers. I primarily analyze the economy-wide impacts of the air transport sector, but also consider growth in other industries that

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[5] UK Office of National Statistics input-output tables; I also use data from REMI-ECOTEC (53 sectors) and Cambridge Econometrics (34 sectors.)

rely on air transport. Such industries may use air transport for only a small percentage of their total inputs or purchases, but yet rely heavily on air transport for global connectivity and knowledge exchange. Such sectors include creative industries, such as advertising, fashion, or film production, or consulting and service sectors.

As my case studies are focused on the Greater London (Heathrow) and East Midlands airports, I primarily analyze the economic activity in these regions. Based on input from Greater London Authority (GLA) Economics, I also include discussion of the South East region of England as part of London's catchment area. I focus on the relative inter-industry relationships between these regions relative to those in the rest of the United Kingdom and the Rest of the World. Employment, relative wages, and relative prices of goods all affect how economic growth and migration are distributed among the various regions and their overall performance.

3.4.2 Noise and Damage Cost Indicators

Despite the known physics of sound propagation, aircraft noise measurement is nevertheless a complex process that is often debated between anti-noise advocates and noise regulatory agencies, such as the FAA or the BAA (Stenzel et al., 1996, p. 19). In the United Kingdom, the UK DfT uses the 57-dBA L_{Aeq} noise level as the threshold for significant community annoyance from daytime noise (UK Department for Transport, 2003c, p. 9). I use this threshold as a reference to identify the changes in noise-damage costs. The UK DfT also uses the 63- and 69-dBA L_{Aeq} contours to determine the points of moderate and high aircraft noise exposure or annoyance, respectively.

3.4.3 Evaluating the Results

One of the key questions is how to evaluate the results of these analyses and this methodology as a whole. Input-output models are well-established and very straightforward. While the REMI-ECOTEC model is one of the most popular economic policy models of its type in the United States, it is still somewhat of a black box. I focus my model evaluation on three areas: (1) understanding the structure of the models that I utilize, (2) ensuring that I use appropriate model inputs, and (3) evaluating the reasonableness of the results.

First, I review the model documentation and conduct simple sensitivity tests to understand the model assumptions and behavior as best as possible. While basic econometric models are evaluated in terms of how well they fit the empirical data, behavioral models such as REMI-ECOTEC need to be evaluated in terms of their performance: how well the model behavior reflects overall theory and expected outcomes. In addition, the long-term, ex-ante nature of this analysis means that understanding the differences between the scenarios, is more useful than the economic forecasts themselves. I then use this understanding of the model to ensure that the model inputs are appropriate in magnitude and reflect the types of effects that I am trying to model. Finally, I evaluate the outputs to see if they are reasonable.

3.4.4 Methodological Limitations

Although there are a number of methodological limitations with the estimation of noise-damage costs and regional economic impacts, I use these analyses as more general research instruments to understand some of the internal and external relationships within the air transportation system, rather than as definitive statements on the value of aircraft noise impacts. Ashford and Wright (1992, p. 498-499) note that measuring airport noise impacts is an inexact science that requires considerable attention to its subjective aspects. The limitations of hedonic price studies include statistically confounding factors, equilibrium assumptions, unequal day/night benefits, non-uniform populations, and self-selection biases (UK Department for Transport, 2000b, p. 4). Although I recognize these limitations, I use hedonic price studies in the absence of other market-traded (economic) proxies to ascertain the value of airport-noise damages.

There are certainly also limitations with ex-ante regional economic-impact studies, but such methodologies have been used for decades by regional analysts. In such studies, one of the major sources of error is in estimating the size of the exogenous shock—such errors may be greater than those due to the choice of modeling technique (Loveridge, 2004, p. 313). Although integrated econometric input-output models such as the REMI-ECOTEC Policy Insight offer the econometric advantages of dynamic forecasts while providing the detailed industry-level specifications of input-output models, the lack of regional-specific data or fixed [input-output] technology proportions may lead to the misspecification of the model or other errors (Loveridge, 2004, p. 310). Also, input-output models are often based on the transactions accounted for within a single year, and may thus project such irregularities over time (Bendavid-Val, 1991, p. 113). Nevertheless, input-output models can be used to identify the indirect impacts of an economic change and highlight the explicit interconnections of different sectors within an economy—thus keeping it an indispensable part of effective regional science research (Isard et al., 1998, p. 42).

One of the potential limitations of this specific version of the REMI-ECOTEC model is its use of US and European data to calibrate some of the economic-geography relationships. Because this model is based on the 2002 UK input-output tables, however, it does not provide ex-post forecasts of previous years for comparison. Also, the implementation of the new economic geography features in the REMI model have not been generally critiqued in the literature, although previous versions of REMI have been discussed (Bolton, 1985; Mourouzi-Sivitanidou and Polenske, 1989; Rey, 2000). Even so, I have used REMI-ECOTEC for almost three years and have become very familiar with its operation. In comparison with other UK models, the vendor has been willing to allow us to operate the model ourselves—enabling us to gain experience and familiarity with the model parameters and sensitivities. In contrast, other vendors required that their services be hired; we determined that the costs of this were excessive and that we also would not know the model well unless we operated it ourself. Also, the model is a close derivative of a well-established and widely-used model in the United States (REMI Policy Insight), thus providing a larger resource base of practitioners and academics. Indeed, Loveridge (2004, p. 306) notes that factors such as model availability or budget, user experiences, or desired outcomes, often drive model selection in practice

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Chapter 4

Accounting for the Multi-Regional Economic Role of Air Transport

To document the role of air transport in the regional and national economy of the United Kingdom, I use a regional economic accounting framework which focuses on the economic output of the air transport industry (and related industries) rather than metrics of physical output, such as number of passengers or freight-tons moved. I discuss the magnitude of the air transport sector and its role relative to other industries in the regional economy using a well-established regional input-output accounting framework.

Although such static analyses include the direct and indirect supply-chain impacts, they do not show how these impacts might evolve over time. As discussed in Chapter 2, policymakers and other community stakeholders often use dynamic economic models to consider long-term, inter-regional policies—especially when the scale and wide scope of transportation systems brings issues of equity and resources to the forefront of policy debates. I extend my analytical framework to include such an analysis of aviation growth over time and across regions. I use the REMI-ECOTEC model to simulate different levels of economic activity at the East Midlands airport and identify the associated economic impacts across different regions of the United Kingdom. I also use the example of a temporary increase in air travel demand, such as during a cycle of airport growth and decline, to illustrate the structure of the REMI-ECOTEC model.

4.1 Aviation and Regional Economies

Regional analysts often exploit the descriptive analytical power of input-output analyses to create comprehensive pictures of how economies work (Bendavid-Val, 1991, p. 113). Using such studies of interregional production linkages, analysts can identify how exports and imports contribute to regional economies and highlight strategic opportunities to strengthen regional incomes and employment. Hirschman (1958, p. 100), for example, used the backward derived-demand linkages between intermediate and total purchases to identify local suppliers that could enhance the effectiveness of industrial development strategies. Hirschman also used the concept of forward linkages to identify how the outputs from one industry can enable the growth of other industries (Polenske and Sivitanides, 1990, pp. 148-149).

In this section, I use the 2002 UK input-output tables to discuss the role of the air transport sector and its relationship to the biggest industrial sectors in the United Kingdom. By identifying these primary attributes of the regional and national economies, I will set the groundwork for the analysis of aviation growth over time.

4.1.1 National and Regional Role of the Air Transport Sector

Table 4.1 shows the national supply and demand for the air transport sector in the United Kingdom as described by the 2002 UK input-output tables. Over half of the £21 billion

Table 4.1: Supply and demand for air transport in the UK, 2002

Type	Category	Amount (£m)	Percent (%)
Demand	Total intermediate demand	5,418	25.8
	Household Consumption	11,005	52.3
	EU Service Exports	2,049	9.7
	Non-EU Service Exports	2,561	12.2
	Total Demand for Air Transport	21,033	100.0
Supply	Total domestic output of products	13,008	62.7
	EU Imports of Services	4,171	20.1
	Non-EU Imports of Services	2,763	13.3
	Taxes less subsidies on products	814	3.9
	Total Supply of Air Transport	20,756	100.0

Output in basic prices; supply in purchasers' prices. Self-supply excludes margins and net taxes. EU Data includes 25 member states. Source: Author's calculations from UK ONS Data

total demand for air transport is for final personal consumption by households (i.e., personal travel). Exports account for over 20% of the total air transport demand in the United Kingdom. UK companies supply about 60% of the total economic demand for air transport in the country, while over 30% of the demand is met through imports from the rest of Europe and abroad (i.e., UK passengers purchasing tickets on foreign air carriers).

Just over a quarter of the total demand for air transport in the UK was for intermediate use by other industries–about £5.4 billion. Table 4.2 shows how different types of industry sectors use air transportation to meet their total intermediate demands. In essence, this table shows how much air transport each sector uses in order to produce its final output. The manufacturing sector, for example, purchases about £675 million in air transport each year—or about 0.3% of its £258 billion in intermediate inputs. The basic services and telecom sectorgroup is the largest user of air transport—accounting for about 1.2% of its total intermediate inputs and £2.5 billion in intermediate demand.

Table 4.2: UK demand for air transport as a percentage of total intermediate Inputs, 2002

Sector	Total Intermediate Demand (£ m)	Air Transport Sector	
		Demand (£ m)	Share of Intermediate Demand (%)
Agriculture and Mining	20,793	122	0.59
Manufacturing	245,070	657	0.27
Fuel	12,868	17	0.14
Utilities and Construction	121,852	41	0.03
Retail Services	103,360	518	0.50
Hotels and Restaurants	32,674	127	0.39
Other Transport	50,499	472	0.94
Air Transport	7,811	562	7.19
Basic Services and Telecom	191,070	2,544	1.33
Nonbasic Services and Households	180,052	357	0.20
Total	966,049	5,418	0.56

In 2002 £. Source: Author's calculations from UK ONS data

Overall, the intermediate demand for air transport (£5.4 billion) represents about 0.6% of the total £966 billion in intermediate purchases.

Because it is a vertically integrated industry with specialized sub-suppliers, the air transport sector purchased a very large portion of its intermediate inputs from itself. Airlines, for example, purchase goods and services from aircraft catering and aircraft maintenance firms who are also identified as part of the air transport sector. Retail and hotel/restaurant sectors were very large consumers of air transport for intermediate purchases as a percentage of total intermediate inputs (0.5% and 0.4%, respectively).

The top ten industrial sub-sectors that use air transport are shown in Table 4.3. These ten industries account for about two-thirds of the total intermediate demand for air transport, or about £3.6 billion. The Banking and Finance industry was the top purchaser of air transport—purchasing over £750 million of air transport services and about 14%

Table 4.3: Top ten UK industrial sectors' use of air transport (intermediate demand) by rank, 2002

Rank	Sector Group	Industry Sub-Sector	Demand (£m)	Percent (%)
1	Basic Services	Banking & finance	755	13.9
2	Air transport	Air Transport	562	10.4
3	Basic Services	Insurance & pension funds	541	10.0
4	Basic Services	Ancillary transport services	379	7.0
5	Basic Services	Postal & courier services	342	6.3
6	Retail Services	Wholesale distribution	300	5.5
7	Basic Services	Other business services	284	5.2
8	Basic Services	Recreational services	155	2.9
9	Retail Services	Auto distribution, repair, and fuel	137	2.5
10	Manufacturing	Printing & publishing	131	2.4
–	All Other Sectors		1,831	33.8
Total Intermediate Demand			5,418	100.0

In 2002 £. Source: Author's calculations from UK ONS data.

of the total intermediate demand. The insurance and pension funds sector invested or purchased £540 million from the air transport sector in 2002. Much of this demand for air transport is also presumably related to aircraft leasing and finance, and the insurance and pension funds rely on these leases as part of their overall investment portfolio.

Table 4.4 shows how the air transport sector uses £7.8 billion in inputs from other sectors in order to create its £13.0 billion in output. In the input-output accounting framework, it is the spending by the air transport sector in these other areas that lead to the indirect economic effects. A large percentage of the inputs are from the manufacturing sector—which includes refined petroleum. About 20% of the total intermediate inputs came from the petroleum sector (about £1.6 billion). This roughly matches with the fuel costs as reported by the airline sector—about 25% of all operating expenses for large airlines in the United States in 2007 (US Bureau of Transportation Statistics, Office of Airline Information, 2008).[1] Other large intermediate demands by the

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[1] Data from 2007, before the dramatic increases in fuels costs during the first half of 2008.

Table 4.4: Commodity purchases for intermediate use by the Air Transport sector, 2002

Sector	Intermediate Demand (£m)	Percent (%)
Agriculture and Mining	0	0.0
Manufacturing	770	9.9
Fuel	1,581	20.2
Utilities and Construction	94	1.2
Retail Services	113	1.4
Hotels and Restaurants	172	2.2
Other Transport	1,528	19.6
Air Transport	562	7.2
Basic Services and Telecom	2,366	30.3
Nonbasic Services and Households	625	8.0
Total	7,811	100.0

In 2002 £. Fuel includes coke ovens, refined petroleum, and nuclear fuel. Source: Author's calculations from UK ONS data

air transport sector include computer services, aircraft, pension funds, and real estate. Later in this chapter, I discuss how these production relationships are applied within the REMI-ECOTEC model in order to estimate the wider indirect and induced economic effects of an exogenous shock.

4.1.2 Air Transport Relative to the Entire Economy

Having identified the role of the air transport sector, I now focus on how air transport compares to other sectors. As shown in Table 4.5, REMI-ECOTEC estimates that the air transport sector produced £3.2 billion of regional value-added in London and about £100 million in the East Midlands region. This amounted to about 1.5% of the total economy in Greater London and 0.2% in the East Midlands. Nevertheless, the air transport sector in 2005 employed about 43,000 people in Greater London and 2,000 in the East Midlands—making these airports among the largest employers in either of these regions.

Table 4.5: Gross regional value-added by sector, 2005

Value-added by sector (£m)	Region				UK Total
	Greater London	South East	East Midlands	Rest of UK	
Agriculture and Mining	2,520	3,160	1,160	21,800	28,650
Manufacturing	17,270	25,570	19,310	132,580	194,730
Fuel	280	3,050	490	23,180	27,010
Utilities and Construction	11,150	12,410	5,700	54,250	83,520
Retail Services	19,930	20,540	7,740	71,850	120,050
Hotels and Restaurants	9,060	6,400	2,330	24,370	42,170
Other Transport	8,710	6,310	2,560	22,160	39,740
Air Transport	3,230	1,310	130	1,690	6,360
Basic Services and Telecom	78,620	45,050	11,070	125,860	260,590
Nonbasic Services and Households	61,820	44,480	16,310	177,540	300,160
Total	212,600	168,290	66,800	655,280	1,102,970

In 2002 £. Source: Author's calculations from REMI-ECOTEC UK Version 6.0

Table 4.6: Total forward and backward linkages in REMI-ECOTEC model by industry-groupings

Sector Name	Total Linkages*		Rank Order	
	Backward	Forward	Backward	Forward
Agriculture and Mining	1.639	1.984	8	3
Manufacturing	1.641	1.654	7	6
Utilities and Construction	2.148	1.862	1	4
Retail Services	1.904	1.751	3	5
Hotels and Restaurants	1.702	1.178	6	9
Other Transport	2.051	2.494	2	1
Air Transport	1.703	1.499	5	7
Basic Services and Telecom	1.836	2.278	4	2
Nonbasic Services and Households	1.631	1.362	9	8

*Direct and indirect linkages. Source: Author's calculations from REMI-ECOTEC UK version 6.0

Table 4.7: Air freight as percentage of total UK trade by volume and value, 1998

	Trade by Volume			Trade by Value		
	Total Tonnes (m)	Air Freight Tonnes (m)	Air Freight Share (%)	Total Value (£m)	Air Freight (£m)	Air Freight Share (%)
Imports	177.2	0.9	0.50	172,500	53,600	31.0
Exports	169.1	0.7	0.39	147,500	46,600	32.0

Source: UK Department for Transport (2000a). Data from CAA, HMC&E

One way of illustrating the relative impact of these supply-chain relationships for different industries is shown in Table 4.6. Backward linkages show the dependence of a sector on other sectors, while forward linkages show how the output from one sector is utilized in other sectors (Dietzenbacher, 2002, pp. 126-127). Backward linkages are calculated by summing down each of intermediate demand columns in a direct-input-coefficient table (inputs per unit of output), while the forward linkages are the row sum from a direct-output-coefficient table (sales per unit of output) (Polenske and Fournier, 1993; Miller and Blair, 1985).

Higher relative forward linkages show greater utilization of that sector as intermediate inputs into other sectors. As an intermediate industry, aviation has relatively low backward and forward linkages compared to other industries such as basic services/telecom or even other types of land transport in general. Indeed, Table 4.3 on page 103 shows that over 52% of the demand for air transport in the United Kingdom comes from household consumers in the form of final demand.

Although the air transport sector itself is a relatively small industry within the context of supply-chain purchasing relationships, other evidence suggests that it is crucial to national exports. Table 4.7 shows that while only about 0.5% of all UK imports and 0.4%

of all exports by volume occur via air-freight in 1998, this accounts for over 30% of all trade by value. The strategic value of an input is not necessarily reflected in the input-output linkages, because such simplified models do not account for alternative production technologies or changes inter-regional purchasing relationships. Some analysts try to incorporate such longer-term trends within more sophisticated econometric input-output models, such as REMI.

4.2 Forecasting with the REMI-ECOTEC Model

Having discussed the role the air transport sector and its relationship to the rest of the regional economy in the United Kingdom, I now focus on the use of a model to explore these relationships over time. The transition between documenting economic relationships to modeling and forecasting these relationships over time, however, is not necessarily straightforward. Although modelers make tradeoffs between theories, data, and methodologies (Greenberger et al., 1976, pp. 63), they often select models based on outcome or availability (Loveridge, 2004, p. 306). Stakeholders and decision-makers in areas such as energy policy or international trade regularly view computer models with suspicion (Meadows and Robinson, 1985, p. 6)—presumably due to the difficulty in evaluating modelers' underlying assumptions and motivations. Moreover, Greenberger et al. (1976, p. 20) suggest that the political environment plays a decisive role in how models are received by policymakers and the public; models can be bitterly attacked despite the use of well-known theories (Greenberger et al., 1976, p. 67).[2]

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[2] In 1976, Greenberger et al. noted that the use of models in analysis, guidance, and problem-solving in the rational validation of policy decisions will give way to their use in providing political validity. Complex models employed to corroborate policy proposals may be used as political instruments not only by their sponsors, however, but also by antagonists (Greenberger et al., 1976, pp. 43-46).

Nevertheless, computer-based forecasting models are recognized as being able to bring elements of rigor, comprehensiveness, logic, accessibility, and flexibility to socio-economic decision-making processes (Meadows and Robinson, 1985, p. 6). For this analysis, I use the REMI-ECOTEC model—a UK-specific version of a widely-used regional forecasting model in the United States. Here, I refer to the theory, data, and methodology behind the underlying US REMI model.

4.2.1 Theory, Data, and Methodology

The REMI model generates industry-level details on output and employment, as well as detailed regional forecasts of population migration, prices and inflation, labor supply, and other socio-economic indicators. The REMI model variables and structure closely map the data and tools that policymakers use in real-life, and is thus easier to understand than many economic models. The REMI model is based on neoclassical economic theory and assumptions that firms and consumers are rational profit and utility maximizers and that entrepreneurs have perfect information about relative national and regional costs (Polenske et al., 1992, p. 6). The underlying basis for the REMI model is that economic units in one region of a country have the same behavioral characteristics as in other regions, and that there are no unique interregional differences in firm or household motivation or behavior. The model assumes that regional and national production processes are the same, but with different total factor productivity and factor intensities in each region (Polenske et al., 1992, p. 6).[3] As such, the observed differences among regions in reaction to exogenous shocks can be explained by differences in industrial

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[3] The model uses a Cobb-Douglas production function with constant returns to scale.

composition, regional purchase coefficients, and other variables that can be modeled (Cassing and Giarratani, 1992, pp. 1562-1563).

The data used to solve and calibrate the REMI-ECOTEC model structure include a 53-sector version of the 2002 UK national input-output tables, as well as data on employment, wage rates, productivity, occupational characteristics, and growth rates from the UK Office of National Statistics, Eurostat, the United Nations, and other sources. Long-term regional demographic trends, such as population, survival rates, migration, and labor force, are also integrated into the model parameters and are based on data from the UK Actuary Department. Inter-regional commodity and labor flows are calibrated using data from the United States and Europe, while the response rates to economic stimuli are set to be faster than in Europe in general, but slower than in the United States (Whitfield, 2005).

The REMI model iteratively couples input-output and econometric sub-models until a equilibrium solution is reached (Loveridge, 2004, pp. 309-310). Loveridge notes that such a methodology overcomes many of the criticisms of standard input-output (I-O) approaches, but that the inter-regional trade estimates still rely on fixed regional trade relationships (i.e., the regional purchase coefficients). The model parameters reflect the causal relationships between the exogenous (external to the model) and endogenous (internal to the model) variables that are based on historical data. The distinction between these variables is that the endogenous variables, such as personal consumption, are used to represent economic phenomena that are determined within the economic region of interest, while the exogenous variables, such as national exports, are determined outside the region (Treyz, 1993, pp. 7-8). Socio-economic data at the

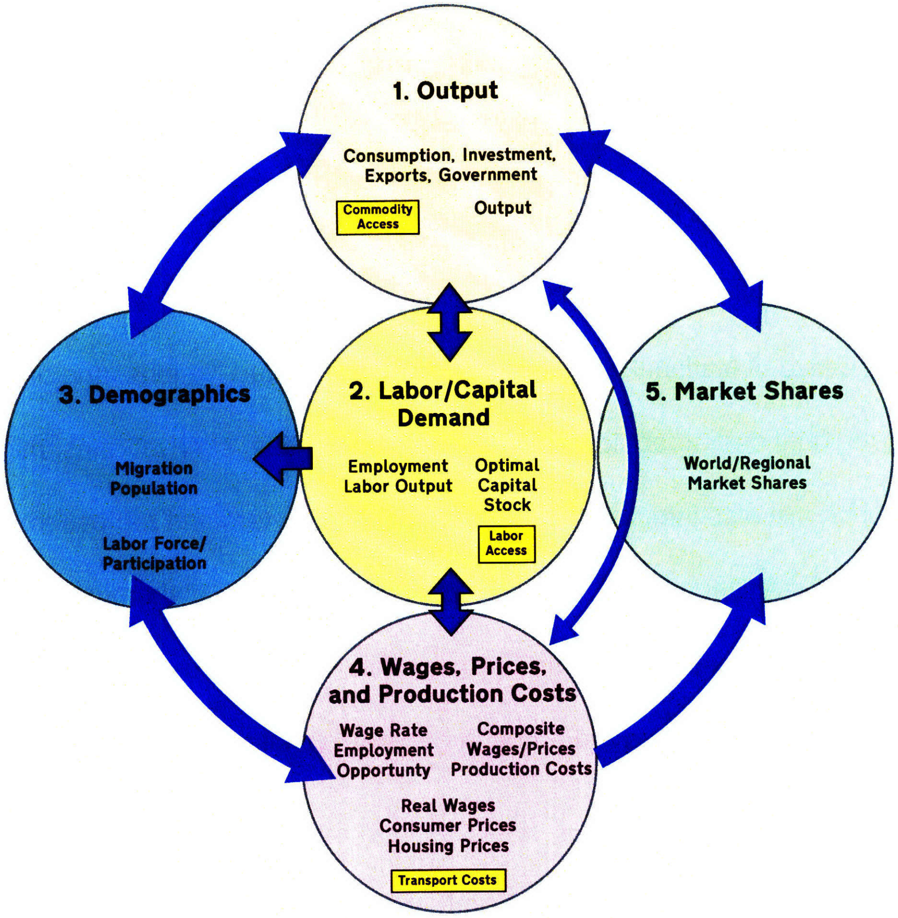

Figure 4-1: Overall structure of the REMI-ECOTEC model

regional level are typically more scarce and inconsistent than national data, so the REMI approach of using a relatively large amount of local data to calibrate these relationships ensures better model performance (ECOTEC Research and Consulting Limited, 2004, p. XXIV) and a richer representation than would be otherwise possible (European Commission Regional Policy Evaluation Unit, 2003, pp. 3-4). Overall, this modeling approach may actually improve the long-term forecasting accuracy of the REMI model over other economic models (Cassing and Giarratani, 1986, p. 1611), because the forecasts are based on fundamental economic principals instead of historical data.

The different linkages within the model are shown in Figure 4-1, and are conceptually organized into the following five blocks: (1) Output, (2) Labor and Capital Demand, (3) Demographics, (4) Wages, Prices, and Production Costs, and (5) Market Shares. As with traditional macro-economic models, industry-level output (Block 1) is affected by personal consumption, investment, government spending, and exports. Output affects employment (Block 2) and wages (Block 4). Wages and transportation costs affect the delivered prices for each industry (Block 4), which then affect the regional and international market shares for each industry (Block 5). Relative wages, employment opportunities, housing prices, and purchasing power also affect economic migration and population (Block 3), which then affect government spending and output. Investment (Block 1) is based on the difference between optimal and actual capital stock (Block 2) for residential, non-residential, and equipment needs (REMI, 2004b, p. 7-8).

4.2.2 Model Application

As part of the development of a region-specific model, Regional Economic Modeling, Inc. (Amherst, Massachusetts) and ECOTEC (Birmingham, United Kingdom) (REMI-ECOTEC) develop a baseline control forecast by setting the exogenous variables and then solving for a unique set of endogenous variables that are consistent with both the model parameters and baseline exogenous variables (Treyz, 1993, pp. 7-8). The model calibration process involves two parts. First, the overall model structure is calibrated by using information from cross-sectional studies using data from all regions of the United States in order to yield econometric response parameters that are representative of all regions. Next, REMI solves for the region-specific coefficients that capture the explicit demand and supply relationships for labor and product markets (Cassing and Giarratani, 1992, pp. 1550-1551). For the UK-specific REMI-ECOTEC model, the inter-regional commodity and labor accessibility relationships are calibrated using data from both the United States and Europe. To reflect the nature of the United Kingdom economy, the economic response rates are set to be faster than in Europe, but slower than in the United States (Whitfield, 2005).

With a baseline regional forecast, model users can then simulate changes to the economy by modifying any of a wide range of "policy variables" that are included as part of the model structure itself. These policy variables include typical economic analysis categories, such as industry sales, demand, government spending, consumer spending, or investment. The selection of the appropriate policy variables is one of the most critical steps in the modeling process, especially since the REMI model has thousands of variables. This process is somewhat subjective, and it requires the analyst to determine how the shock will affect the economy—thus where it would best fit within the model.[4] The analyst then runs the model with these changes in order to determine the changes in multi-regional effects. By comparing the economic impacts of a policy simulation with a baseline regional control forecast that is supplied by REMI, analysts can identify the wider effects over time of a given policy change across different sectors and regions.

Analysts often use a detailed diagram of the REMI model structure, such as one similar to that shown in Figure 4-2, in order to help conceptualize the appropriate policy variables to use. The diagram shows the overall structure of the REMI "economy," including the general location of the key policy variables within the model, as well as

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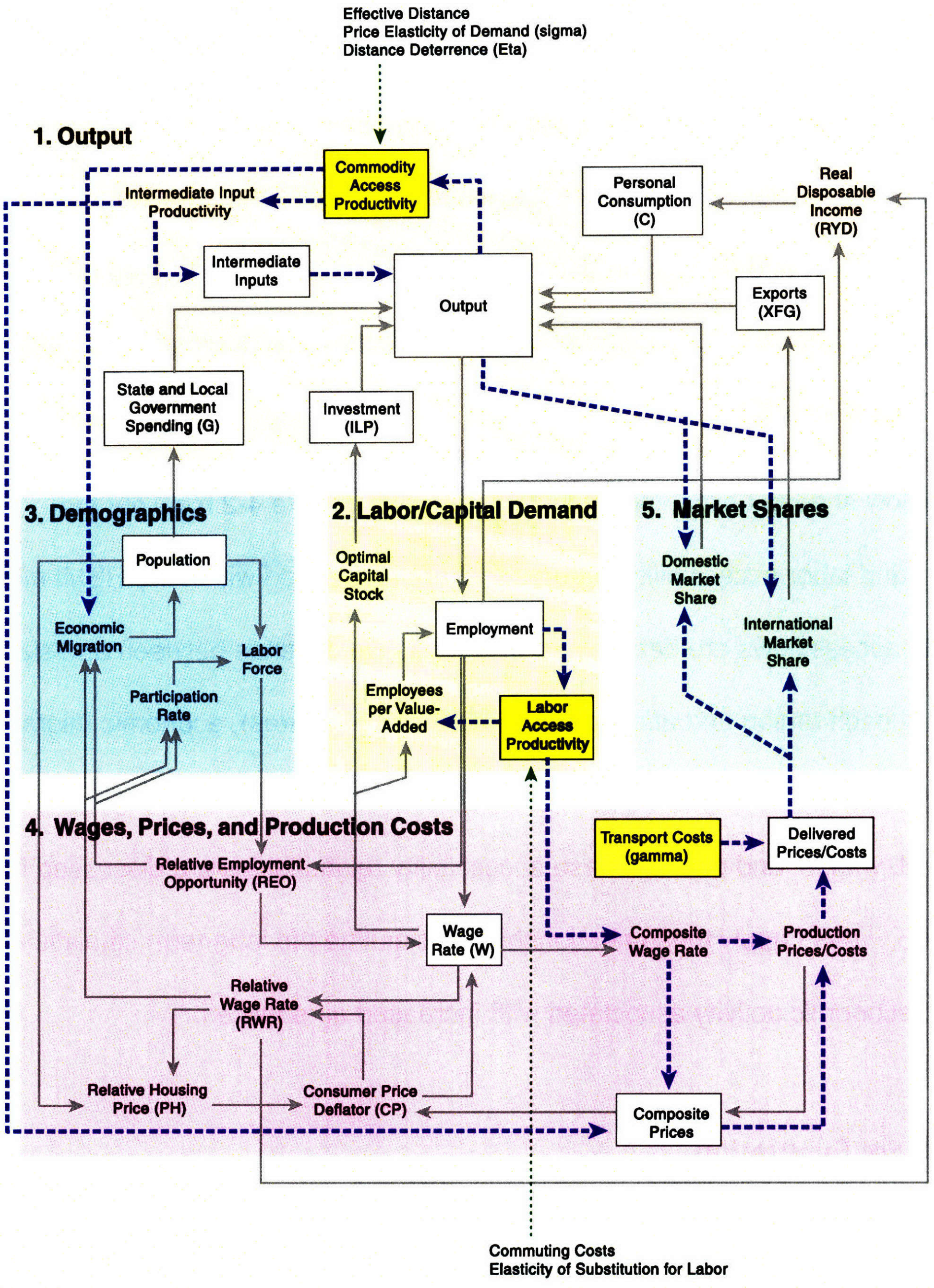
[4] In some cases, consultants from REMI have suggested spreading economic shocks across several different policy variables, in order to capture the effects (Regional Economic Modeling, Inc., 2005).

the main linkages between the variables. In the scenarios tested later in this chapter, for example, changes in exogenous industry sales for the air transport industry affect overall industry output (Block 1). These changes in output affect the level of employment in each industry (Block 2), and then wage rates and relative employment opportunity (both in Block 4), as well as real disposable income (Block 1). Relative wage rates affect economic migration and population demographics (Block 3), and then feed back into housing prices (Block 4). Wages and prices then affect overall domestic and international market shares (Block 5).

The yellow shaded boxes and dashed blue lines in Figure 4-2 highlight the commodity and labor accessibility features that are embedded within the REMI model. Commodity access flows are determined by the relative distance between and size of the industries in each region and affect outputs (and market shares), economic migration, and composite prices. Labor access is determined by commuting costs and affects employment, wages, and prices. These accessibility relationships are discussed further in Chapter 5, when I apply these relationships to simulate the long-term catalytic changes in regional economic activity associated with increased air services.

4.2.3 Model Evaluation

The REMI-ECOTEC model was developed jointly by REMI and ECOTEC for the United Kingdom, but is based on the REMI Policy Insight model. Historically, one of the distinguishing features of REMI has been its user transparency and documentation compared to other models. Mills (1993) lauded REMI for keeping explicit detail about its methodologies within the public domain. He contrasted this with the proprietary models



Adapted from REMI (2004b, pp. 19-20)

Figure 4-2: Detailed structure of the policy variables and accessibility relationships within the REMI-ECOTEC model of many consulting firms, for which there is often no easy way to evaluate the outputs or model structure (Mills, 1993, p. 30).

Analysts have found the REMI model in the United States to be comparable to other modeling approaches (Bolton, 1985; Mourouzi-Sivitanidou and Polenske, 1989; Rey, 2000). Rickman and Schwer (1995, p. 372) found that the multipliers in the REMI models were statistically indistinguishable from other popular regional impact models, such as the IMPLAN and RIMS II models, after benchmarking and controlling for the differences in the model structure. The IMPLAN and RIMS II models are commonly used throughout the United States for simple impact analyses.[5] Because they are static input-output models, which use a fundamentally different methodology than REMI to determine the regional flows of goods and services, they are limited in comparability (Rickman and Schwer, 1995, pp. 365-372).

Cassing and Giarratani (1992) and Polenske et al. (1992) conducted comprehensive reviews of the South Coast Air Quality Management District (SCAQMD) version of the REMI model. Cassing and Giarratani observed that the model responded in the proper size and direction to changes in the cost of production and the effects of an export shock, and that there are advantages to REMI's explicit theoretical structure. Polenske et al. (1992, pp. 28-31) conducted sensitivity tests of several variables, such as consumer spending and relative energy costs, within the context of assessing proposed policies for the SCAQMD. Polenske et al. found that the economic impacts resulting from changes to specific policies are very small—thus demonstrating that the model is not sensitive to small biases or errors in preparing the inputs to the model.[6]

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[5] IMPLAN was initially developed by the US Agriculture and Forest Service

[6] For example, they found regional employment impacts of fewer than 10 jobs from a one-time change (+/- 20%) in the demand for public utilities—impacts which are essentially zero. They also found the dynamic

Since the time that many of these evaluations were conducted, the REMI model has evolved substantially to include features such as a dynamic capital-stock-adjustment process (Rickman et al., 1993), migration equations with detailed demographics (Greenwood et al., 1991; Treyz et al., 1993), consumption equations (Treyz and Petraglia, 2001), and commodity/labor accessibility features (Fan et al., 2000). REMI has updated the Policy Insight model almost yearly since 2002, with additional data, new policy variables, expanded industrial sectors, and several new population cohorts. The continual model revisions and some changes to the user interface have made it difficult for independent analysts to conduct detailed evaluations of the REMI forecasts and model structure, although Tirado (2004) conducted a limited sensitivity analysis and Barbhaya (2005) examined the economic and population variables in a baseline model.

In a multi-regional model of El Paso County, Texas, Tirado (2004, pp. 102-103) found that the test shocks produced the expected related increases to output and employment, which were linked, in turn, to increased wages, economic migration, and population. Tirado noted that the relatively small multiplier effects, however, were due to economic "leakages" from El Paso to the larger neighboring regions. Barbhaya (2005, p. 78) found that potential labor force, relative employment opportunity, and relative wage rates all had significant impacts on economic migration and population changes in a baseline REMI model of Hamilton County, Ohio. Although Barbhaya concluded that the amenities and commodity access were of less importance to overall population change than the other variables that he studied, his methodology did not include any sensitivity tests. It is also not evident if he enabled the commodity-accesss index.

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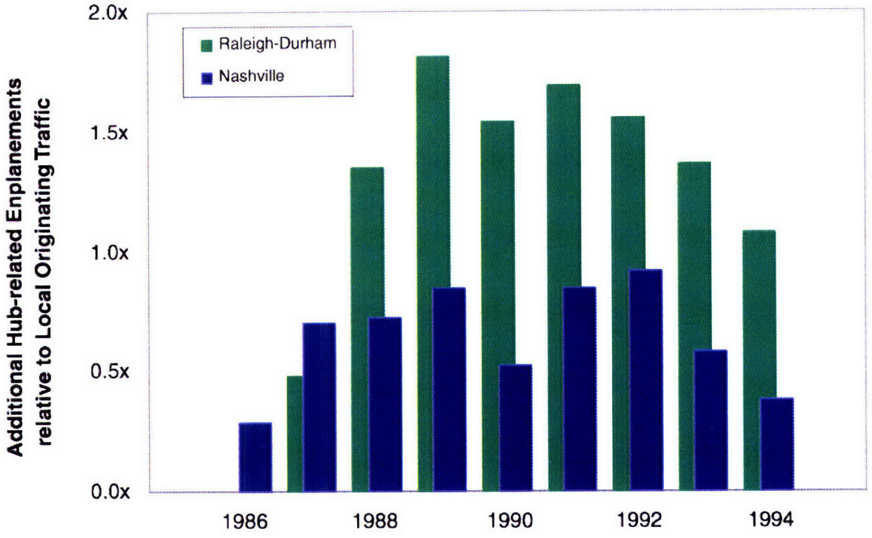
structure of the model means that input values have different effects depending on the year of entry into the model (Polenske et al., 1992, p. 28).

To my knowledge, there have been no recent analysts who have described or evaluated the theoretical structure and performance of the recent versions of the US REMI or UK REMI-ECOTEC models. As such, I conduct my own sensitivity tests to examine the interregional and dynamic impacts of the REMI-ECOTEC model. I observe how the model responds to a temporary shock and how it returns to its baseline equilibrium in order to demonstrate and examine the model's structure and dynamics. I focus my sensitivity analyses in three main areas: (1) interindustry performance, (2) interregional competition, and (3) socioeconomic indicators.

4.3 Model Sensitivity Test

In this section, I use the example of temporary growth in the air transport sector in the East Midlands region to analyze the interregional and dynamic impacts of the REMI-ECOTEC model. Although Tirado (2004) focused on single-year shocks to the El Paso region, I use multi-year shocks to explore some of the long-term effects in the REMI model. In this sensitivity test, I also analyze how the economy returns to the pre-shock equilibrium, in order to understand the relationships embedded into its structure.

I develop this example based on the experience of two regional airports in the Southeastern United States that handle roughly the same number of passengers as the East Midlands Airport: Raleigh-Durham, North Carolina, and Nashville, Tennessee. Both of these airports experienced a rapid traffic growth in the mid-1980s as American Airlines built large hubs to connect passengers from Florida to the Northeast and



Source: Author's calculations using data from DOT Airport Activity Statistics, Raleigh-Durham Airport, DOT Form 41 data, and O-D Plus

Figure 4-3: Hub-related enplanements relative to total enplanements at Nashville and Raleigh-Durham

Midwest, respectively.[7] Due to competition and changing global airline industry dynamics, however, American shut both hubs by 1995. Figure 4-3 shows the additional airport traffic generated by the hubs relative to the local non-connecting traffic. At its peak, the presence of the hub nearly tripled the passenger enplanements at Raleigh-Durham (1.8x) and doubled those at Nashville (0.9x). Traffic levels declined slightly in 1990 due to the outbreak of the first Gulf War and declined to pre-hub levels within 8-9 years.

I construct a similar hypothetical example of a temporary hub using an exogenous increase in air transport industry sales in the East Midlands. I increase the proportion of exogenous sales by amounts corresponding to levels seen at Nashville (except for 1990, when I remove the downturn associated with the Gulf War for simplicity), and assume that the first year of impacts is seen in 2006. Within the REMI-ECOTEC model, I use the

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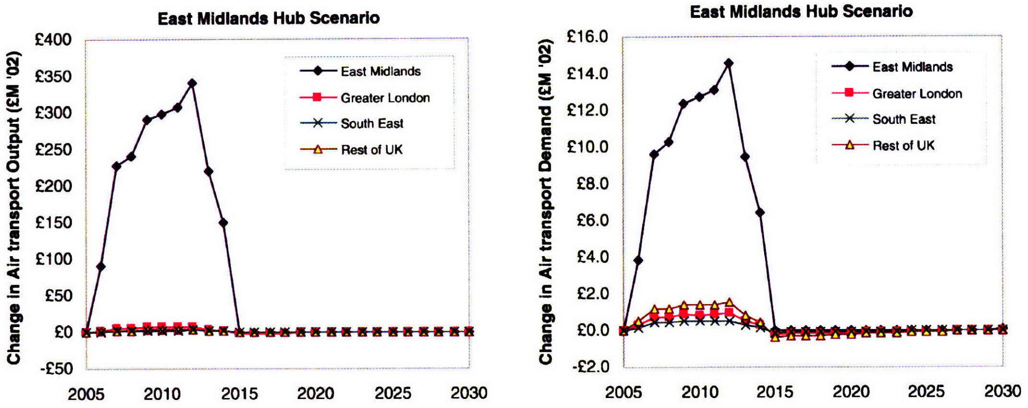
[7] With new terminals, runways, and other support facilities, American by 1991 was providing nonstop service from Raleigh-Durham to 62 cities in North America and the Caribbean. Yet the airline closed its hub operations by 1995.

"exogenous industry sales of air transport" policy variable, because this increases the activity in the region of interest only (East Midlands)—just as airport growth at the East Midlands Airport (EMA) would affect the region. Using the air transport demand policy variable, in contrast, would increase air transport activity in the East Midlands as well as the regions that typically supply air transport to the region, such as London and the South East.

Under the REMI-ECOTEC baseline control forecast, the total output of the air transport sector in the East Midlands in 2005 is £303 million, with total value-added of £127 million. Only about £83 million of the total air transport output is consumed by the East Midlands region itself (self-supply), and the remaining £230 million is exported to other regions and the rest of the world. Total air transport demand for the East Midlands is £1,045 million. To meet this demand, another £962 million of air transport is imported from other regions and the rest of the world.

The East Midlands hub scenario adds between £89.8 to £339.1 million in exogenous air transport industry sales to the East Midlands economy between 2006 and 2014. In the peak year of the scenario (2012), the total output of the air transport industry increases to £711 million. Figure 4-4(a) shows the changes in air transport demand by region under the hub scenario relative to the baseline control forecast. The underlying baseline control forecast, for example, includes £370 million of air transport industry output in the East Midlands in 2012. The hub scenario increases the air transport output by £341 million over the baseline—as shown in Figure 4-4(a).

Because the hub scenario adds the extra air transport activity as exogenous sales (outside the model), the maximum annual increase in regional demand for air transport



(a) Air Transport Output

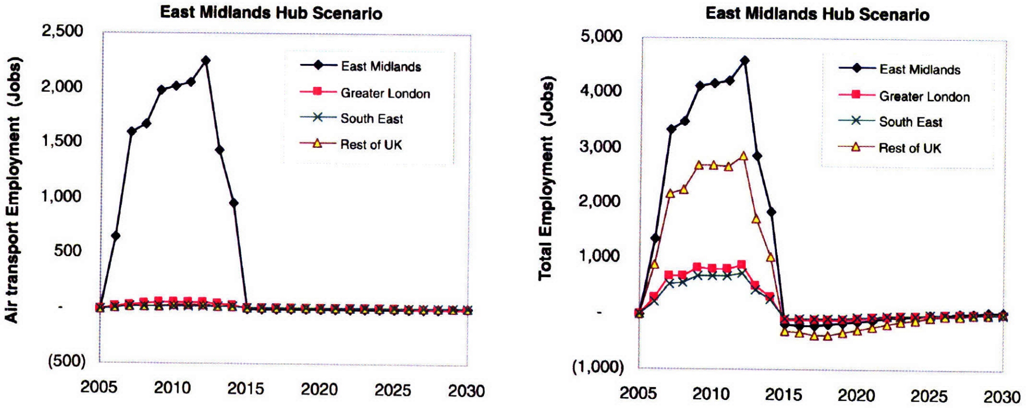
(b) Air Transport Demand

Source: Author's calculations using REMI-ECOTEC UK version 6.0

Figure 4-4: East Midlands hub scenario - Air transport sector output and demand by region

relative to the baseline is only about £14.6 million in 2012. In addition, almost all of this increase is added to the East Midlands (per the modeled scenario), and there is very little increased air transport demand in other regions. This is shown in Figure 4-4(b).

In the REMI-ECOTEC model, changes in output and demand are translated into employment (Figure 4-5). In 2012, for example, the increased air transport output in the East Midlands requires an additional 2,300 jobs in the air transport sector relative to the baseline scenario. As shown in Figure 4-5(a), about 95% of all additional employment impacts for the hub scenario in the air transport sector are located in the East Midlands region. But only a little over a quarter of the total impacts across all sectors are in the air transport sector itself. At its peak, the additional air-transport employment in the East Midlands also generates another 2,300 jobs in other sectors of the economy. This, in turn, creates 4,500 jobs throughout all other sectors in the rest of the United Kingdom. The total economy-wide employment impacts relative to the baseline forecast are shown in Figure 4-5(b).



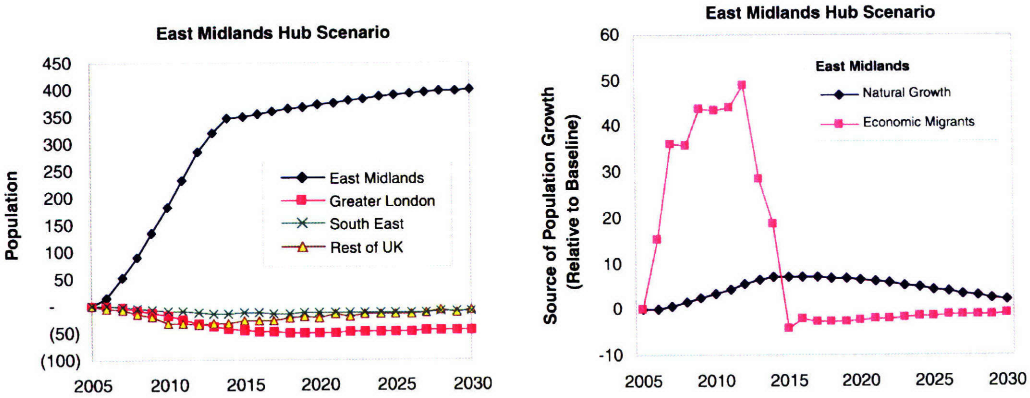
(a) Air Transport Employment

(b) Total Employment

Source: Author's calculations using REMI-ECOTEC UK version 6.0

Figure 4-5: East Midlands hub scenario - Air transport and total employment by region

This added economic activity and employment also has long-term impacts on population growth, and the REMI model makes slight adjustments to the overall impact forecasts in order to capture some of these other impacts. Figure 4-6(a) shows the total cumulative impacts on population by region. The additional economic activity increases the population of the East Midlands faster than would otherwise occur under the baseline scenario—by about 350 persons in 2014. As such, London, the South East, and the rest of the United Kingdom would have slightly slower population growth than the baseline scenario. Most of this population growth is due to the economic migration associated with the increased job opportunities in the air transport and other sectors in the East Midlands relative to other regions. Figure 4-6(b) shows that in the East Midlands between 2006 and 2014, about 90 to 98% of the annual population growth is due to economic migration—adding another 50 persons per year at its peak in 2012. As the base population of the region increases, the natural population growth (total births less deaths) also accounts for an increasing part of the population. Although these changes



(a) Population Change by Region

(b) Components of Population Change: East Midlands

Source: Author's calculations using REMI-ECOTEC UK version 6.0

Figure 4-6: East Midlands hub scenario - Regional population change

are relatively small—especially within the context of a region, which contains about 4.3 million people—they illustrate how the REMI model adjusts ths impact forecasts beyond the direct, indirect, and induced economic impacts associated with inter-industry activity.

4.3.1 Impacts by Industry and Region

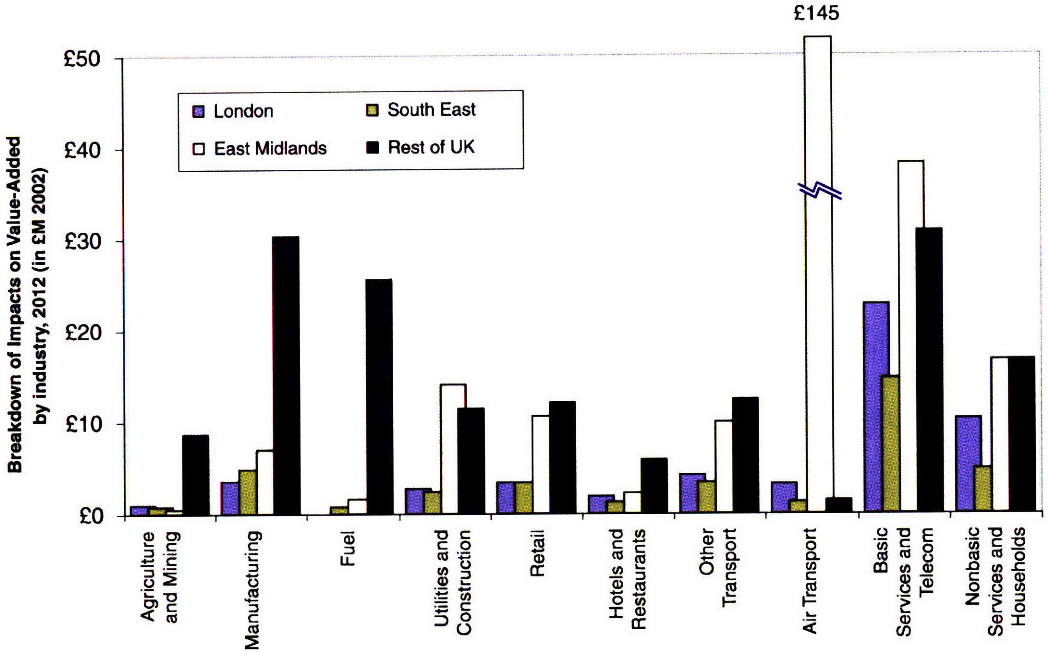
About 30% of the total UK-wide economic impacts (in terms of value-added) are within the air transport sector, and about 50% of the total impacts occur in the East Midlands. The diffusion of the economy-wide impacts across the different sectors is determined by the input-output relationships (technology coefficients), while the distribution of the impacts across the different regions is based on relative production costs and delivered prices.

The UK input-output table embedded in the REMI-ECOTEC model is responsible for most of the interindustry impacts, but interregional competition is also responsible for allocating the activity among the regions. About two-thirds of the total impacts between

2006 and 2014 can be attributed to the basic input-output relationships (exogenous households). Using a simplified input-output model, the total cumulative increase in GVA in all regions through 2014 relative to the baseline would be £2.1 billion; the hub scenario increases GVA by £3.1 billion in total.

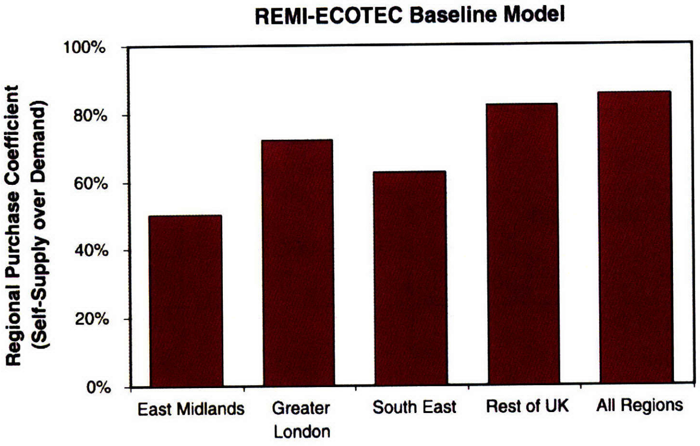
Figure 4-7 shows the cumulative increases in GVA by sector and region for the East Midlands hub scenario at its peak in 2012. Other than air transport, the largest GVA impacts between 2006-2014 occurred in the manufacturing sector (about 15% of the total, or £479 million. Most of these manufacturing impacts occurred in regions outside of the East Midlands, London, or the South East, and they were concentrated in the petroleum-refining sub-sector (37% of all manufacturing impacts). Indeed, about 86% of the total petroleum-refining impacts are located outside of these regions under the baseline scenario in 2005. As revealed in my study of the UK input-output tables (Section 4.1.1), these strong linkages between the manufacturing sector and air transport due to the importance of fuel costs.

The next largest group of impacts occurred in the export (basic) and local (nonbasic) services. Basic and nonbasic services accounted for 31.6% of all impacts (~£1 billion). About the same level of impacts in the retail and nonbasic services impacts occur in the rest of the United Kingdom as in the East Midlands. Utilities, retail, and other transport services each accounted for about 6% (~£190 million) of all impacts, while agriculture/mining and hotels each accounted for about 2% (~£70 million) of all impacts. The agriculture/mining impacts are largely concentrated in the oil/gas extraction sub-sector, and are again located in regions other than the East Midlands, London, or the



Source: Author's calculations using REMI-ECOTEC UK version 6.0

Figure 4-7: East Midlands hub scenario - Impacts on value-added by region and sector, 2012



Source: Author's calculations using REMI-ECOTEC UK version 6.0

Figure 4-8: Regional purchase coefficients, REMI-ECOTEC baseline model, 2005

South East—similar to the petroleum-refining sub-sector. Most of the hotel sector impacts occur in the rest of the United Kingdom.[8]

The location or regional distribution of regional purchases is dependent on the relative prices and delivered costs. These are reflected in the regional purchase coefficients shown in Figure 4-8. The East Midlands has a much lower total share of self-supply (about 50%) than other regions, and thus the overall economic impacts of any increased activity in this region will be shared with suppliers in other regions.

Table 4.8 shows the prices and costs in 2005 for the air transport sector in different regions relative to the UK national average (UK = 1.0). The smaller market share of air transport in the East Midlands relative to other regions such as Greater London is reflected by the higher overall relative delivered price of air transport there (1.001 versus 0.949). Figures 4-11 and 4-9 show the changes in relative costs, prices, wages, and labor productivity for the air transport sector under the hub scenario. The large exogenous

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[8] In aggregate, about 18% of the impacts in the rest of the United Kingdom occurred in the West Midlands. Our license for the REMI-ECOTEC model does not include the West Midlands and some of its subregions, although the model performs calculations for these regions as part of the runs.

Table 4.8: Relative prices and costs in the air transport sector: Baseline versus East Midlands hub scenario

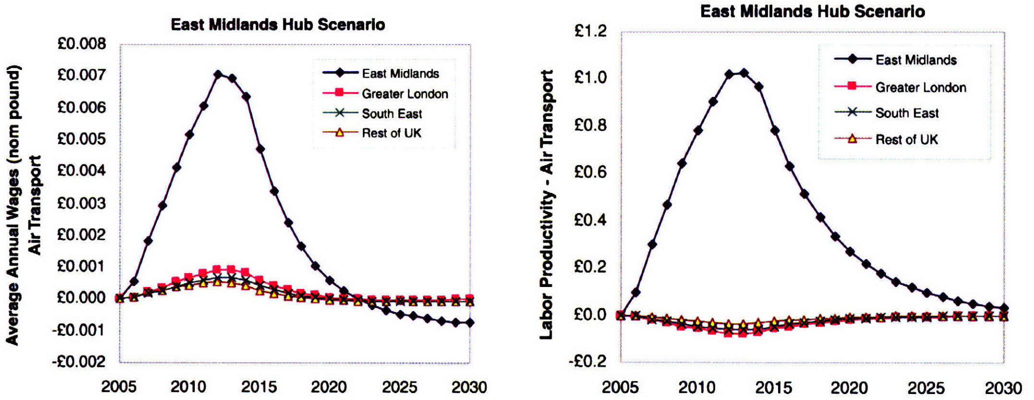
	East Midlands	Greater London	South East	Rest of UK
Relative Cost of Production				
Baseline (2005)	1.0601	0.9427	1.0469	1.0677
East Midlands Hub Scenario (2012)	1.0578	0.9438	1.0481	1.0687
Relative Delivered Price				
Baseline (2005)	1.0010	0.9495	1.0041	1.0158
East Midlands Hub Scenario (2012)	1.0016	0.9506	1.0050	1.0166

Source: Author's calculations based on data from REMI-ECOTEC UK version 6.0

increase in demand and output of air transport in the East Midlands enhances its labor productivity (Table 4-9(b)) relative to other regions, thus reducing its overall cost of production. As the relative price of air transport in the East Midlands decreases, the price in Greater London increases.

The overall corresponding changes in multi-regional imports and exports of air transport are shown in Figure 4-10. In order to meet the increased demand for air transport in the East Midlands, large increases in regional exports occur in Greater London and the South East while the hub is present (Figure 4-10(a)). Conversely, there are large increases in imports of the air transport sector during the same time period (Figure 4-10(b)).

The increase in output and employment for air transport in the East Midlands under the hub scenario dramatically enhances that sector's relative labor productivity compared to other regions (Figure 4-9(b)). This reduces the relative cost of production (Figure 4-11(a)) and relative delivered prices (Figure 4-11(b)) of air transport in the East Midlands, allowing it to increase its market share compared to other regions. Figure 4-9(a) shows that the increase in output and supply of air transport also increases the relative wages.

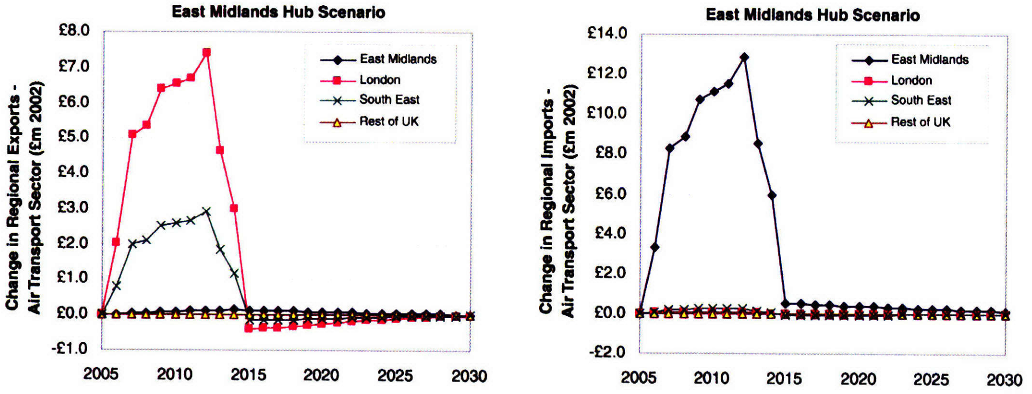


(a) Change in Relative Wages - Air Transport

(b) Change in Relative Labor Productivity - Air Transport

Source: Author's calculations using REMI-ECOTEC UK version 6.0

Figure 4-9: East Midlands hub scenario - Relative wages and labor productivity for the air transport sector

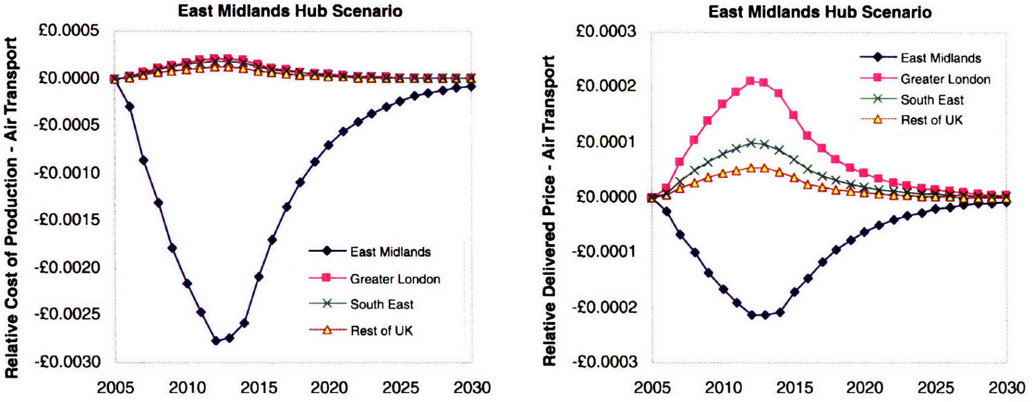


(a) Change in Regional Exports - Air Transport

(b) Change in Regional Imports - Air Transport

Source: Author's calculations using REMI-ECOTEC UK version 6.0

Figure 4-10: East Midlands hub scenario - Changes in regional exports and imports for the air transport sector



(a) Change in Relative Cost of Production - Air Transport

(b) Change in Relative Delivered Price - Air Transport

Source: Author's calculations using REMI-ECOTEC UK version 6.0

Figure 4-11: East Midlands hub scenario - Relative costs and delivered prices for the air transport sector

4.3.2 Context and Analysis

I compared the REMI-ECOTEC forecasts for the East Midlands hub scenario with an approximation of a basic I-O model (Type I–exogenous households).[9] Although the standard REMI-ECOTEC model forecasts essentially the same impacts for the air transport sector as an I-O model (< 1% difference), its total economy-wide GVA impacts are about 50% higher. Figure 4-12 shows a comparison of these forecasts by region. The REMI-ECOTEC impacts for the East Midlands are about 21% higher than those in the I-O model, and the forecasts for the other regions are essentially double those of the I-O model. The large differences between REMI-ECOTEC and standard input-output models illustrate the importance of considering population changes and interregional competition in prices and costs within a dynamic, multi-regional framework.

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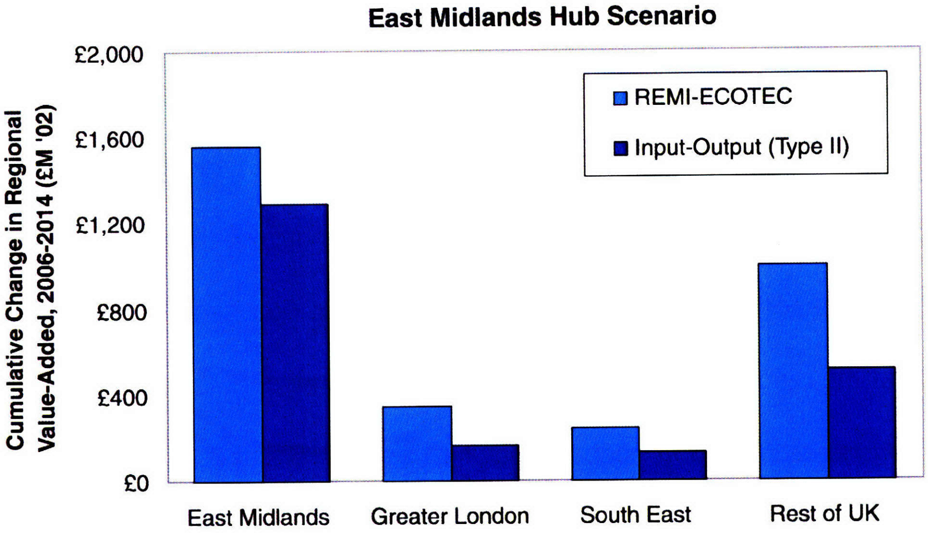
[9] I approximate this model by suppressing all of the features in the REMI-ECOTEC model except for the input-output module. This also makes it similar to the RIMS II and IMPLAN multiplier-impact models in the United States.

One of the dynamic characteristics of the REMI-ECOTEC model is its inclusion of long-term impacts as a regional economy returns to a baseline equilibrium after an exogenous shock ends. A sudden decline in the air-transport sector, for example, should lead to increased unemployment and slower economic growth than would be otherwise expected. Increased competition for jobs should lead to declines in wages and even regional out-migration. Figures 4-4, 4-5, and 4-6(a) show negative impacts to output, employment, and population, respectively, between 2015 and 2030 as the economy returns to its baseline forecast. The total cumulative reduction in GVA relative to the baseline is £378 million between 2015 and 2030. Thus, the total net long-term impact is only £2.8 billion after these negative impacts are taken into account. Considering these post-shock negative impacts may be important for modeling certain types of temporary policy changes.

One unanswered question is whether or not the REMI-ECOTEC model is overly sensitive to changes in prices and costs. According to Rockler and Weisbrod (2007), there are other attributes of production—such as quality, speed, inter-firm relationships, or even tacit knowledge/skills—that may not necessarily be reflected in price competition. From a modeling perspective, however, attributing regional change to these differences is a perhaps a more practical (and theoretically cogent) way of reflecting economic forecasts than other CGE or econometric methods, which obscure these changes within statistical parameters. Relating industrial activity with employment and population via prices and wages does provide a holistic and accessible "story" of how regional economies change over time.



Source: Author's calculations using REMI-ECOTEC UK version 6.0

Figure 4-12: Comparison of cumulative impacts on value-added as forecast by the REMI-ECOTEC model and a basic input-output model (exogenous households): East Midlands hub scenario, 2006-2014

Two other issues with this version of the REMI-ECOTEC model include the use of fixed technical coefficients and the lack of international trade flows (Weisbrod/Rockler, 2007). Changing technology, energy resources, and globalization are likely to create different intermediate commodity requirements and geographical distributions of activities over the very long-term. Including such estimates, however, may introduce large sources of bias into the forecast. Although international trade continues to shape regional economic development due to global outsourcing and supply chains, the lack of regional data on international trade often prevents their inclusion in economic models such as REMI. Such impacts are especially important when considering the impacts of air transportation on facilitating global trade and commerce. In Chapter 5, I overcome some of these inherent limitations in the REMI-ECOTEC model by using exogenous changes to industry activity to incorporate my own forecasts of growth into the model.

Table 4.9: Baseline model: Economic activity in 2030 by region

Metric	Region				UK Total
	Greater London	South East	East Midlands	Rest of UK	
Value-Added (£m)					
Air Transport Sector	5,800	2,300	200	3,000	11,300
Regional Total	308,400	229,400	88,600	859,400	1,485,900
Employment (jobs)					
Air Transport Sector	58,800	25,300	3,000	37,900	124,900
Regional Total	4,345,000	3,767,800	1,813,700	16,999,900	26,926,300
Population	8,096,800	8,617,600	5,277,100	43,139,500	65,131,000

In 2002 £. Source: Author's calculations from REMI-ECOTEC UK version 6.0

4.4 Alternative Air Transport Growth Impacts, 2006-2030

Having identified the key relevant characteristics and features of the REMI-ECOTEC model, I use it to develop forecasts of the overall direct, indirect, and induced economic impacts from the air transport sector in the East Midlands. For comparison purposes, I reference the REMI-ECOTEC baseline forecast of about 2.2% average growth in the output of the air transport industry. Under this forecast, the air transport sector in the East Midlands will grow to about £230 million in GVA by 2030. Table 4.9 shows the baseline 2030 forecast in economic activity for the air transport sector and the region as a whole. Table 4.10 shows the average annual growth in regional value-added between 2005 and 2030.

As discussed in Chapter 3, I develop aviation growth scenarios that are roughly based on alternative forecasts from international air transport organizations. Again, I use a "Low Growth" scenario that corresponds to the most conservative estimates of passenger growth developed under the European CONSAVE scenarios (Berghof and

Table 4.10: Baseline growth in regional value-added, 2005-2030

Scenario	Region				UK Total
	Greater London	South East	East Midlands	Rest of UK	
Value-added, 2005 (£m)	212,600	168,300	66,800	655,300	1,103,000
Value-added, 2030 (£m)	308,500	229,400	88,600	859,200	1,485,800
Average growth in value-added per annum (£m)	3,800	2,400	900	8,200	15,300
Average growth rate per annum (%)	1.8	1.5	1.3	1.2	1.4

In 2002 £. Source: Author's calculations from REMI-ECOTEC UK Version 6.0

Schmitt, 2005)—about 1.5% per year. The UK DfT forecast of 4.5% annual growth through 2020 (UK Department for Transport, 2003e) would essentially triple the size of the aviation industry over current levels, and I include this in my analysis as a "high growth" scenario. I also develop a "Medium Growth" scenario with air transport growth of about 3.4% annually. These scenarios are shown in Table 4.11 and Figure 4-13.

In the REMI-ECOTEC model, I use changes to the "Exogenous Industry Sales - Air Transport" policy variable (same policy variable as the example in Section 4.3) in order to simulate this airport growth within the regional economy. I identify the target aviation output levels associated with each growth rate. Starting in 2006, I gradually increase the proportion of air transport sales above the baseline until the total air transport output achieves the target level in 2030.[10] For example, the total output of the East Midlands air transport sector in 2030 under the baseline forecast (2.2% annual growth) is about £540 million. Under the high-growth scenario (4.5%), the total exogenous output of the air transport sector would be about £910 million pounds—or about £370 million above the

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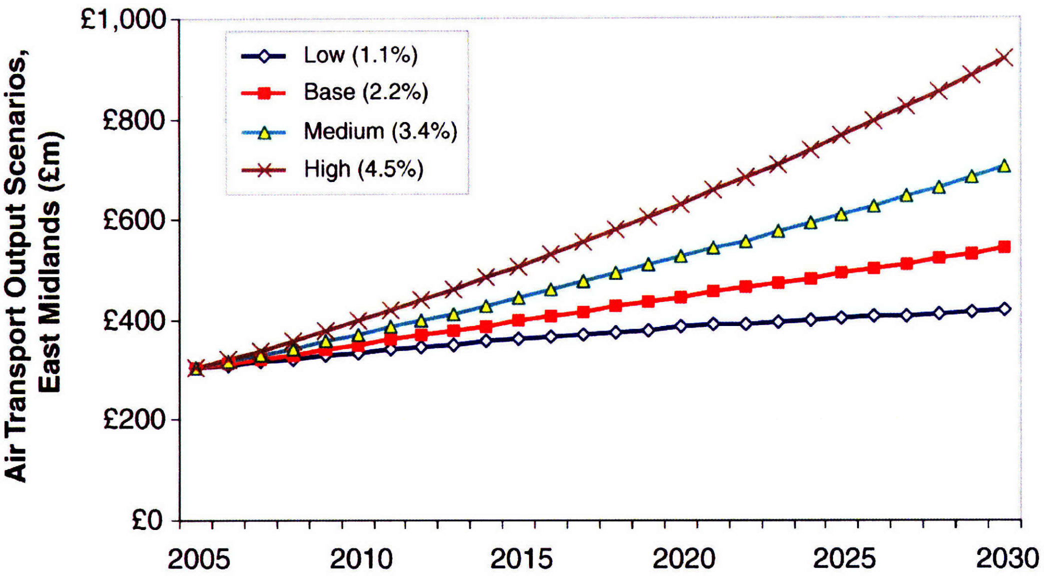
[10] I use proportions instead of specific amounts in order to reflect any economic recessions or other changes during the time period which are a part of the REMI-ECOTEC baseline control forecasts.

Table 4.11: East Midlands alternative aviation growth scenario inputs

Metric	Scenario		
	Low Growth	Medium Growth	High Growth
Average air transport annual growth rate (%)	1.5	3.4	4.5
East Midlands - air transport scenario output in 2030 (£m)	419	699	911
Difference from baseline (£m)	-123	+157	+369
Ratio of scenario output to baseline forecast output	0.77	1.29	1.68
Change in ratio relative to baseline	-0.23	+0.29	+0.68

In 2002 £. Baseline air transport output in 2030 is £542 million. Source: Author's calculations using REMI-ECOTEC UK 6.0



Source: Author's calculations using REMI-ECOTEC UK version 6.0

Figure 4-13: East Midlands air transport output growth scenarios relative to baseline

baseline (+69%). In the low-growth scenario which assumes that output is less than that of the REMI-ECOTEC baseline, I decrease the total exogenous sales (and thus output) of air transport until it reaches about £120 million below the baseline in 2030.

4.4.1 Alternative Growth Scenarios: East Midlands

Despite the large changes in aviation activity under the alternative growth scenarios (up to -23% and +69% in the East Midlands), however, the resulting impacts on total regional GVA are small: -0.10% and +0.29% relative to the baseline for the Low- and High-growth scenarios, respectively. This is because the air transport sector is a small industry in the East Midlands—less than 0.2% of total GVA. By 2030, the REMI-ECOTEC baseline scenario forecasts that air transport will account for only about 3,000 jobs out of 1.8 million throughout the East Midlands. And even though the high-growth scenario would add nearly 2,000 jobs to the air transport sector by 2030, many of these jobs would be displaced from other industries—thus having little net total impact on the regional economy.

Table 4.12 shows the impacts on air transport and total regional GVA. Almost all of the impacts to the air transport sector occur in the East Midlands (£157 million under the high-growth scenario). Air transport only accounts for about 60% of the total economic impacts in the East Midlands, however, as the indirect and induced purchases filter through the regional economy (£262 million). These purchases also filter through the UK as a whole, and thus the East Midlands only accounts for about half of the total economy-wide impacts in the United Kingdom (£507 million).

Table 4.12: Aviation growth in the East Midlands - Air transport and total regional value-added relative to baseline scenario, 2030

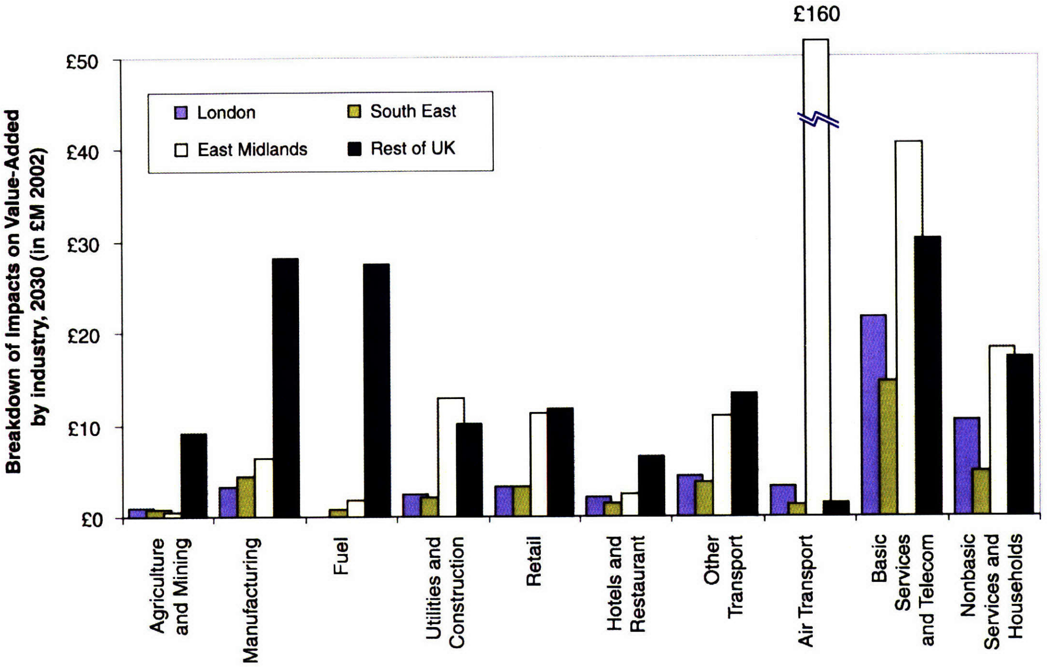
Scenario	Region				UK Total
	Greater London	South East	East Midlands	Rest of UK	
Air Transport Sector Value-Added (£m)					
Low Growth	-1.1	-0.4	-51.9	-0.5	-53.9
Medium Growth	1.4	0.6	67.3	0.6	69.9
High Growth	3.3	1.3	157.2	1.5	163.3
Total Regional Value-Added (£m)					
Low Growth	-17.2	-12.5	-86.6	-51.5	-167.7
Medium Growth	22.1	16.1	112.1	66.4	216.7
High Growth	51.9	37.6	261.9	155.6	507.2

In 2002 £. Source: Author's calculations from REMI-ECOTEC UK version 6.0

As such, the total economy-wide impacts under the different growth scenarios range from a reduction in GVA of -£0.2 billion to +£0.5 billion, based on a change of -£0.1 to +£0.3 billion in air transport sales. These suggest economic multipliers of 1.5 to 1.6, and are well within the range of the economic impacts that are to be expected.

Table 4.13 and Figure 4-14 illustrate the changes to individual sectors by region. Note the similarity to the impacts from the East Midlands hub scenario in Figure 4-7 as well as the UK-wide impacts in Table 4.2 shown earlier. Because the underlying input-output table is the same for all of these calculations, these impacts should be consistent.

Because these scenarios were modeled using exogenous shocks, air transport demand remains relatively constant across the different scenarios—decreasing by -£71 million (-0.3%) under the low-growth scenario and increasing by +£216 million (+0.8%) under the high-growth scenario across the United Kingdom. Total demand also remains relatively constant across the different scenarios—decreasing by £2.9 billion (-0.1%) under the low-growth scenario and increasing by £8.7 billion (+0.3%) under



Source: Author's calculations using REMI-ECOTEC UK version 6.0

Figure 4-14: Aviation growth in the East Midlands - Value-added impacts by region and sector, 2030 high-growth scenario

Table 4.13: Aviation growth in the East Midlands - Differences in value-added by sector, high-growth scenario, 2030 (£m)

Value-added by sector (£m)	Region				UK Total
	Greater London	South East	East Midlands	Rest of UK	
Agriculture and Mining	1.0	0.8	0.4	9.2	11.4
Manufacturing	3.2	4.5	6.3	28.2	42.2
Fuel	0.1	0.8	1.7	27.5	30.1
Utilities and Construction	2.5	2.2	12.9	10.1	27.6
Retail Services	3.3	3.3	11.2	11.7	29.5
Hotels and Restaurants	2.1	1.5	2.5	6.5	12.6
Other Transport	4.3	3.7	10.9	13.3	32.2
Air Transport	3.3	1.3	157.2	1.5	163.3
Basic Services and Telecom	21.7	14.6	40.6	30.1	107.0
Nonbasic Services and Households	10.5	5.0	18.2	17.3	51.0
Total	51.9	37.6	262.0	155.3	506.9

In 2002 £m. Source: Author's calculations from REMI-ECOTEC UK Version 6.0

Table 4.14: Aviation growth in the East Midlands - Impacts on personal income, 2030 high-growth scenario

High Growth Scenario	Region				UK Total
	Greater London	South East	East Midlands	Rest of UK	
Real Personal Income (£m)	20.1	15.7	132.6	53.6	222.2
Real Disposable Personal Income (£m)	14.4	12.0	103.7	39.9	169.9
Real Disposable Personal Income with Housing Prices (£m)	12.5	10.7	94.1	37.9	155.3
PCE-Price Index (£m)	0.0084	0.0070	0.0230	0.0067	0.0081
PCE-Price Index with Housing Prices (£m)	0.0107	0.0086	0.0567	0.0076	0.0114
Relative Housing Price	0.0002	0.0001	0.0013	0.0001	0.0002

In 2002 £. Source: Author's calculations from REMI-ECOTEC UK Version 6.0

the high-growth scenario. This affects the regional share of purchases and the overall exports and imports by region. Due to the regional purchasing characteristics and market competitiveness, only about 52% of the total impacts in GVA occur in the East Midlands; another 10% are in Greater London and the remaining 38% in other regions of the United Kingdom (including the South East).

Table 4.14 shows the impacts to total personal income under the high-growth scenario. Across the United Kingdom, the additional £317 million in exogenous air transport sales generates a total of £222 million in real personal income. This translates to about £170 million in real disposable personal income, and £155 million in income when increases in housing prices due to economic migration are taken into account. Although the total net impacts in wages per capita are relatively small, the growth of the air transport sector in the East Midlands does have wider regional benefit in terms of raising overall income. The cumulative impacts between 2006 and 2030 are shown

Table 4.15: Aviation growth in the East Midlands - Cumulative total value-added impacts over 25-years, 2006-2030

Scenario	Region				UK Total
	Greater London	South East	East Midlands	Rest of UK	
Air Transport Sector Value-Added (£m)					
Low Growth	-13	-5	-578	-5	-601
Medium Growth	16	6	749	7	779
High Growth	38	15	1,751	17	1,821
Total Regional Value-Added (£m)					
Low Growth	-201	-145	-973	-594	-1,913
Medium Growth	261	188	1,260	766	2,474
High Growth	612	439	2,944	1,794	5,789

In 2002 £. Source: Author's calculations from REMI-ECOTEC UK version 6.0

in Table 4.15. Total economic impacts over the 25-year period include an additional £5.8 billion in total value-added throughout the United Kingdom under the high-growth scenario.

Lastly, I do note that the when the dynamic and accessibility features of the REMI-ECOTEC are suppressed, the total impact of a similarly-sized exogenous shock to the air transport sector (+£353 million) results in a £474 million increase in total GVA relative to the baseline—slightly less than that with the features enabled. This is a +0.032% change in total GVA relative to a endogenous household baseline forecast (which itself is about £12.2 billion less than the baseline REMI forecast (£1.47 trillion)—or about 0.82% less. In comparison, the dynamic REMI model (findings presented earlier) has a +0.034% change in GRP, so that the two models are relatively consistent.

Table 4.16: Baseline model - Economic activity in 2030 by region

Metric	Region				UK Total
	Greater London	South East	East Midlands	Rest of UK	
REMI-ECOTEC Baseline Value-Added (£m)					
Air Transport Sector	5,800	2,300	200	3,000	11,300
Regional Total	308,400	229,400	88,600	859,400	1,485,900
Endogenous Household Value-Added (£m)					
Air Transport Sector	5,700	2,300	200	11,100	2,900
Regional Total	311,300	227,700	84,900	1,473,500	849,600

In 2002 £. Source: Author's calculations from REMI-ECOTEC UK version 6.0

4.4.2 Alternative Growth Scenarios: Endogenous Household Model

The forecast also includes the impacts from induced spending by households receiving income from jobs directly and indirectly supported by this extra activity. These impact forecasts also incorporate adjustments to the regional economy which would result from long-term population changes and inter-regional trade. The labor and commodity accessibility increases the total value-added by about 7%; thus, most of the impacts are derived from the air transport sector supply-chain plus related household spending. Table 4.16 compares the REMI-ECOTEC baseline control forecast for 2030 with a simplified forecast which only includes endogenous household impacts (no migration or accessibility).

In order to look at the sensitivity of these forecasts to the dynamic forecasts of the REMI-ECOTEC model, I also conducted a run with only the endogenous household spending impacts enabled. This more closely simulates the typical multiplier impacts models (such as the RIMS II or IMPLAN models discussed earlier). Table 4.17 shows the results of these runs.

Table 4.17: East Midlands air transport growth - Impacts to Air transport and total regional value-added relative to an endogenous Household Model baseline, 2030

Scenario	Region				UK Total
	Greater London	South East	East Midlands	Rest of UK	
Air Transport Sector Value-Added (£m)					
Low Growth	-1.2	-0.5	-48.4	-0.5	-50.6
Medium Growth	1.6	0.6	63.8	0.7	66.8
High Growth	3.8	1.5	149.7	1.6	156.5
Total Regional Value-Added (£m)					
Low Growth	-17.6	-11.8	-78.7	-45.2	-153.3
Medium Growth	23.3	15.6	103.7	59.9	202.6
High Growth	54.6	36.5	243.2	140.1	474.4

In 2002 £. Source: Author's calculations from REMI-ECOTEC UK version 6.0

4.5 Summary

In this chapter, I used a regional economic accounting system to document the role of air transport in the regional and national economy of the United Kingdom. Based on the supply-chain impacts alone, I see that continued growth in aviation could have large economic impacts (assuming that the cost of aviation remains at current levels).

I found that aviation growth at 4.5% in the East Midlands alone would increase the air transport GVA by £157 million in 2030 above the baseline forecast and add another £105 million in total regional GVA (total of £262 million). The cumulative impacts over 25 years are £2.9 billion in the East Midlands and £5.8 billion throughout the United Kingdom. In impact-multiplier terms, the additional growth of the air transport industry leads to another 1.6x the impacts through the rest of the economy.

This analysis, however, is based on the assumption that the structure of the regional economies in the United Kingdom stays constant over time—that the supply-chain

Table 4.18: Regional economic impacts relative to baseline scenario under an East Midlands high-growth scenario (4.5% annually)

Sector	Impacts in 2030 (£m)		
	Within East Midlands	Other Regions	Total UK-wide
Air transport sector	150–160	5–10	155–170
Other sectors	95–100	225–240	320–340
Total impacts, all sectors	245–260	230–250	475–510

In 2002 £. Source: Author's calculations using REMI-ECOTEC 6.0

relationships do not change. My hypothesis, however, is that the way in which air transportation enhances global accessibility can lead to a catalytic change in regional economies and their supply chains. In the next chapter, I explore the magnitude of these potential impacts on the regional economy.

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Chapter 5

Catalytic Growth Impacts

Direct, indirect, and induced economic impacts essentially measure how an economy responds to the demands imposed by an external shock—such as the increases in air transport activity, which I modeled in Chapter 4. Although such an impact analysis may be appropriate for a typical manufacturing industry or for transportation under a simplified "derived-demand" assumption (page 34), it would not necessarily indicate how an economy might evolve relative to other regions as a result of changes to inter-industry competition and access. Good passenger and freight air services are widely attributed to provide a competitive economic advantage to a region (Porter, 2001a). Companies can use air services to either enhance their supply chains or join other supply chains—improving productivity (reducing costs) or improving quality. At the regional level, it is important for planners and analysts to account for such catalytic or spillover effects of transportation on shaping how and where activities occur. Memphis, Tennessee, for example, has attracted more than 130 foreign-owned firms from 22 countries employing over 17,000 workers—largely due to the presence of a FedEx hub (Oxford Economic Forecasting and MacDonald, 2006, p. 30).

Analysts often use survey-based methodologies to account qualitatively for the impact of air transport services on business activity. Companies in the East Midlands report that 18% of all sales are dependent on passenger or cargo air services (Oxford Economic Forecasting, 2006b, p. 8). Another survey of banking, insurance, and other professional services firms in London City indicated a strong recognition that air travel was critical for staff, clients, and the delivery of air freight (Oxford Economic Forecasting, 2002, p. 22). Although such surveys provide evidence of the "catalytic" role of aviation in shaping economic geography and inter-regional competition, applying these results within forecasting models can be a subjective exercise due to limitations in both data and methods. Dynamic changes to estimates of regional technical coefficients—the ratio of goods and services demanded per unit of economic output—should be able to account for some of these impacts, but many economic models do not incorporate such features at the regional level.

In this chapter, I compare alternative methods of estimating regional catalytic impacts at the regional level: one based on changes to economic *productivity* and another based on changes to inter-regional industrial *accessibility*. I use changes in TFP and commodity accessibility (affecting prices and costs) within the REMI model to identify the range in catalytic impacts associated with different levels of aviation growth. Again, I focus these analyses on the East Midlands region, since the complexity and size of the Greater London economy makes it difficult to identify significant impacts from changes to the air transport sector there.

5.1 Productivity-based Catalytic Impacts

The concept of economic catalytic impacts, as defined by OEF and others, refers to economic impacts that are in addition to the traditional direct, indirect, or induced household spending. These economic impacts can include additional activities which locate in a region (demand-side catalytic effects) or enhanced underlying economic productivity (supply-side). For air transportation, the mechanisms generating such catalytic effects include enhanced competitiveness due to price and travel times, identifiable long-run impact on productivity and investment, and long-term attraction of jobs (Airport Cooperative Research Program, 2008, p. 23). To quantify the impacts of these supply-side catalytic effects, some analysts have estimated production functions based on the relationships between public infrastructure ("public capital stock") and changes in business output or costs (Weisbrod and Treyz, 1998, p. 73). These are based on equations of the general form in which output is a function of the quantity and productivity of labor, capital, public infrastructure, and other other factors:

$$\text{Output} = f\left(\begin{array}{l}\text{Quantity and productivity of employment, private}\\ \text{capital investment, public infrastructure, and other}\\ \text{input factors}\end{array}\right)$$

Source: Weisbrod and Treyz (1998, p. 73)

In a seminal paper, Aschauer (1989, pp. 182, 193) used a production-function model to find that a 1% increase in the ratio of public to private capital stock raised total factor productivity by 0.39% between 1949 and 1981 and that most of this was attributable to core infrastructure, such as airports, other transportation, and utilities. Although this research was widely accepted by policymakers, economists question the direction

Table 5.1: Summary of findings from previous studies of relationship between infrastructure and productivity

Author / Year	Coefficient	Infrastructure Variable	Productivity Variable
National-level studies			
Aschauer (1989)	0.39	public capital	national output
Munnell (1990a)	0.33	public capital	national output
Aschauer (1989)	0.24	core public capital	national output
Lynde and Richmond (1992)	0.20	public capital	national output
Hulten and Schwab (1991)	0.03	public capital	national output
State-level studies			
Moomaw and Williams (1991)	0.25	highway density	total factor
Costa et al. (1987)	0.20	public capital	gross state product
Munnell (1990a)	0.15	public capital	gross state product
Munnell (1990a)	0.06	highway density	gross state product
Garcia-Mila and McGuire (1992)	0.04	highway density	gross state product
Metropolitan-level studies			
Deno (1988)	0.31	highway density	personal income
Duffy-Deno and Eberts (1991)	0.08	public capital	manufacturing output
Eberts (1986)	0.03	core public capital	manufacturing value-added

Source: OECD (2006, p. 41)

of causality between public investment and output growth, and that it did not provide any clear indications for public policy (Munnell, 1990b, p. 190). Some analysts were astonished by Aschauer's findings of relatively large output elasticities and criticize his methodology, data, and findings (Rockler, 2000, p. 30-31). Yet while Ashauer's research was widely critiqued, many subsequent analysts have found statistical links between the level of public infrastructure stock, economic growth, and productivity (Banister and Berechman, 2000, p. 6).

In general, analysts have generally found productivity elasticities of 0.2 to 0.4 at the national level, around 0.15 at the regional or state levels, and as low as 0.04 at the metropolitan levels (Weisbrod and Treyz, 1998, p. 74). Using a cost-function model and data on UK manufacturing sectors, for example, Lynde and Richmond (1993, p. 891) found public capital elasticities—the ratio of the change in output per change in productivity—of 0.17. Most analysts have looked at the relationship between public capital on economic growth and productivity, while only a few have looked specifically at the role of transportation capital (Banister and Berechman, 2000, p. 145). Table 5.1 includes several studies which look at the relationship between highway density and gross state product or personal income. Very few analysts, however, have looked at the relationship between air transportation and productivity.

5.1.1 Air Service and Productivity

In a series of aviation-specific studies since 1999, OEF has quantified the supply-side economic catalytic effects by analyzing the logarithmic relationships between total factor productivity and investment with transportation demand. Total factor productivity is an

Table 5.2: Economic catalytic effect elasticities

Study	UK Aviation 1999	Eurocontrol 2005	UK Aviation 2006
Total Factor Productivity Elasticity	0.135	0.056	0.060
Key Independent Variable	General Transport	Air Transport usage (metric tonne-equivalent) / GDP	Air Transport Business Passengers and Freight / GDP
Data Level	UK: 27 sectors 1979-1997	EU: 24 countries 1994-2003	UK: 31 sectors 1979-2005

n/a = not available. Sources: Oxford Economic Forecasting 1999, p. 85; Cooper and Smith 2005, p. 41-42; Oxford Economic Forecasting 2006a, p. 67

index of technological change which compares total output per unit of total inputs. After accounting for the weighted growth of labor and capital, the residual growth in TFP can be attributed to education, innovation, economies of scale, technological change, or other factors (Samuelson et al., 1995, p. 543). When compared to other metrics such as labor productivity, analysts consider TFP to be a better measure of an economy's efficiency and its rate of technical change because it measures the ratio of output to the sum of all basic inputs (Wolff, 1985, pp. 30-31).

In all of these studies, OEF uses total factor productivity as the primary dependent variable and presents these results in terms of an elasticity showing the change in transport output per change in productivity. Table 5.2 shows that in the most recent of these studies, OEF found catalytic impact elasticities of about 0.060—meaning that a 10% increase in air-transport output or business air traffic is associated, on average, with a 0.6% increase in long-term total factor productivity. These elasticities can also be analyzed in terms of the marginal contribution relative to GDP growth. In the Eurocontrol study, for example, OEF found that air transport has contributed about 4.0% of the

European GDP in terms of supply-side economic catalytic impacts (both investment and productivity) between 1994 and 2003. This is equivalent to about €410 billion euros (Cooper and Smith, 2005, p. 46).

The main differences among the OEF studies involve the unit of analysis as well as the specificity of the independent variables for transportation and other factors. The two UK studies (1999 and 2006a) are based on the pooled effects of air transport on productivity from each of up to 31 different sectors. In contrast, the Eurocontrol study (2005) analyzes productivity across 24 countries and also incorporates other explanatory variables, such as research and development intensity or education, to control for the underlying economic differences between countries. Although the magnitudes of some of these other factors are higher than that for air transport, the highly positive R^2 (0.67) of this model suggests that air-transport usage plays an important role along with research and development spending, educational standards, and some country-specific effects in influencing long-run underlying productivity (Cooper and Smith, 2005, p. 42).

One of the other key differences among the OEF studies is the level of specificity for the independent variable for transportation. While the 1999 study used general transportation output to explain the differences in the total factor productivity in the United Kingdom, the 2005 Eurocontrol study focused on the output of the air-transport sector. The 2006 UK study further refined this approach by creating a proxy that combines business travelers and cargo into a "workload unit." The workload units are calculated by multiplying the number of passengers by 0.1 and then adding the amount of air cargo (in metric tonnes). In addition, both the Eurocontrol and the 2006 UK studies divide the air-transport metrics by GDP in order to control for fluctuations in the overall economy and differences in wealth (and thus propensity to fly). Finally, although the increased specificity of the independent variables for air transportation is more appropriate for these studies, OEF admits that this in itself could be a source of bias in the estimates (Cooper and Smith, 2005, pp. 35-37).

In another study for International Air Transport Association (IATA), Smyth and Pearce (2006, p. 30) incorporate the size of the destination airport and airline route network connectivity—measuring the product of the number of destinations, the frequency of flights, and seat capacity per flight, all divided by a scalar factor of 1000. In general, the magnitudes of these elasticities are consistent with, and slightly higher than, the results with basic air-transport output, but result in a higher R^2. In this study, connectivity feeds directly into GDP–so that a 10% increase in connectivity leads to a 0.9% increase in GDP. In addition, connectivity also affects GDP through investment. The ratio of capital to GDP is 0.35, so that the 10% increase in connectivity leads to a 0.6% increase in investment and a 0.2% increase in long-run GDP. Thus, the total impacts of connectivity are 1.1% of GDP (Smyth and Pearce, 2006, p. 31).

A number of aviation stakeholder groups, such as the Heathrow Association for the Control of Aircraft Noise (HACAN ClearSkies), Strategic Aviation Special Interest Group of the Local Government Association (SASIG), and Friends of the Earth (FOE), have critiqued the OEF studies and its role in UK aviation development strategy. Berkeley Hanover Consulting (2000, pp. 27-28) notes that the original OEF study 1999 failed to prove a clear statistical relationship between air transport and productivity growth. The subsequent OEF studies cover this issue, but Boon et al. (2008, pp. 39-40) suggests that the observed relationships are due to the result of simple data mining—a larger number of tests can result in a greater likelihood of finding a random relationship.

One of the more general issues is the potential for diminishing or negative returns to investment from transport infrastructure in a mature economy, as suggested by the Standing Advisory Committee on Trunk Road Assessment (1999, p. 70) and AirportWatch (2006). The marginal benefits to productivity associated with current and future projects may not be the same as the average benefits to productivity associated with past spending (Weisbrod and Treyz, 1998, p. 76). Also, Cohen and Paul (2003) found evidence of regional spillovers on airport investment—suggesting that network externalities need to be considered in air transport policy. Although it is clear that the literature in this area is still emerging, the OEF studies are among the first to apply such productivity studies directly to the air transportation sector. Nevertheless, their findings are generally consistent with the overall literature on transportation, public investment, and productivity.

5.1.2 Productivity-based catalytic impacts

To examine the magnitude of these catalytic effects of aviation at the regional level, I test several increases in TFP that are based on the relationships between air transport usage and productivity. I use an economy-wide increase in TFP to frame the upper range of the catalytic impact estimates, and an increase of TFP in selected private non-farm industries[1] to frame the lower range of the estimates. My underlying assumption is that air transport is inherently related to the viability of regional supply chains in

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[1] Includes manufacturing, retail/hotels/catering, transport, telecom, and basic regional export-related services.

Table 5.3: Productivity-based catalytic impacts under an East Midlands high-growth scenario (4.5% annually)

Scenario	Productivity Change in 2030 (%)	Impacts on value-added in 2030 (£m)		
		Within East Midlands	Other Regions	Total UK-wide
Low Growth	0.078	50–70	80–90	150–160
Baseline	0.132	90–110	160–170	250–270
Medium Growth	0.204	130–170	240–260	390–410
High Growth	0.270	170–230	310–340	510–540

In 2002 £. Source: Author's calculations using REMI-ECOTEC 6.0

manufacturing, services, and tourism—thus enabling such industrial activities to locate in a given region such as the East Midlands.

I test changes in overall TFP in the East Midlands that are proportional to the assumed growth rate scenarios and the OEF TFP elasticity of 0.06—assuming a constant linear relationship between growth and TFP. These are summarized in Table 5.3. A 1.3% growth in air transport output should increase total factor productivity by 0.078%. In the East Midlands, this raises the total GVA above the baseline forecast by about £50 to £65 million annually by 2030. I also found that an increase in total factor productivity of 0.132% results in about a £130 million increase in GVA above the baseline by 2030. In addition, I also considered productivity increases of 0.204%, and 0.270% for the medium-growth, and high-growth scenarios, respectively. A 0.204% increase in productivity translates into an annual increase of about £200 million in GVA by 2030, while the impact is about £260 million for a 0.270% increase in productivity.

Although these productivity-based catalytic impacts were equivalent to only 0.06% to 0.26% of the East Midland's £89 billion-pound economy in 2030, these impacts are large relative to the total annual growth. REMI-ECOTEC forecasts that the East Midlands regional economy will grow by £672 million in GVA between 2029 and 2030. As such, the catalytic impacts could thus contribute another 40% to the total annual regional economic growth by 2030 under a high aviation growth scenario.

Due to variations in intermediate supply chains and regional competitiveness, however, the wider productivity-based catalytic impacts are distributed differently across the various UK regions than those from the baseline air transport growth scenarios. Under the baseline aviation growth scenarios (in which only the air transport sector in the East Midlands is modified), about 52% of the total economy-wide impacts are observed in the East Midlands. Only about 36% to 42% of the total UK-wide productivity-based catalytic impacts occur in the East Midlands. The enhanced productivity of industries in the East Midlands presumably also helps to increase the competitiveness of nearby regions such as the West Midlands or Yorkshire and Humber. The illustration of these wider benefits to other parts of the country may help to inform regional policy and equity concerns.

5.2 Accessibility-based Catalytic Impacts

Another approach to analyzing the catalytic impacts of air transportation involves applying neoclassical economic trade theories to account for the inter-regional impacts of distance and choice on productivity and output. Fan et al. (2000) demonstrated that "new economic geography" or "accessibility" concepts can be used to reflect the urban agglomerative or dispersal relationships related to the intensity of intermediate inputs and land prices (Fan et al., 2000, p. 694). These accessibility impacts are essentially the same types of "catalytic" effects discussed earlier, except that they enter the economic model directly through prices and economic migration rather than through aggregate productivity. I consider these accessibility impacts to be catalytic effects because the migration and changes in prices affects the underlying inter-regional and technical structure of the economy.

In this section, I simulate the effect of increased air services by modifying the commodity-access index for the air transportation sector in the East Midlands and then analyzing the resulting changes in regional GVA. In the REMI model, the commodity-access index measures the relative change in access to specialized inputs for production in order to predict the change in the productivity of intermediate inputs (Regional Economic Models, 2007). The commodity-access index affects the intermediate inputs and productivity (and thus output), as well as migration/population. Ultimately, it affects both the composite cost of production by industry and the consumption-access index in the economic migration equation (Lee and Zohir, 2006, p. 6).

5.2.1 Accessibility and Agglomeration

In 2002, REMI introduced accessibility concepts into its U.S. Policy Insight forecasting model to account for agglomeration in commodities, consumption, and labor (Treyz and Treyz, 2004b, p. 7). The REMI-ECOTEC model is unique in that it is, to the author's knowledge, the only known model that implements accessibility relationships to affect interregional trade and migration, although the Regional Dynamics (REDYN) model uses impedance measures to affect commodity flows (Rockler, 2007). The REMI model assumes that regional agglomeration occurs because producers and consumers benefit from access to variety, but that land prices and congestion will tend to disperse economic activities (REMI, 2004b, p. 3). The model also assumes that access to a large labor pool will improve productivity by permitting a good match between jobs and skilled workers. Proximity to suppliers is also important because distance and transportation costs affect the overall delivered price of a commodity (REMI, 2004b, p. 17). Economic migration between regions is based on the relative attractiveness of access to consumer commodities or amenities.

In the REMI model, the accessibility linkages affect three elements of economic forecasts: (1) interregional trade flows, (2) the price elasticity of demand, and (3) composite prices. Trade flows are based on a distance-deterrence effect which uses a double-constrained gravity model to predict regional output subsequent to changes in output demand by industry and region; trade declines exponentially with distance (travel times) and accessibility costs (Treyz and Treyz, 2004b). These parameters are based on 30 years of time-series data by industry for each of about 3,000 counties in the United States (Treyz, 2005, pp. 5-6). The price elasticity of demand is associated with delivered costs or prices. The delivered price is the cost of producing the output at the location of production, plus the costs of transporting the output to the location where it is used. Finally, accessibility increases productivity—lowering costs, increasing market competitiveness, and increasing output. These productivity benefits are reflected in the composite prices. The composite price is the delivered price divided by the relative access index.

The accessibility variables in the REMI model are sensitive to small changes. In the examples provided by REMI, accessibility is usually measured in terms of changes to vehicle-passenger miles or vehicle hours traveled, and trips. The REMI TranSight

Table 5.4: Catalytic impacts under an East Midlands high-growth scenario (4.5% annually) compared to a baseline scenario

Scenario	Accessibility Change in 2030 (%)	Impacts on value-added in 2030 (£m)		
		Within East Midlands	Other Regions	Total UK-wide
Low Growth	1.3	650	1,210	1,860
Baseline	2.2	1,090	2,030	3,120
Medium Growth	3.4	1,200	2,240	3,440
High Growth	4.5	2,210	4,090	6,300

In 2002 £. Source: Author's calculations using REMI-ECOTEC 6.0

software is typically used to analyze the impacts of specific surface transportation projects. The proportion of travel in a specific corridor affected by such a project, for example, may be extremely small relative to the total region-wide travel. The commodity-access index can also be used to gauge how other changes in the regional economy affects accessibility. The large growth of the East Midlands aviation high-growth scenario (presented at the end of Chapter 4), for example, reduces the commodity-access index of the air transport sector by -0.0000507 (-0.005%) to 0.9998. The additional growth in the East Midlands air transport sector increases its productivity—thus reducing its cost and making it more competitive relative to other regions. While some of these accessibility effects are already reflected in the baseline REMI model forecasts, I also test direct changes to accessibility (and thus delivered prices) in order to examine the range of catalytic effects.

5.2.2 Accessibility-based catalytic impacts

Although I was not able to investigate the full relationships between air transport supply and accessibility, I conduct some sensitivity tests using direct changes to the commodity-

Table 5.5: Regional distribution of catalytic effects over time (% share)

	Productivity-based			Accessibilty-based		
	2006	2015	2030	2006	2015	2030
East Midlands	16.2	29.9	33.9	8.2	28.6	35.0
Greater London	16.8	11.9	11.2	17.9	11.3	10.4
Rest of UK	67.4	58.2	54.9	73.5	60.1	54.5
Total	100.0	100.0	100.0	100.0	100.0	100.0

High growth scenario. Source: Author's calculations from REMI-ECOTEC UK version 6.0

access index. I apply changes to the commodity-access index from 1.3% up to 4.5%, which correspond to the annual air transport growth rates. I conduct two sets of tests: (1) a more conservative set which changes air accessibility to only those sectors that would be most likely to be affected by improved supply-chain access to air transport, such as manufacturing, tourism, or financial or consulting services, and (2) a more liberal set of scenarios in which accessibility affects all sectors in the general regional economy.

The annual accessibility-based impacts on regional value-added in 2030 are summarized in Table 5.4. I found that under a low-growth scenario, a 1.3% increase in accessibliity in the East Midlands increased the region's GVA by £645 million in 2030. The high-growth scenario (4.5%) increased the East Midlands GVA by £2.2 billion. About 35% of the impacts occur in the East Midlands, while 65% of the impacts occur outside of the region. Overall, these impacts were equivalent to about 0.7% to 2.5% of the total East Midlands economy, and over three times the total amount of annual growth in 2029-2030. The total national accessibility-based catalytic impacts totaled £6.3 billion in 2030 under the high-growth scenario. This was equivalent to about 50% of the total economic growth forecast for that year (£12.2 billion in GVA, so it still represents a sizeable economic benefit.

Aside from the large differences in magnitude between the productivity- and accessibility-based catalytic impact methods, one of the key differences was the timing and distribution of these impacts over time. Table 5.5 shows the increase in value-added for each region relative to the baseline scenario in 2006, 2015, and 2030 under the high-growth scenarios for productivity and accessibility. During the initial year of the change (2006), about 16% of the productivity-based catalytic impacts but only 8% of the accessibility-based impacts were observed in the East Midlands. Ultimately, the regional distribution of the catalytic impacts in 2030 was similar between both methods. In the REMI-ECOTEC model, the accessibility-based changes to prices, market shares, and output appear to be slower than the changes in total factor productivity—despite having a larger total cumulative impact. The large magnitude of the impacts as well as the relative decline of London also appears to reflect the agglomeration benefits associated with enhanced economies-of-scale. The implication is that the market development benefits associated with aviation accessibility may take longer to accrue, but may be larger than the more immediate efficiency and productivity gains.

5.3 Summary

I found that the total accessibility-based impacts were much larger in magnitude than the productivity-based catalytic impacts. Both the productivity and accessibility impacts were large in the context of the total annual economic growth, but this underscores the strategic value of air transport in shaping regional economic growth.

As shown in Table 5.6, both the productivity- and accessibility-based measures of catalytic growth generally produced larger impacts than traditional direct, indirect, and

Table 5.6: Comparison of productivity- and accessibility-based catalytic impacts under an East Midlands high-growth scenario (4.5% annually) compared to a baseline scenario

Type of Catalytic Impact	Impacts on value-added in 2030 (£m)		
	In-region impacts	Out-of-region impacts	Total UK-wide impacts
Productivity-based	170–230	310–340	510–540
Accessibility-based	650–2,200	1,260–4,100	1,900–6,300

In 2002 £. Source: Author's calculations using REMI-ECOTEC 6.0

induced impacts of aviation sector growth when all of the total national impacts were taken into account. Under the high-growth scenario, for example, the total productivity-based catalytic impacts were £550 million, while the accessibility-based impacts were as much as £6.3 billion. Traditional measures of aviation growth result in an impact of about £500 million.

Although these results are sensitive to different assumptions, the magnitude suggests that these catalytic effects are significant compared to traditional measures of economic impacts. Further testing is needed to identify the sensitivity of the REMI-ECOTEC accessibility indices to variations in prices and costs as each region competes for national economic activity.

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Chapter 6

Airport Noise Impacts

Having in previous chapters established the magnitude of the impacts of air transport on regional socio-economic growth, I now consider how aviation noise affects the local neighborhoods around London Heathrow and East Midlands airports. First, I use an airport noise model to identify the changes in noise levels under different airport growth scenarios. I then monetize these noise impacts and calculate the total and annual community damage costs of these growth scenarios.

In particular, I use the depreciation on housing prices as a proxy for the socio-economic impacts of airport noise on the surrounding communities. Analysts typically use a Noise Depreciation Index (NDI) to describe these relationships. Because NDIs reflect location-specific, empirically observed relationships of noise levels and housing prices (after controlling for all other factors), Schipper et al. (1998) and others have used meta-analyses of NDIs in order to generalize these results for benefit transfer applications in different regions. Nelson (2004) conducted one of the most extensive studies in this area, and I apply his findings to Heathrow and East Midlands.

To show the sensitivity of these noise-damage costs to the NDIs and other parameters within the model pathway itself, however, I calculate the noise-damage costs using several different noise-depreciation indices, ambient-noise reference values, and alternative annual-capital recovery methods. I focus on how differences in NDIs and noise-damage costs reflect differences in noise measurement, threshold noise levels, and the functional form of underlying statistical models. I use these sensitivity tests to estimate the range of plausible values for the community damage costs and build confidence in my results. I also analyze these costs within the context of other community socio-economic indicators, such as income and housing tenure, in order to consider some of the distributional and environmental-equity impacts of airport growth.

6.1 Community Noise Impact Modeling

As shown in Figure 6-1, the two main components of my noise-damage-cost calculations are: (1) identification of the population affected by airport noise, and (2) calculation of the property values and associated damage costs for these affected areas. I use the flight operations under each airport growth scenario as inputs into INM in order to calculate the noise levels at specific locations around the airport. I then use the noise levels at each of these points together with population and housing unit counts, housing prices, and a noise-depreciation index to calculate the total community noise-damage costs. First, I discuss the flight operations data used to model the noise impacts of different growth scenarios at London Heathrow and East Midlands airports. I then discuss my methodology for applying the NDIs and annualizing the total community damage costs.

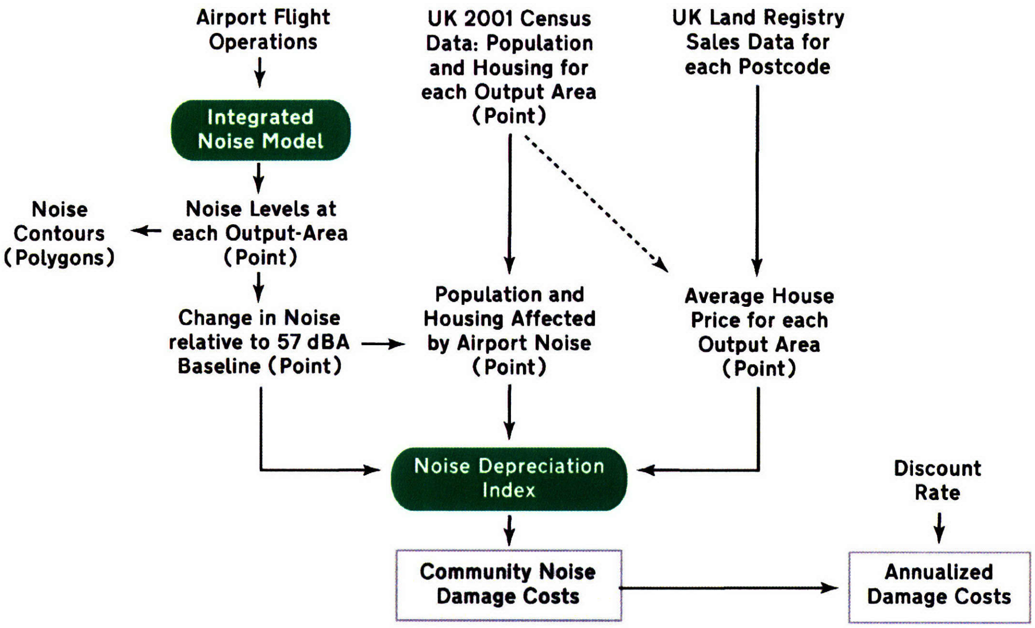

Figure 6-1: Methodology for calculation of noise-damage costs

6.1.1 Airport Noise Impact Modeling

In order to focus on the aggregate long-term impacts of aviation growth, I apply simplified model inputs using (1) how many flights are operated within each aircraft noise-class, and (2) when these flights operate. I start with the annualized high and medium airport growth scenarios for each airport to generate the number of average daily flight operations. The high-growth scenario, for example, has 754,000 annual air-transport movements at London Heathrow Airport and 262,000 annual movements at East Midlands. I use airline schedule and operational data to allocate the flights by time-of-day (Table 6.1) and aircraft noise class (Table 6.2), using five aircraft types (Dash-8, 737-700, 767-300, 747-400, and 747-200) as a coarse approximation for the fleet operated at each airport.

I generally assume the same fleet mix and flight timings for all scenarios, except for replacing the handful of noisiest aircraft operations (represented by the 747-200) with the

Table 6.1: Aggregate time-of-day distributions, 2005

Period	Description	Percent Share (%)	
		Heathrow	East Midlands
Day	7am-7pm	71.6	62.9
Evening	7pm-11pm	20.1	13.9
Night	11pm to 7am	8.2	23.2
Total		100.0	100.0

Source: Author's Calculations based on data from CAA, NEMA, and (Bowler, 2008)

Table 6.2: Aircraft class distributions, 2005

Noise Class	Description	Typical Aircraft	Percent Share (%)	
			Heathrow	East Midlands
1/2	Turboprops	Dash 8	0.8	7.1
3	Narrowbody jets	737-700	67.4	78.5
4	Widebody twins	767-300	18.3	11.3
5	Widebody longhaul	747-400	13.0	3.0
6-8	Older, noisier jets	747-200	0.6	
Total			100.0	100.0

Source: Author's Calculations from CAA and NEMA

747-400 under the medium- and high-growth scenarios. I explicitly do not consider the overall evolution of airline fleets (replacement of all 737-200s with A319s, for example). Although these simplified assumptions do not take fleet replacement into account and will thus somewhat overstate the growth of the noise contours, they enable me to focus on the impacts of growth rather than changes in technology. I consider technology changes separately, by modeling several scenarios that assume that the Silent Aircraft Initiative (SAI) SAX-40 replaces several categories of the nosiest medium- and large-aircraft types.

Analysts typically use INM to calculate aircraft noise for each given flight operation using a combination of (a) aircraft spectral class profiles, (b) noise-power-distance curves, and (c) various coefficients for jet, prop, flap, and other noise sources. Because spectral class profiles were not available for the SAX-40, I use the spectral profiles for the noisier Boeing 767-300 as a conservative substitution. The SAI team derived Noise-Power-Distance (NPD) curves for the SAX-40 by integrating noise hemisphere data from the different component sources of the SAX-40 design (Mobed et al., 2006). In the absence of noise-source coefficients, I use fixed-point flight profiles (i.e., thrust, altitude, and speed) at specified distance from the runway.[1] Finally, I setup 1.3-km displaced-approach thresholds at London Heathrow Airport to reflect the special low-noise operations that the SAI team designed to keep the SAX-40 at a higher altitude than conventional aircraft when passing over the airport boundary.

Finally, I use average movement data to allocate the total daily flight operations to specific runways and flight tracks. The set of arrival and departure flight tracks for westerly operations at Heathrow Airport is shown in Figure 6-2. I digitized the flight

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[1] These noise-source coefficients enable the user to calculate the noise based on how aircraft are flown: manipulation of thrust settings, climb or descent angles, and energy management (flaps) to maintain altitude or airspeed targets. Select aircraft, such as the MD-11 (with GE engines), are modeled this way when noise-coefficient data are not available.

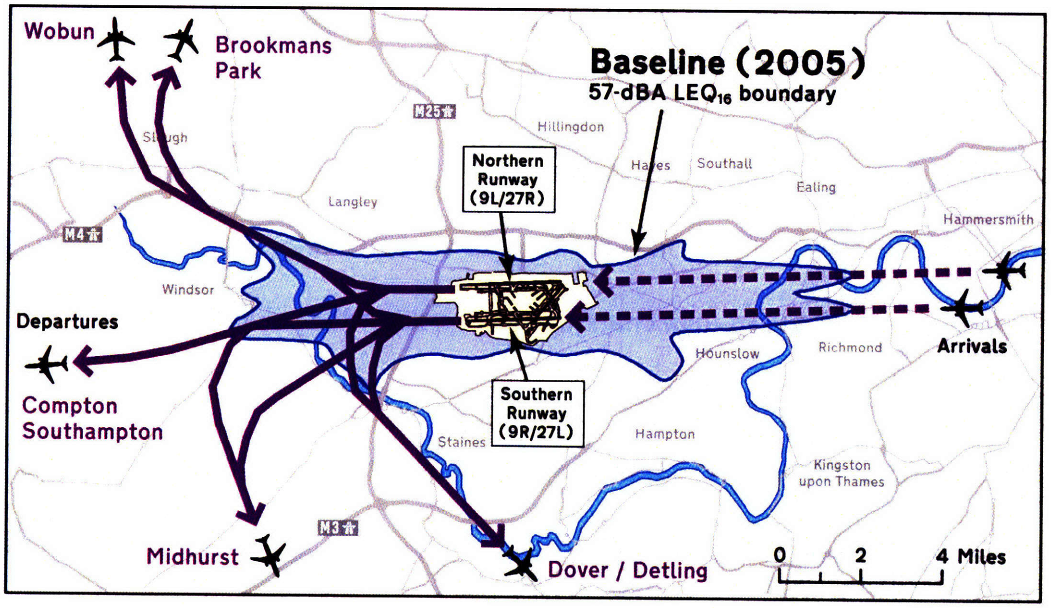

Figure 6-2: Example of 2005 flight tracks and noise contours: London Heathrow Airport (Westerly operations)

tracks into INM using data from CAA and EMA. The distribution of ATMs on the various departure flight tracks was published by the CAA and the East Midlands Airport. Table 6.3 also shows the directionality of the runway use at London Heathrow Airport. About 80% of the flight operations were in the westerly direction in 2004, but this decreased to about 70% in 2005. This changes the cumulative noise impacts on the ground and is important due to the densely populated areas to the east of Heathrow airport. For the high-growth scenario at London Heathrow airport, I also add a third, 2000-meter runway to the north of the existing runways. Up until 2007, the UK government had planned the new runway for short-haul aircraft. The current scheme is for a more functional, all-purpose 2,200-meter runway with additional displaced thresholds used for takeoffs (Department for Transport, 2007, pp. 44-45).

Table 6.3: Operational flows at London Heathrow airport, 1997, 2004, and 2005

Operational Flow	Percent Share (%)		
	1997	2004	2005
Westerly (Runways 27R and 27L)	74.0	81.0	71.0
Easterly (Runways 9R and 9L)	26.0	19.0	29.0
Total	100.0	100.0	100.0

Source: CAA

6.1.2 Noise Damage Cost Calculations

The output from INM includes plots of noise contours (highlighting areas of similar noise levels) as well as the actual predicted noise levels at specific locations. Each of these locations corresponds to a census output area centroid, and thus each accounts for roughly 300 persons and about 130 dwelling units. There are about 14,000 such points in the 50x30-km (1,500 km^2) study area around London Heathrow airport—encompassing about 4.2 million people and 1.8 million households.[2] In the 45x35-km (3,750 km^2) study area around the East Midlands airport, there are about 4,100 points. As discussed in Chapter 3, I use a baseline reference noise level of 57 dBA, and calculate the difference in noise levels relative to that baseline. In the baseline 2005 model, for example, there were 550 output areas with noise levels of 57 dBA or greater. The average noise level for these areas was 60.8 dBA, or +3.8 dBA relative to the 57-dBA baseline.

Using the noise levels and population data at each of these points along with the associated average housing sales price data from the UK Land Registry Department, I calculate the noise-damage costs for each of these output areas. This differs from almost all other previous housing-price studies, in which census areas were assigned to noise-

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[2] The size of these areas was constrained by a maximum grid size in the INM model.

contour bands–usually 3-dBA or 5-dBA wide. The additional precision offered by this approach enables more accurate calculations of the damage costs, even though humans can typically only perceive a 3-dBA difference in noise. For the baseline scenario, this method produces noise-damage costs that are about 75% higher than those calculated using population points assigned to noise-contour bands.

I calculate the noise-damage costs as a function of the total noise quantity and the noise-damage costs value (per decibel). The general form of this relationship, as applied by Pearce and Pearce (2000, p. 13) and others, is shown in Equation 6.1. I multiply the proportion of households $\frac{H_j}{H}$, within noise contour j, by the amount of noise generated by the airport relative to a background noise level QN_j, which is applied to the noise depreciation index NDI and the assessed value of these homes P, in order to get the total noise damage costs T_n .

$$T_n = \sum_{j=1}^{n} \left(\frac{H_j}{H} * QN_j \right) * \mathrm{NDI} * P \tag{6.1}$$

I use a more refined version of this model by using the population centroid-specific noise levels to calculate the actual noise damages for each census output area—rather than using the contour averages. I calculate the community noise-damage costs T_{nk} for every census output area, k, by multipliying the Noise Depreciation Index (NDI) by the noise levels in that area relative to a background noise level (QN_j), the number of households (H), and the average home sales price (P). This is shown in Equation 6.2.

$$T_{nk} = \sum_{k=1}^{n} (H_k * QN_k * NDI * P_k) \tag{6.2}$$

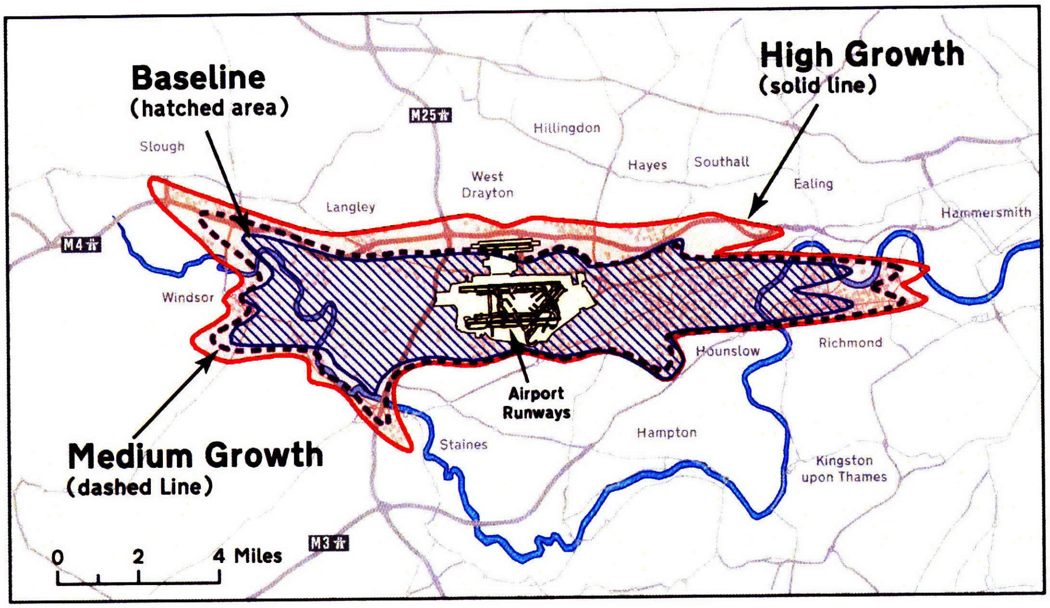
These NDI applications present the total cumulative damage costs of noise—as if every household were compensated with a one-time payout. As another way of analyzing these damage costs, I convert these noise-damage costs into an annualized cost using a standard discount rate. The HM Treasury (2008, p. 97-98) recommends using a Social Time Preference Rate (STPR) of 3.5% in order to discount future benefits and costs across different generations in perpetuity. The STPR is based on the discount of future consumption over present consumption, in addition to the expected rise in per capta consumption and the associated change in utility of consumption. I use this STPR for my annual damage-cost calculations in Section 6.2.

6.2 Noise-Damage Cost Results

In this section, I use the airport noise model and NDIs in order to calculate the community damage costs at London Heathrow and East Midlands airports. I do not incorporate expected reductions in the noise generated by conventional aircraft in the future, such as the ICAO Chapter 4 noise requirements which took effect in 2006. Under the Chapter 4 requirements, all new commercial aircraft will be 1/3 quieter than current (Chapter 3) aircraft (IATA, 2004, pp. 9-10). As such, my noise impact and damage costs calculations are likely to be conservative over-estimates of the actual damage costs.

6.2.1 London Heathrow Noise-Damage Costs

Figure 6-3 shows my calculations for the current and future noise contours for London Heathrow. The medium- and high-growth scenarios represent about 20% and 65% increases in capacity over current levels. The 57-dBA contour increases by about 18%



Source: Author's calculations using INM 6.1 and ArcMap 9.2

Figure 6-3: Baseline (2005) and future 57-dBA LEQ_{16} noise contours at London Heathrow airport

under the medium-growth scenario and 64% under the high-growth scenario. The population and housing units both grow by about 19% and 67% under the medium- and high-growth scenarios.

The noise-damage costs, however, rise much faster than the increases in affected population or households. As shown in Table 6.4, the current noise damages are about £310–£410 million. The noise damages increase by about 35% to £420—£550 million under the medium-growth scenario, and increase by 85% to £570–£750 million under the high-growth scenario.

To put this in a slightly different way, the baseline willingness-to-pay for a reduction in noise is about £65–86 (€83–110) per dBA per household per year, based on a 3.0% discount rate and a 30-year useful house life. The per-dBA willingness-to-pay per dB per household has a large distribution of values and ranges from a minimum of £43–

Table 6.4: Noise-damage-cost calculations at London Heathrow under different traffic growth scenarios

	Baseline (2005)	Medium Growth		High Growth	
		Levels	Change[1] (%)	Levels	Change[1] (%)
Annual Air Transport Movements	461,000	551,000	20	754,000	64
Affected area at 57-dBA LEQ_{16} level					
Land area (km^2)	84.8	99.8	18	139.4	64
Population	168,490	201,550	20	283,110	68
Housing Units	69,500	84,560	22	118,590	71
Noise-Damage Costs					
Total cost (£m)	310–410	420–550	34	570–750	83
Annual at 3.5% (£m)	10.8–14.2	14.6–19.2	35	20.0–26.3	85
Annual cost per dB per household[2] (£)	65–86	73–96	12	72–94	9

[1]Relative to baseline. [2]At 3.0% for 30 years. Source: Authors' calculations using INM 6.2 and ArcGIS 9.1

206 (€55–263).[3] In contrast, Kish (2008, p. 28) found a mean willingness-to-pay of €56 per-dBA/household/year around international airports and €76 for airports in the United States. The higher values which I find for the UK airports reflects the more detailed noise-level and population data used here.

In Table 6.5, however, I disaggregate the baseline noise-damage costs into 3-dBA contour-bands using a 0.67% NDI. On a per-household basis, the noise-damage costs amount to £18,500 for each of the 1,100 housing units in the 69- to 72-dBA contour. This is less than 2% of all the households affected by noise (> 57-dBA). Notably, over 51% of the households are located in the 57- to 60-dBA contour, and have damage costs of about £2,100 per household. Despite the large population in this area (36,000

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[3] The average household in the area with noise levels above 57-dBA contains 2.4 persons. Using a 3.5% annuity rate, the average willingness to pay is £45–59 or €58–76 per dBA per household per year.

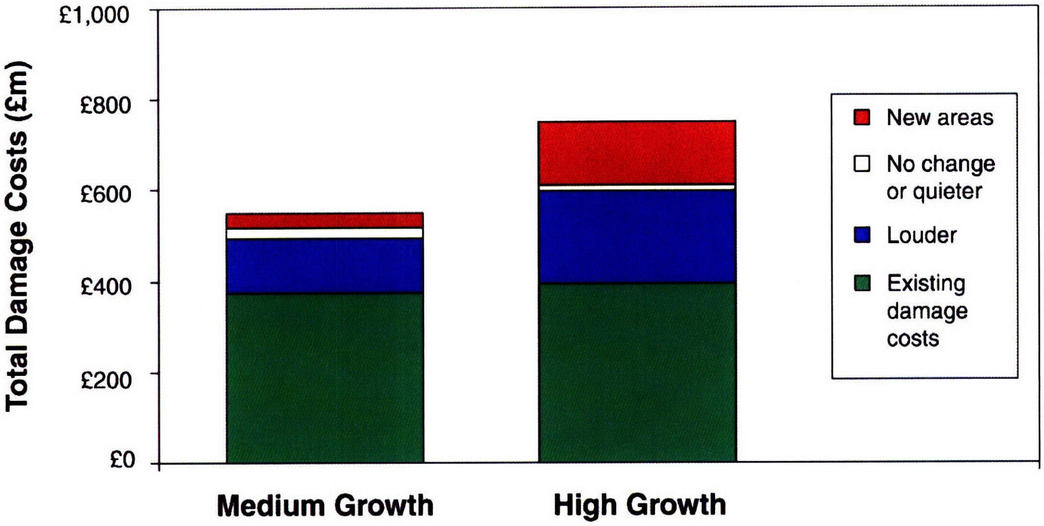
Table 6.5: Contour-level noise-damage costs at London Heathrow Airport under baseline scenario (0.67% NDI)

Noise Contour Level	Housing Units		Total Damage Costs		Damage Costs per Household	
	Amount	Share (%)	Amount (£m)	Share (%)	Total (£)	Annual (£)
>72 dBA	230	0.3	10	1.3	23,180	810
69-72 dBA	1,110	1.6	20	5.1	18,560	650
66-69 dBA	4,700	6.8	70	16.7	14,490	510
63-66 dBA	10,410	15.0	110	26.9	10,480	370
60-63 dBA	18,980	27.3	130	31.4	6,730	240
57-60 dBA	35,860	51.6	80	18.6	2,110	70
> 57 dBA	69,500	100.0	410	100.0	5,850	200

NDI of 0.67%, and annual annuity rate of 3.5%. Source: Authors' calculations using INM 6.2 and ArcGIS 9.1

households), the relatively low damage cost-per household leads to a relatively low overall share of total damage costs (18%).

I also use the noise-damage-cost calculations to identify how underlying areas are affected by the changes in noise impacts under the medium- and high-growth scenarios relative to the baseline. Because the total noise-damage costs combine the severity of the impact (cost per decibel of noise level) with the extent of the impact (number of housing units affected), it provides more depth than traditional analytical metrics. Figure 6-4 shows that only a small portion (6% or £30 million) of the noise-damage costs in the medium-growth scenario occur in new areas that were not previously exposed to aircraft noise above the 57-dBA LEQ level, while about 20% (£140 million) of the damage costs under the high-growth scenario are in such areas. This is attributable to the addition of the third northern runway under this high-growth scenario. In both scenarios, about a quarter of the noise-damage costs are from areas that would be exposed to louder noise levels.



Source: Author's calculations

Figure 6-4: Changes in noise-damage costs relative to the baseline (2005) scenario

6.2.2 London Heathrow Noise-Damage Costs with Low-Noise Aircraft

I consider the changes in noise damages at London Heathrow if air carriers introduced an advanced, low-noise aircraft into their operating fleets, based on the estimated performance of the SAX-40 concept aircraft (Crichton et al., 2007; Hileman et al., 2007). I did not develop a set of advanced low-noise technology aircraft scenarios for the East Midlands Airport, because medium- and long-haul aircraft currently represent a small percentage of operations there. For this scenario, I assume that by 2030, advanced technology, low-noise aircraft, such as the SAX-40, are readily available for incorporation in the fleet. I stress that this is a scenario and may not reflect what is probable in this time period.

I consider the high-growth scenario (754,000 annual air-transport movements) as a basis for reference. Figure 6-5 shows the noise-contour calculations for a "SAX Phase 1" scenario under which the SAX-40 replaces all Noise Class 4 aircraft (represented by the

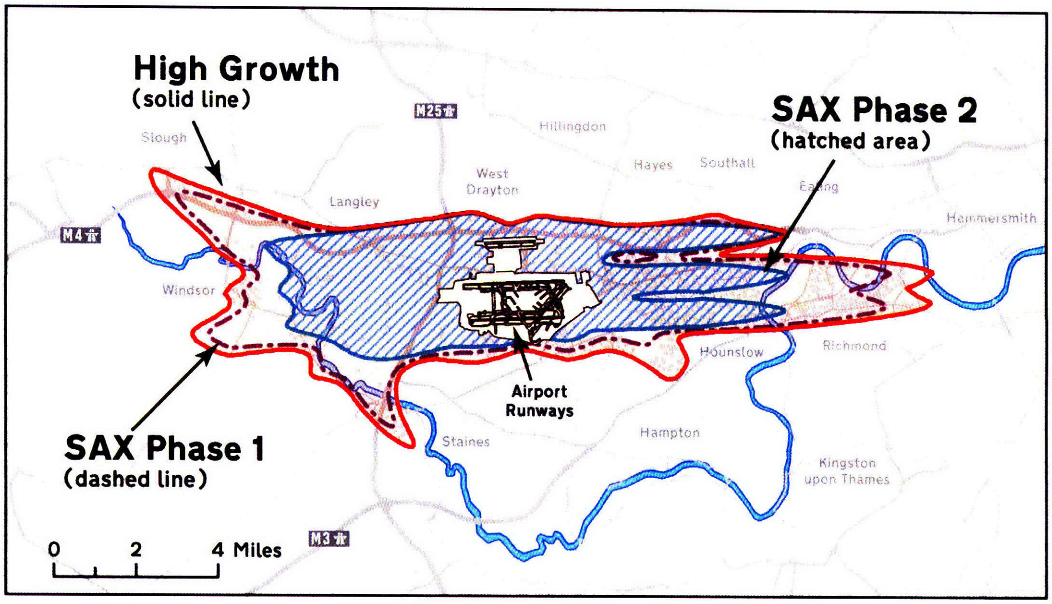


Figure 6-5: 57-dBA LEQ_{16} noise contours under high-growth scenario and alternative advanced technology, low-noise aircraft replacement scenarios

767), and a "SAX Phase 2" scenario under which the SAX-40 replaces both Noise Class 4 and 5 aircraft (represented by the 767 and 747, respectively). Again, note that the noise characteristics of all other (conventional) aircraft remain unchanged.

Under the SAX Phase 1 scenario, the noise-contour area shrinks by about 18% relative to the high-growth scenario. Table 6.6 shows that the corresponding noise-damage costs decline by about 32% to £390–£510 million (versus £570–£730 million for the high-growth scenario). Under the SAX Phase 2 scenario, the noise-contour area shrinks by about 46% relative to the high-growth scenario, while the noise damages decline more steeply–by about 66% to £190–£250 million. When compared to the baseline (2005) contours, the SAX Phase 1 scenario has a 26% net increase in noise-damage costs, while the SAX Phase 2 scenario has a 38% decrease.

To put these estimates in context, I compare the damage costs in 1997, 2005, and the high-growth scenario in Table 6.7 and Figure 6-6. I calculate the 1997 noise

Table 6.6: Noise-damage-cost calculations at London Heathrow under advanced technology, low-noise aircraft scenarios

	High Growth	SAX Phase 1		SAX Phase 2	
		Levels	Change[1] (%)	Levels	Change[1] (%)
Annual Air Transport Movements	754,000	same	–	same	–
Affected area at 57-dBA LEQ_{16} level					
Land area (km^2)	139.4	116.5	-16	79.2	-43
Population	288,830	214,140	-26	125,150	-57
Housing Units	121,000	88,490	-27	49,420	-59
Noise-Damage Costs					
Total cost (£m)	570–750	390–510	-32	190–250	-67
Annual at 3.5% (£m)	20.0–26.3	13.7–17.9	-32	6.8–8.9	-66
Annual cost per dB per household[2] (£)	72–94	68–89	-5	57–75	-20

[1]Relative to baseline. [2]At 3.0% for 30 years. Source: Authors' calculations using INM 6.2 and ArcGIS 9.1

contours using INM along with Aircraft Communication Addressing and Reporting System (ACARS) flight movement data (Bowler, 2008). Assuming the same population characteristics and housing values which I use for the previous calculations, I find that the total noise-damage costs under a 1997-type scenario is about £560–£730 million. Thus, the damage costs in 2005 have been reduced by about one-third from 1997 levels. Although a high-growth scenario would create total noise-damage-costs only slightly higher than 1997 levels, there are key differences in which communities would be exposed to noise. The addition of a third northern runway, for example, would expose a new set of households to high noise levels.

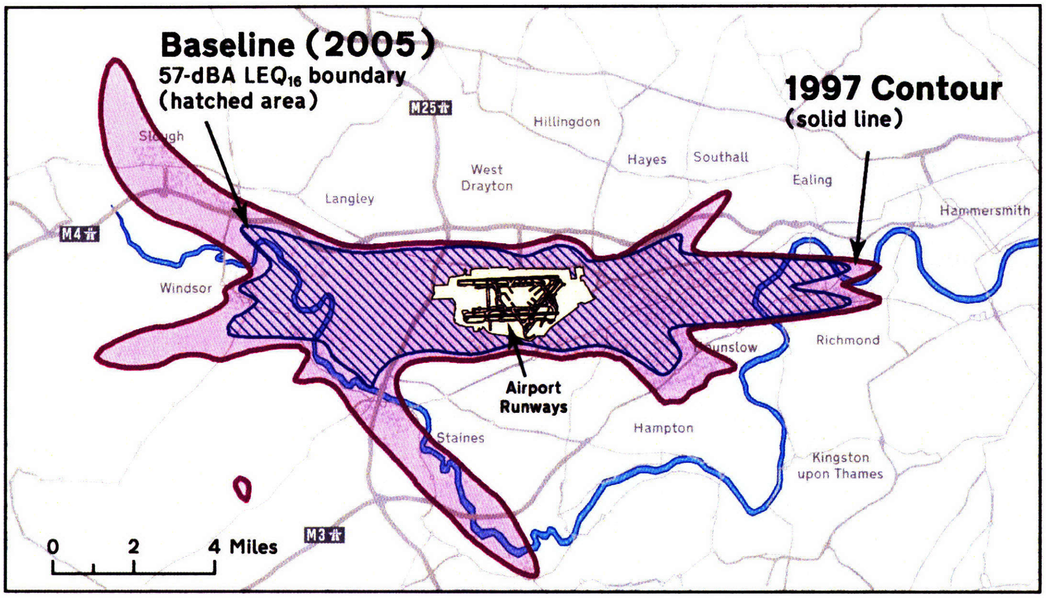


Figure 6-6: Comparison of noise contours at Heathrow, 1997 and 2005 (baseline)

Table 6.7: Noise-damage-cost calculations at London Heathrow: 2005 baseline versus 1997 and high-growth scenario

	Baseline (2005)	1997 Levels	High Growth
Annual Air Transport Movements	461,000	426,320	754,000
Contour Area (km^2)	84.8	151.6	139.4
Population > 57-dBA	168,490	287,030	283,110
Housing > 57-dBA	69,500	120,210	118,590
Total Damage Costs (£m)	310–410	560–730	570–750
Annual Damage Costs at 3.5% (£m)	10.8–14.2	19.5–25.6	20.0–26.3
Damage Costs per dB/household/year[1] (£)	65–86	68–89	72–94

[1] At 3.0% for 30 years. Source: Authors' calculations using INM 6.2 and ArcGIS 9.1

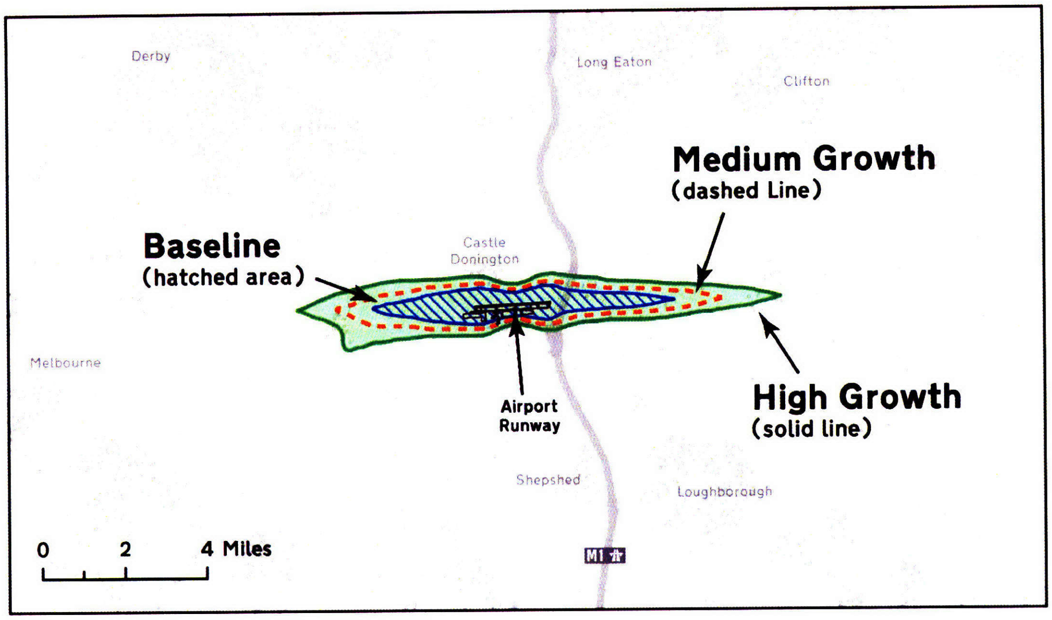


Figure 6-7: Baseline (2005) and future 57-dBA 16-hour LEQ contours at East Midlands Airport

6.2.3 East Midlands Noise-Damage Costs

The scenarios at East Midlands include a roughly 100% increase in operations under the medium-growth scenario and 350% increase under the high-growth scenario. As shown in Figure 6-7, the area of the 57-dBA contour grows by about 75% under the medium-growth scenario and about 200% under the high-growth scenario. Although the geographic extent of the noise impacts grows somewhat modestly relative to the increase in operations, the number of housing units affected increases more steeply. Under the current airport operational scenario, there are about 390 dwelling units within the 57-dBA contour. As the traffic levels increase, the contour area grows to include about 1,300 housing units under the medium-growth scenario and 4,200 housing units under the high-growth scenario.

Table 6.8: Noise damage cost calculations around East Midlands Airport under different traffic growth scenarios

	Baseline (2005)	Medium Growth		High Growth	
		Levels	Change[1] (%)	Levels	Change[1] (%)
Annual Air Transport Movements	57,400	122,300	113	262,200	357
Affected area at 57-dBA LEQ_{16} level					
Land area (km^2)	9.4	16.6	77	29.2	211
Population	890	3,000	237	9,930	1,016
Housing Units	390	1,300	233	4,200	977
Noise-Damage Costs					
Total cost (£m)	0.94–1.24	3.33–3.47	180	10.83–14.23	1,048
Annual at 3.5% (£m)	0.03–0.04	0.12–0.15	275	0.38–0.5	1,150
Annual cost per dB per household[2] (£)	45–60	47–62	3	50–66	10

[1]Relative to baseline. [2]At 3.0% for 30 years. Source: Authors' calculations using INM 6.2 and ArcGIS 9.1

The area surrounding the East Midlands airport is much more sparsely populated than London, and the housing prices are also much lower—with average prices about £93,000 to £100,000 pounds (compared to about £315,000 in London). As such, there are disproportionate increases in the noise-damage costs relative to increases in capacity. Table 6.8 shows that the current noise-damage costs range from about £0.18 to £0.24 million. Under the medium-growth scenario, the noise-damage costs increase by about 300% to about £0.7–£1.0 million—a greater change than the population or dwelling units affected. Under the high-growth scenario, the noise-damage costs increase to £3.2—£4.2 million. On an annual per household per decibel basis and assuming a 3.0% discount rate and a 30-year house lifetime, the average noise-damage costs are £45–60 (€58–77) under the baseline scenario and £50–66 (€64–85) under the high-growth scenario.

Table 6.9: Contour-level noise-damage costs at East Midlands Airport under baseline scenario (0.67% NDI)

Noise Contour Level	Housing Units		Total Damage Costs		Damage Costs per Household	
	Amount	Share (%)	Amount (£m)	Share (%)	Total (£)	Annual (£)
>72 dBA	-		-		-	-
69-72 dBA	-		-		-	-
66-69 dBA	-		-		-	-
63-66 dBA	-		-		-	-
60-63 dBA	260	66.5	1.1	90.2	4,320	150
57-60 dBA	130	33.5	0.1	9.8	940	30
> 57 dBA	390	100.0	1.2	100.0	3,190	110

NDI of 0.67%, and annual annuity rate of 3.5%. Source: Authors' calculations using INM 6.2 and ArcGIS 9.1

Table 6.9 shows a breakdown of the total damage costs and damage costs per household under the baseline scenario at the East Midlands airport. At a per-household cost of £4,320 in the 60-63-dBA band and £940 in the 57-60-dBA band, the noise-damage costs at the East Midlands are significantly less than those for similar contour areas at London Heathrow airport (Table 6.5).

6.3 Decomposing the Damage Costs

My calculations of the noise-damage costs in the previous section are based on the concept of benefit transfer: using the findings or parameters from one study and applying them elsewhere (Johnson and Button, 1997, p. 224). For my noise-damage-cost calculations at London Heathrow and the East Midlands airports, for example, I use the results of empirical studies that relate a change in property value per decibel change in noise exposure. Yet differences in how these studies are conducted can produce wide variations in Noise Depreciation Indexs (NDIs). Schipper et al. (1998), for example, found NDIs ranging from 0.10% to 3.57% change in property values per decibel change in noise exposure. Some of the key differences in these studies include the way in which the equations are specified, the threshold noise levels, and whether or not airport accessibility is included in the model (Nelson, 2004, pp. 7-10).

As benefit transfers are often used in policymaking for purposes such as benefit-cost analyses, analysts need to understand how key indices such as NDIs are developed and applied. Here, I further illuminate the noise-damage cost pathway by conducting a series of sensitivity analyses to identify how changes to key model inputs affect the noise-damage costs. First, I examine how changes in the NDIs and baseline reference noise levels affect the damage costs. I then compare the noise-damage costs using several different noise metrics, and also look at sensitivity of different discount rates.

6.3.1 Noise Depreciation Indices

My damage-cost calculations in Section 6.2 are based on NDIs observed in previous studies of airport noise. Yet NDIs can vary widely, due to the ways in which analysts setup their empirical models, as well as the type of data that are available. In this section, I analyze the sensitivity of the damage costs to the NDIs themselves, as well as the noise-metric type and the background threshold-noise levels—two key factors in models of noise and housing prices.

The NDIs used in airport noise-damage cost studies describe the percent change in housing value per change in noise levels. One of the key differences among these studies is in how the aircraft-noise levels are measured (McMillen, 2004, p. 629). Most

Table 6.10: Noise impacts under different metrics

	Metric			
Impact	NEF	NNI	DNL	LEQ_{16}
Measurement Unit	EPNdB	EPNdB	dBA	dBA
Background Noise	25	27	55	57
Little or No Impacts	0-20	35	< 55	57
Some or Moderate Impacts	20-30	45	55-65	63
Considerable Impacts	30-40	55	65	69
Severe Exposure	> 40		> 75	72

NEF = Noise Exposure Forecast; NNI = Noise and Number Index; DNL = Day-Night Level; LEQ_{16} = 16-hour Equivalent Continuous Noise Level. Source: Horonjeff and McKelvey (1983), others

economists used the Noise Exposure Forecast (NEF) metric in hedonic-price studies up through the 1980s, but began using Day-Night Level (DNL) as airports in the United States adopted this metric. Analysts in the United Kingdom used the Noise and Number Index (NNI) metric through the 1990s until it was replaced by the LEQ_{16} metric.[4] Because these average peak noise metrics represent noise over a period of time, however, they may understate the true disturbance cause by increased flight activity in airport noise-housing-price studies (Feitelson et al., 1996, p. 12). Nevertheless, they are widely used by airport operators. Table 6.10 compares the key noise threshold levels for the different metrics. Analysts generally consider background noise to be at the 25 NEF level, or 55-dBA DNL and 57-dba LEQ_{16}.

Tables 6.11 and 6.12 show the wide range in NDIs and noise metrics found in recent studies. Note that the NDIs in Table 6.11 are presented as the percentage depreciation in housing-price per increase in noise level (in dB), while the NDIs in Table 6.12 are shown as the percentage depreciation in total housing-price between a noisy and a non-

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[4] I use this latter metric as the basis for the damage-cost calculations presented earlier.

Table 6.11: Summary of noise-depreciation indices from previous studies: NDIs per decibel

Study	NDI (% per dB)	Metric	Notes
Morey (1990)	0.10	NEF	NEF 15-30
Pennington et al. (1990)	0.15	NNI	NNI 27-40. Initial estimate only– others insignificant. (6% of value)
Kaufman and Espey (1997)	0.34	DNL	includes distance factor; noise at 65/70/75 DNL
O'Byrne et al. (1985)	0.64	NEF	NEF 25-45
	0.67	DNL	DNL 65-80
Uyeno et al. (1993)	0.65	NEF	Detached family houses; NEF 25-40
	0.90	NEF	Multi-unit Condos
Tomkins et al. (1998)	0.78	LEQ	Continuous and discrete (LEQ 60 or 57+); NNI 40 or 35+ not significant
Levesque (1994)	1.30	EPNL	Number of events > 75 EPNL
Yamaguchi (1996)	3.57	LEQ	10.72 per 3 dBA LEQ; (2.14 NNI)

NEF = Noise Exposure Forecast, NNI = Noise and Number Index, DNL = Day-Night Level, LEQ = Equivalent Continuous Noise Level, and EPNL = Effective Perceived Noise Level.

noisy area based on a specified background noise threshold (such as 65-dba DNL, for example). This is because some analysts use a binary value (e.g., noisy or not-noisy) in their hedonic price model rather than a continuous noise level variable (e.g., 65- or 66-dBA). Such an approach recognizes that noise is measured on a logarithmic scale, and that the relationship between noise levels and damage costs may not necessarily be linear (Cohen and Coughlin, 2007, p. 23). This non-linearity is contrary to what may be suggested by a non-dimensional NDI.

The small number of noise studies sampled in Tables 6.11 and 6.12 show a relatively wide range in NDIs based on a range of noise metrics, threshold levels, and model types. The highest reported NDI in Table 6.11 is 3.5%, from a study of London airports (Yamaguchi, 1996). Schipper et al. (1998) reported this finding, although they appear to

Table 6.12: Summary of noise-depreciation indices from previous studies: NDIs per total house value

Study	NDI (Price)	Metric	Notes
Feitelson et al. (1996)	1.8–3.0	DNL	For renters
Espey and Lopez (2000)	2.4	DNL	65 DNL vs. 60 DNL zone; Equals 0.28% per dB
Feitelson et al. (1996)	2.4–4.1	DNL	For owners; stated preference; DNL 55 vs. 70 (+15) or 50 vs. 75 (+25)
Tomkins et al. (1998)	5.3	LEQ	57 LEQ
Tomkins et al. (1998)	8.0	LEQ	60 LEQ
Collins and Evans (1994)	8.0–9.5	NNI	NNI 27; Detached houses
McMillen (2004)	9.2	DNL	65 DNL; Equals 0.92% per dB
Cohen and Coughlin (2007)	20.8	DNL	70 DNL vs < 65 DNL; distance -0.15; Equals 3.3% per dB

NNI = Noise and Number Index, DNL = Day-Night Level, and LEQ = Equivalent Continuous Noise Level.

have converted Yamaguchi's NDI specification of 10.7 per 3-dBA LEQ contour band in order to get an NDI on a per-decibel basis.

Using a stated-preference survey, Feitelson et al. (1996, p. 12) found slightly lower NDIs for renters than for home owners—perhaps due to the reduced mobility of homeowners relative to renters. In a relatively small study from 1987, Uyeno et al. (1993) also found slightly higher NDIs for multi-unit condos than for detached family homes around Vancouver, British Columbia.[5] Espey and Lopez (2000) and McMillen (2004) found NDIs of 2.4% and 9.2% of the total home value, but had different sample sizes and sites (Reno and Chicago O'Hare airports). Cohen and Coughlin (2007) found a 20.8% NDI on total housing-prices, but used a higher noise threshold than other studies: 70-75 dBA DNL.

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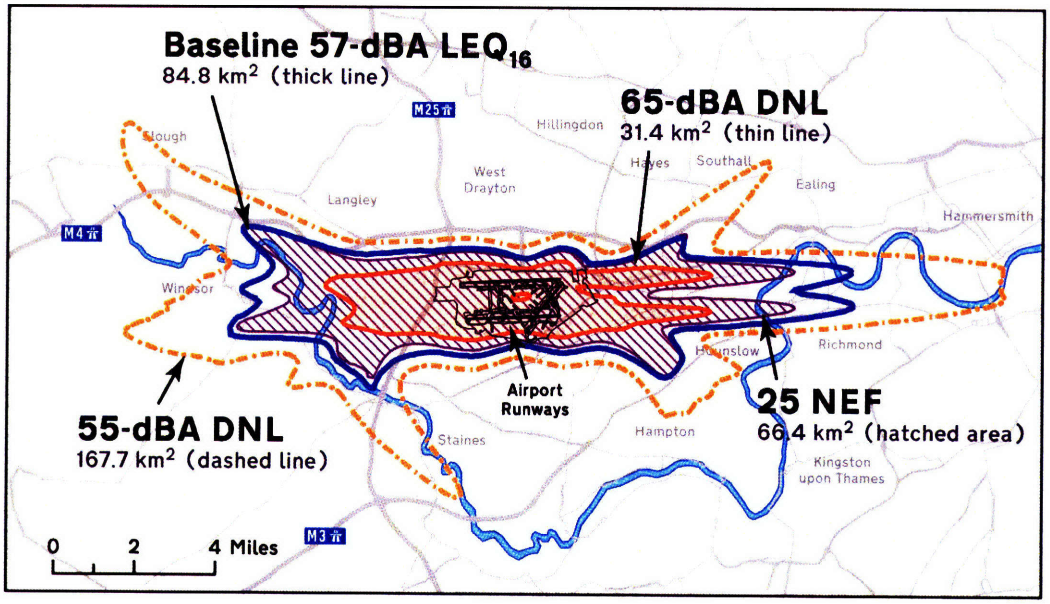
[5] These could be due to the presence of newer, more expensive condos in the City of Richmond, relative to older, more established homes in the Vancouver area.



Day-Night Level = DNL, Noise Exposure Forecast = NEF, and LEQ_{16} = 16-hour Equivalent Continuous Noise Level.

Figure 6-8: Comparison of baseline (2005) noise contours at London Heathrow airport using alternative metrics

Because the noise metrics and threshold levels jointly determine the number of persons affected by airport noise, these become key determinants in the differences in damage costs under different NDIs. Figure 6-8 compares the 55- and 65-dBA DNL contours with 25-NEF and 57-dBA LEQ_{16} contours based on 2005 operations at London Heathrow Airport. The 57-dBA LEQ_{16} contour (84.8 km^2) is slightly larger than the the 25-NEF level (66.4 km^2), but the 55-DNL contour is much larger than either of these (167.7 km^2).

In Figure 6-9, I plot the damage costs at London Heathrow Airport based on the various methodologies shown in Tables 6.11 and Tables 6.12. The X-axis shows the population affected under the each methodology (noise metric and threshold level). The Y-axis shows the total damage costs at London Heathrow under each of the different methodologies. Figure 6-9 shows that most of the methodologies using high thresholds

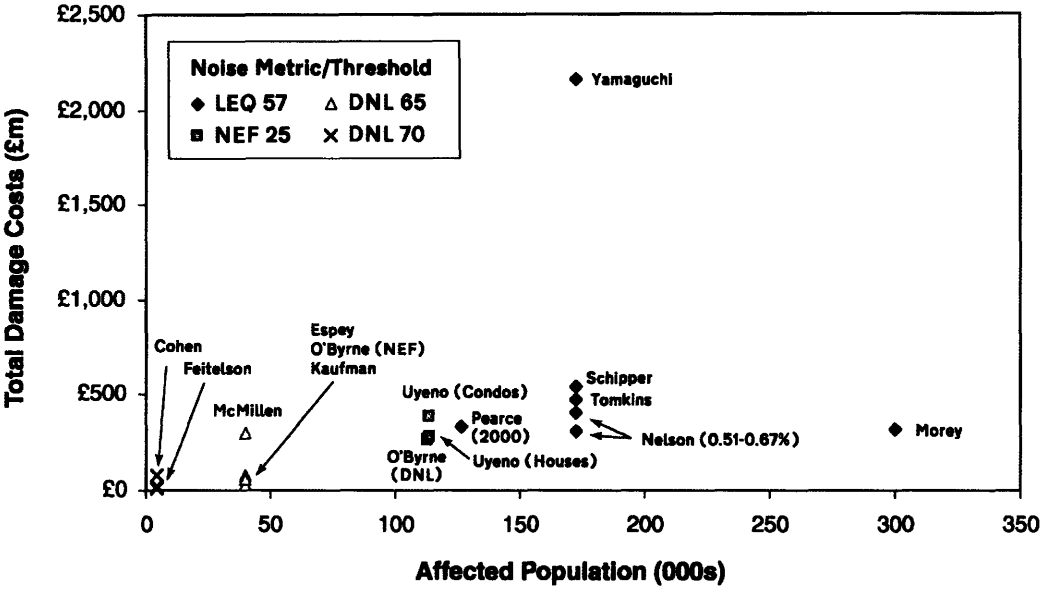


Figure 6-9: Comparison of total damage costs at London Heathrow using different NDIs based on NEF, DNL, and LEQ contour areas

(65- or 70-DNL) generally have total damage costs on the lower end of the range–less than £100 million. The 25-NEF and 57-LEQ$_{16}$ have relatively similar damage costs–around £300 to £500 million. The key difference, however, is that the 25-NEF level contains about 114,000 residents, while the 57-LEQ level contains about 173,000 people. The meta-analyses of Schipper et al. (1998) (0.90% NDI) and Nelson (2004) (0.51%-0.67% NDI) are on the higher end of both affected populations, due to the 57-LEQ basis, and overall damage costs—excluding the major outliers of Yamaguchi (£2.2 billion at 57-LEQ) and Morey (£517 million for 877,000 people at 15-NEF). The higher affected population and damage costs associated with these meta-NDIs reflects a more conservative (and inclusive) modeling approach, from a damage-impact-modeling standpoint.

Finally, I conduct a sensitivity test to examine the range in damage costs associated with different NDIs for a given noise metric/threshold over the different growth scenarios.

Table 6.13: Noise damage cost calculations at London Heathrow under different noise depreciation indices

	Current (2005)	Medium Growth	High Growth
Total Damage Costs (£m):			
at 0.50% NDI	300	410	560
at 1.00% NDI	610	820	1,120
at 3.50% NDI	2,120	2,870	3,920
Annual Damage Costs (3.5%; £m):			
at 0.50% NDI	10.6	14.3	19.6
at 1.00% NDI	21.2	28.7	39.2
at 3.50% NDI	74.3	100.4	137.3

Source: Authors' calculations using INM 6.2

I test three different NDIs: 0.5%, 1.0%, and 3.5%. The DfT used NDIs of 0.5% to 1.0% in its analysis of airports in the South East (UK Department for Transport, 2003d), while Lazic and Golaszewski (2006) suggests that a 1% NDI is a reasonable estimate, based on a survey of recent literature. Yamaguchi (1996) found an NDI of 3.5% for the London airports.

Table 6.13 shows the noise-damage costs at London Heathrow under different NDIs. An NDI of 1.0% results in damage costs of about £600 million under the current baseline scenario, or about £21.2 million annually. At an NDI of 3.5%, the total current damage costs increase to £2.1 billion, or about £74.3 million annually. The high sensitivity of the damage costs to different NDIs underscores the importance of well-documented studies, especially in benefit-transfer policy applications.

6.3.2 Discount Rates

Another area of modeling subjectivity involves the discounting assumptions used to convert the damage costs into an annualized value. Analysts use discount rates to account for the existence of net productivity and interest rates as well as the time preference of money: capital invested today will earn a profit (interest) over time, but people prefer money today rather than money in the future (Clayton and Radcliffe, 1996, p. 123).

Clayton and Radcliffe (1996, pp. 124-126) suggest that discounting makes it more attractive to defer environmental costs to future generations, and that a discount rate of zero may be appropriate if future generations will derive no less benefit than current generations from an environmental resource. From a noise-nuisance standpoint, however, the recent Attitudes to Noise from Aviation Sources in England (ANASE) study suggests that people are more sensitive to noise today than they were in the past (perhaps due to rising socio-economic standards)—suggesting that some discounting is appropriate.

$$P_v = P\left(\frac{r(1+r)^n}{(1+r)^n - 1}\right) \tag{6.3}$$

Pearce and Pearce used a HM Treasury real annuity interest rate RA of 6.0%, while Lu and Morrell (2001) and Levinson et al. (1997) use the capital recovery formula shown in Equation 6.3 to convert the average house value, P, into an annual house rent, P_v. Levinson et al. use an assumed discount rate, r, of 7.5% and an amortization period n

Table 6.14: Noise-damage-cost calculations at London Heathrow under different annuity rates

	Current (2005)	Medium Growth	High Growth
Annual Values based on Social Time Preference Rates (£m):			
3.5% in perpetuity	10.8–14.2	14.9–19.2	20.0–26.3
6.0% in perpetuity	18.6–24.4	25.1–33.0	34.3–45.1
Annual Values based on Mortgage Rates (£m):			
5.25% at 30 years	20.7–27.2	28.0–36.8	38.2–50.2
7.50% at 30 years	26.2–34.4	35.4–46.5	48.4–63.6

Source: Authors' calculations using INM 6.2 and ArcGIS 9.1

of 30 years. At the end of Feburary 2008, the mortgage rate in the United Kingdom was around 5.25%, while the base 30-year, fixed-rate US mortgage rate was 6.24%.

Table 6.14 shows the different values of the noise-damage costs using both the real annuity rates and the capital-recovery formulas. Using an annuity rate of 6.0% instead of 3.5% increases the annual damage costs by almost 80%. The use of the capital recovery formula substantially increases the total annual damage costs relative to the real annuity rates.

6.3.3 Reference Values

In Section 6.3.1, I note that the combination of the NDIs and the noise level thresholds determines the affected population and the damage costs. Yet noise policies and threshold levels also add some degree of subjectivity into damage-cost calculations, by way of how these policies are established. Although analysts may recommend that noise metrics and threshold levels correspond with the degree of annoyance in the community, policymakers must also weigh the acceptability of such thresholds among a wide range of community stakeholders, including airport-area residents and airport operators. U.K. policymakers, for example, selected 57-dBA as the baseline background noise level based on its correspondence with NNI noise metric levels used for years, in addition to results of noise-annoyance studies. The UK Aircraft Noise Index Study (ANIS) study found that the onset of noise annoyance occurred at 55-dBA (LEQ_{24hr}), while high annoyance occurred at 70-dBA. The study also found that sleep disturbance occurs at about 45-dBA, but that the difference between interior and exterior noise accounts for another 15-dBA. The most recent ANASE study suggests that residents have become more sensitive to noise, and that annoyance may begin at the 50-dBA level.

In order to look at the sensitivity of these damage costs to noise policy thresholds, I test the impact of different baseline reference values apart from the 57-dBA L_{Aeq} level. Table 6.15 shows the damage costs against baseline reference noise levels of 55- and 50-dBA L_{Aeq}. Under the current baseline scenario, there are about 172,500 people within the 57-dBA boundary. This increases to 260,800 people at 55-dBA, and 773,200 at 50-dBA. Thus, lowering the noise threshold by 2-dBA to 55-dBA substantially increases the damage costs from about £300–400 million to £550–725 million. At a threshold of 50-dBA, the noise damages are £2.1–£2.8 billion. Annual damage costs could be as much as £25 million at 55-dBA and almost £97 million at 50-dBA.

6.4 Context

Property values, however, do not tell the whole story. Although property values are associated with household income and socio-economic occupational status, they may not necessarily reveal the full extent of the damage costs imposed on communities.

Table 6.15: Noise damage cost calculations at London Heathrow under different reference values: 55- and 50-dBA LEQ16

	Current (2005)	Medium Growth	High Growth
Affected Housing Units			
> 55-dBA	107,470	136,990	199,680
> 50-dBA	336,350	360,110	508,250
Total Damage Costs (0.51%–0.67% NDI)			
> 55-dBA (£m)	550–720	750–980	1,040–1,370
> 50-dBA (£m)	2,100–2,760	2,470–3,250	3,410–4,480
Annual Damage Costs (3.5%)			
> 55-dBA (£m)	19.3–25.4	26.1–34.3	36.4–47.9
> 50-dBA (£m)	73.4–96.5	88.5–113.6	119.3–156.8

Source: Authors' calculations using INM 6.2 and ArcGIS 9.1

Indeed, contingent-valuation surveys typically produce noise-damage costs values that are higher than hedonic price studies, because they include loss-of-use value rather than just market premiums (Feitelson et al., 1996, p. 12).

Here, I look at household income and other socio-economic indicators to add a further dimension to the damage costs of airport noise on surrounding communities. I use Geographical Information System (GIS) to map several key metrics associated with environmental justice and equity considerations, including household income and socio-economic occupational status. By identifying how these socio-economic characteristics are related to each of the noise-damage costs scenarios, I provide a context from which to analyze the damage costs.

6.4.1 Noise-Price-Distance Relationships

The damage costs that I calculate in Section 6.2 are all based on population centroid-based data for airport noise and housing prices. In Figures 6-10 and 6-11, I plot those data to show the relationships among housing prices, distance to the airport, and noise levels around London Heathrow Airport at the census output-area level.[6]

Despite the undesirable attributes of aircraft noise, Nelson (2004, pp. 8-9) and others note that close proximity or accessibility to the airport can have a positive effect on property value. Cohen and Coughlin (2007) incorporated this into their study and found that housing values declined by -0.15% as distance increased from the airport. Figure 6-10, however, shows the opposite relationship at London Heathrow airport: increasing housing prices with increasing distance from the airport. The R^2 of 0.64 indicates a relatively strong linear relationship. The high-priced outliers(£400,000) at 5-8km from the airport are located near Windsor Castle on the east edge of Windsor and Maidenhead, and represent a unique situation.[7]

In Figure 6-11, I plot the housing prices again on the Y-axis, and decreasing sound levels along the X-axis—similar to the effect of increasing distance (i.e., noise levels are lower as you get further from the airport). I find a positive relationship between decreasing noise levels and increasing housing prices: as noise levels increase, average house prices decrease. The minimum house price is about £150,000, but the maximum house price increases from about £250,000 at the 72-dBA noise level to over £600,000 at the 57-dBA noise level. The wider range in housing prices at lower noise levels (57 to 60-dBA) is partially due the fact that there are some areas that are close to airport

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[6] Again, each representing around 300 residents and 130 housing units

[7] Ward of Horton and Wraysbury (00MENP), in the Royal Borough of Windsor and Maidenhead.

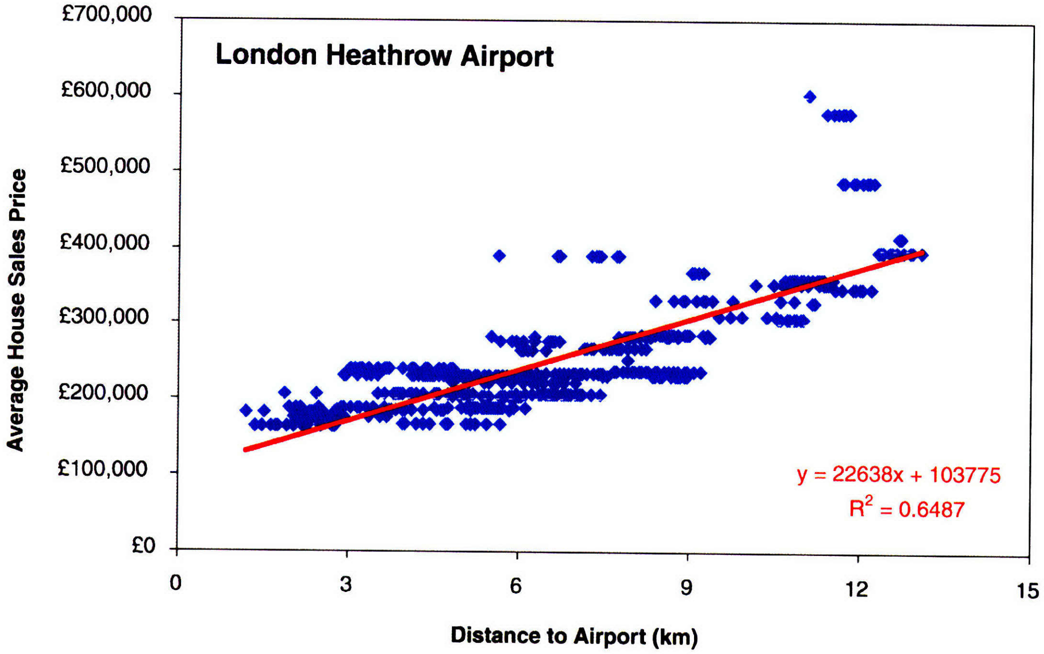

Figure 6-10: Housing prices versus distance to airport - London Heathrow

(3-6 km), but which have low noise levels. Because Heathrow operates in an east-west configuration, most of the noise impacts are concentrated to the east and west of the airport. Although areas directly to the north and south of the areas have much lower noise levels than areas to the east and west of the airport, they still have low average housing prices.

6.4.2 Income

Having established basic relationships between the housing prices and noise levels (or distance to the airport), I now look at the average income of the residents living near Heathrow Airport. Although house value is itself a measure of household permanent income (Nelson, 2004, p. 18), I use income as a more direct indicator of socio-economic status. The 2001 UK census did not ask a question on household income, but the UK Office of National Statistics (ONS) did publish ward-level estimates of weekly income. In

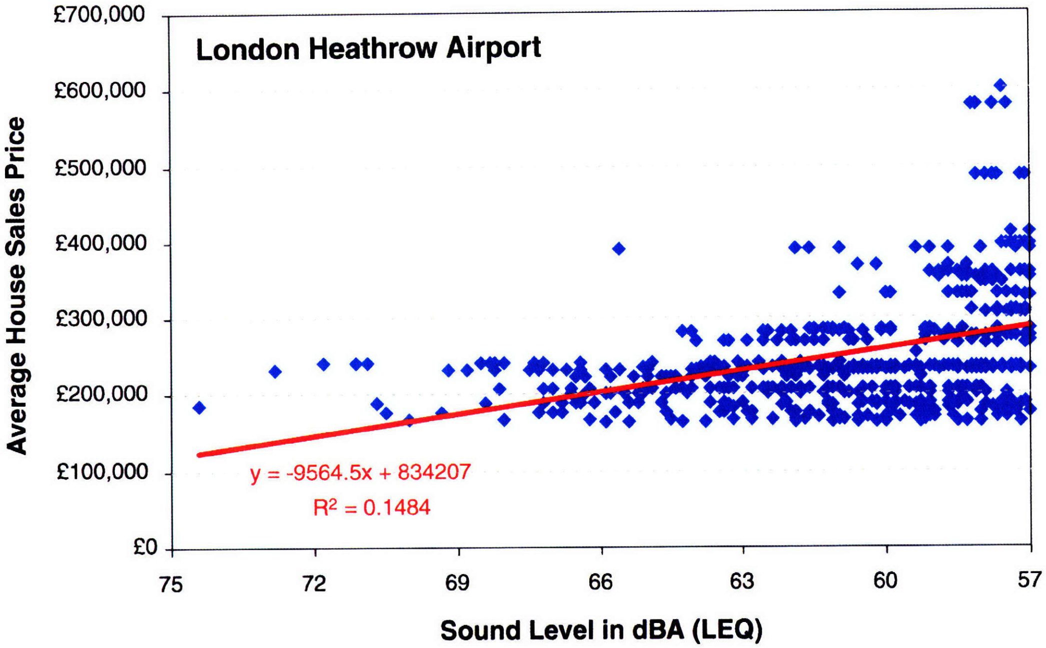

Figure 6-11: Housing prices versus noise levels - London Heathrow airport

Figures 6-12 and 6-13, I show the estimated weekly net household income for residents living around Heathrow Airport and the East Midlands airport, respectively. I also show the 2005 baseline 57-dBA L_{Aeq} contour. Within the 57-dBA contour around Heathrow airport, there is a broad range of weekly incomes up to £1200 pounds, but most of the population is within the lower three quintiles (up to £900 per week). In general, incomes are much lower around the East Midlands airport, but the 57-dBA contour contains incomes within the middle and upper-middle quintiles (£475-624 pounds per week).

To explore the distributional characteristics of noise, I plot the average incomes for households within 3-dBA contour bands in Figure 6-14. Around Heathrow Airport, the louder areas (closer to the airport) typically have average household earnings that are much lower than the regional average (about £760 per week). There is much less of a relationship between noise and incomes around the East Midlands airport. Due to

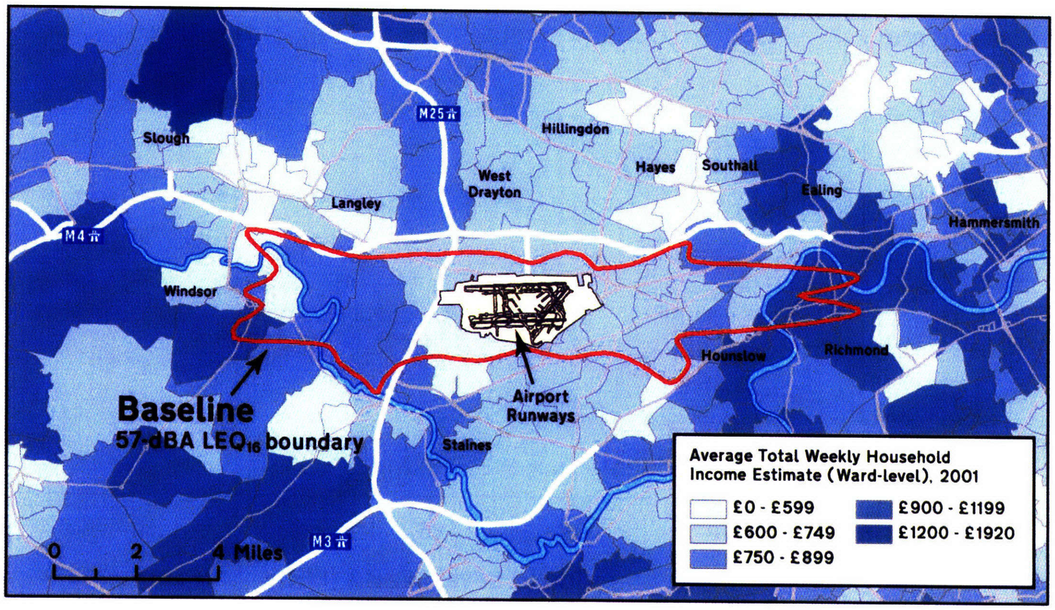

Figure 6-12: Estimated weekly household income - London Heathrow airport, 2001-2002 (Ward-Level)

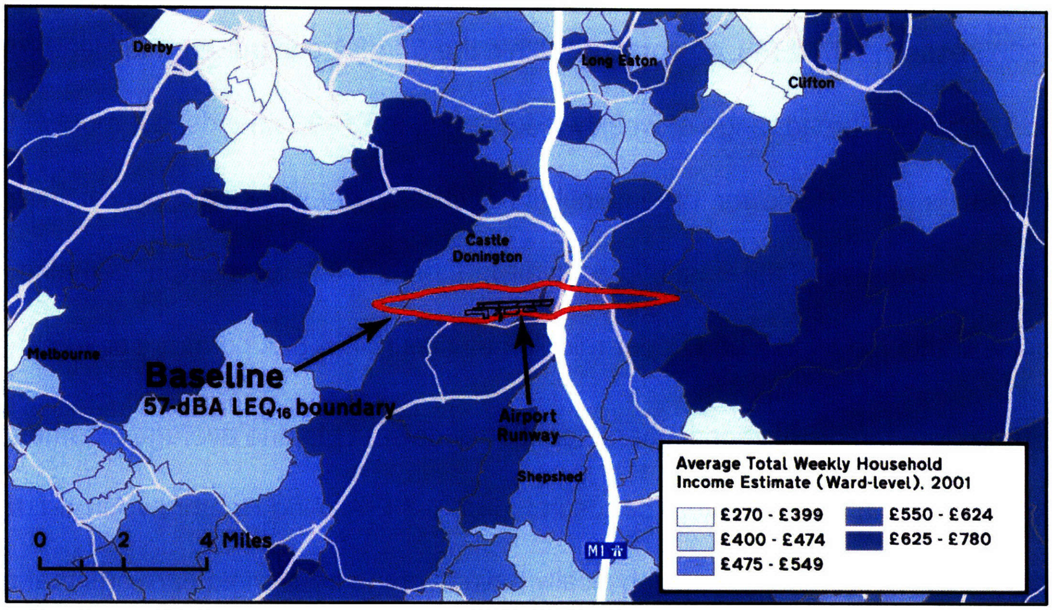

Figure 6-13: Estimated weekly household income - East Midlands airport, 2001-2002 (Ward-Level)

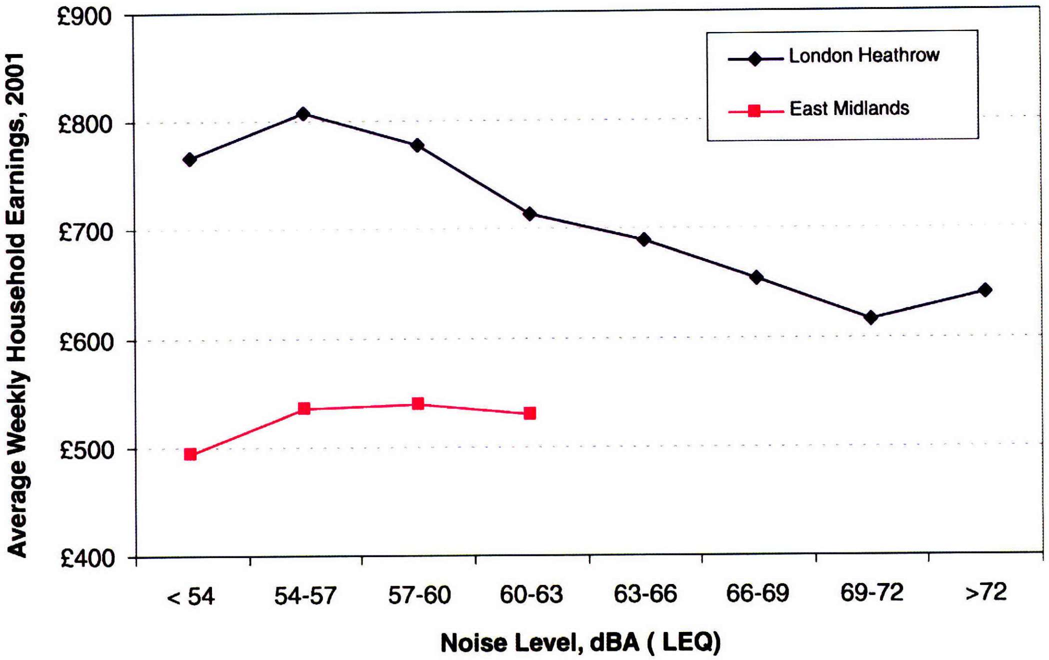

Figure 6-14: Estimated weekly total household income by contour - Baseline scenario (2005)

the relatively rural nature of the East Midlands region, the average household earnings around the airport is slightly higher than the regional average.

Finally, I also use occupational type to add further depth to this analysis at a more detailed level (census output-area) than is possible using only income data (ward-level). I use socio-economic classification (occupation) as a proxy for annual income. In Figure 6-15, I identify the percentage of workers in routine- and semi-routine jobs as well as unemployed persons.[8] The map shows large concentrations of residents in these lower socio-economic class in the areas well within the 57-dBA boundary, close to London Heathrow Airport. There are also large concentrations of such workers to the north of the airport, and these communities would be adversely affected by the addition of a third runway.

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[8] This corresponds to the ONS socio-economic classification categories 6-8 in the UV31 dataset.

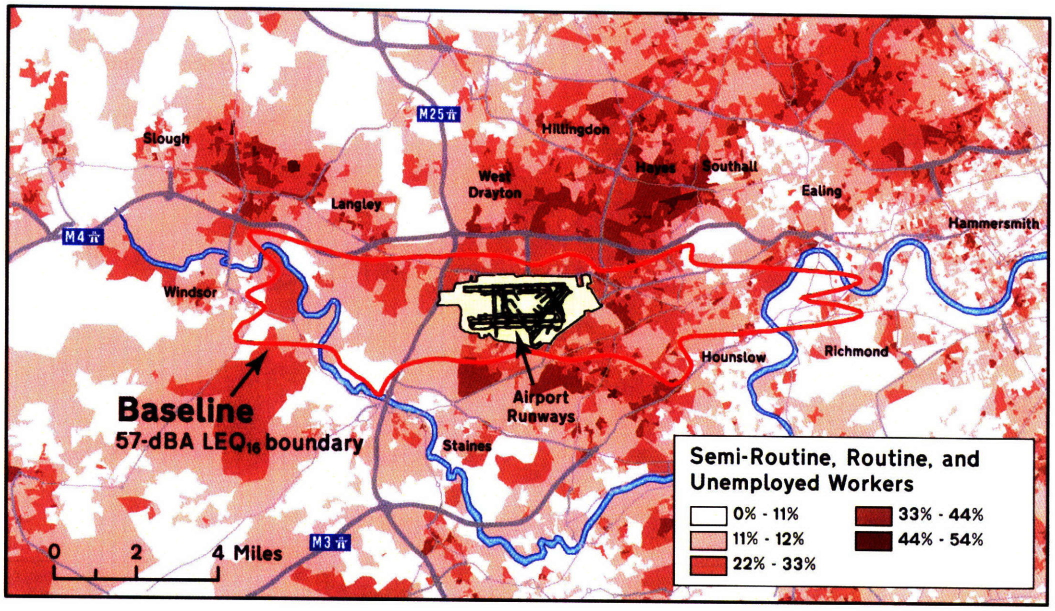

Figure 6-15: Socio-economic classification, 2001

In Figure 6-16, I plot the distribution of workers by socio-economic status for each contour band. As noise levels increase, the percentage of workers in the routine or unemployed positions increases from 18% (regional average) at the > 57-dBA level up to 26% at the > 72-dBA level, while those in high-level managerial positions decreases dramatically from about 15% to 4%. The share of workers in mid-level or supervisory positions remains relatively constant.

At one level, the association between higher noise levels and lower socio-economic groups is consistent with the view of quiet as a luxury good: that people who can afford to live elsewhere will do so. At another level, these data also show that residents in the lower socio-economic groups are bearing a greater burden of the impacts associated with airport noise—and would trigger environmental justice or equity considerations under expansion.

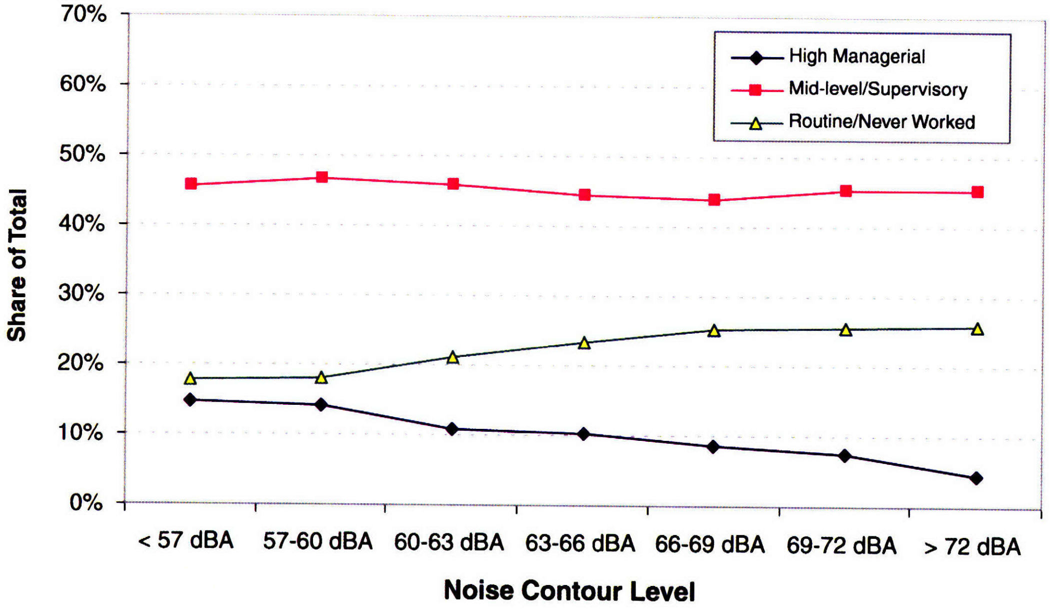

Figure 6-16: Socio-economic status by noise level, baseline scenario (2005)

6.4.3 Household Impacts

In the context of an average household living within the 57-dBA boundary around Heathrow, the average damage cost per household is £4,451–£5,847 on average. This is based on an average noise level of 60.8-dBA—about 3.8-dBA higher than a 57-dBA ambient noise level. On an annual basis, this averages to about £156–£205 per household based on a STPR of 3.5%, or £377–£495 based on a 7.5% capital recovery rate. This is much lower than the $27,500 (£13,870)[9] per-home that U.S. airports spend on noise insulation (see page 54).

The average house price around London is about £314,500, or about £26,600 in annual rent (under a capital recovery rate of 30 years at 7.5%; £7,408 at 3.5%). The average house within the 57-dBA contour has a value of £253,112, or about £21,431 in annual rent (£8,859 at 3.5%). Thus, the damage costs are worth as much as 1.8% to

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[9] Interbank rate of 0.50426 on 05 July 2008 at `www.oanada.com`.

2.3% of the total market value of a standard property. The total average weekly income for the households within the 57-dBA contour is about £738, or about £38,367 per year (52 weeks). Average net income after housing and taxes is £465 per week, or £24,158 per year. To put it another way, the monetized noise-damage costs on average, could be as much as half the weekly income of a household around Heathrow.

6.4.4 Annoyance

Finally, I contrast these noise-damage-cost calculations with annoyance levels. Although disturbance is also a function of flight frequency as well as sound levels, airport operators and analysts do not typically publish metrics that incorporate such factors (Eagan, 2006). Figure 6-17 shows a set of high-, medium- and low-annoyance curves for aircraft noise as a function of DNL noise levels as estimated by Miedema and Oudshoorn (2001). In Figure 6-17, I used data from Fidell and Silvati (2004) to plot the underlying observations from social annoyance surveys—including a dozen recent studies which were not captured by Miedema and Oudshoorn. I use these functions to calculate the levels of population annoyance under the different growth scenarios at London Heathrow airport. In Table 6.16, I find that there are about 120,000 residents living within the 55-dBA DNL contour around Heathrow airport who are annoyed by noise. About 43,000 of these residents are highly annoyed. Within the 65-dBA DNL contour, there are 19,000 residents who are annoyed by aircraft noise, including 10,000 residents who are very annoyed. The large magnitude of these numbers reflects a different dimension of the political economy underlying airport-noise conflicts than is captured by the noise-damage costs, but also underscores why noise can be such a critical issue in airport-communities.

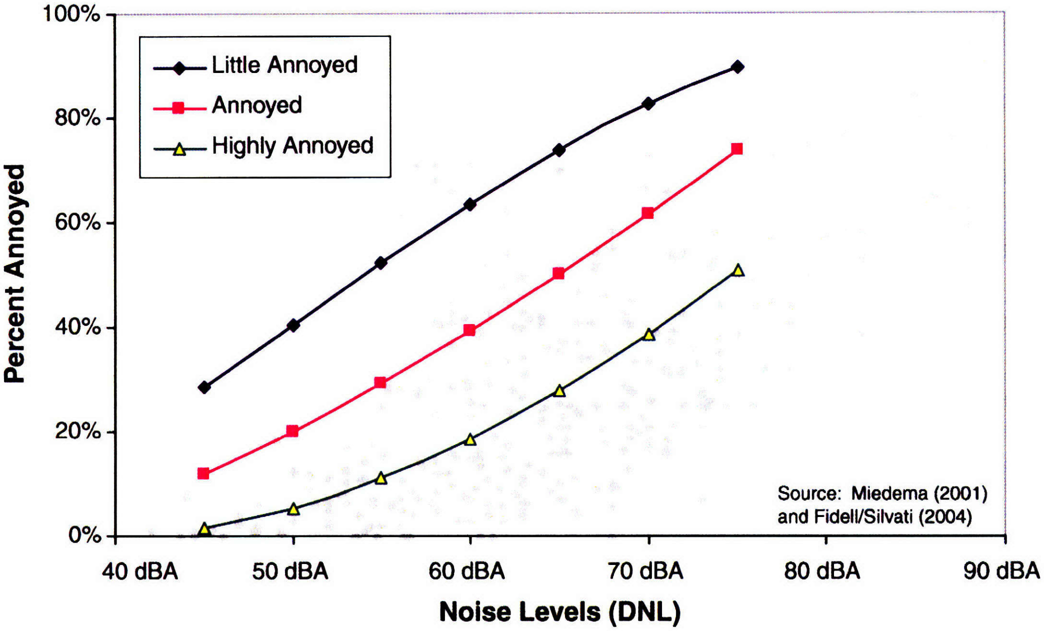

Figure 6-17: High, medium, and low-annoyance curves as a function of DNL estimated by Miedema and Oudshoorn (2001), along with aircraft noise annoyance survey data by Fidell and Silvati (2004)

Table 6.16: Persons annoyed as a function of noise level at London Heathrow airport, baseline scenario

Noise Level (DNL)	Total Population	Annoyed		Highly Annoyed	
		Persons	Percent (%)	Persons	Percent (%)
55 dBA	428,050	118,940	28	43,930	10
65 dBA	39,960	19,300	48	10,570	26
75 dBA	220	160	73	110	49

Source: Authors' calculations using INM 6.2 based on Miedema and Oudshoorn (2001)

6.5 Summary

I analyzed the noise-damage costs at London Heathrow airport using the 2005 levels as a baseline—about 461,000 annual air transport movements, or 1,250 takeoffs and landings each day. I compared a medium-growth scenario with 551,000 annual movements, and a high-growth scenario, which adds a third runway to accommodate 754,000 annual movements. I assume current population levels and housing values for this analysis. Based on my calculations for baseline scenario, there were about 168,500 residents living in 65,500 housing units exposed to noise levels greater than 57-dBA LEQ around London Heathrow airport.

I find that the total noise-damage costs in 2005 were about £300–400 million, and could grow up to £575–750 million under a high-growth scenario with a third runway. I also found that the introduction of an advanced technology, low-noise aircraft could reduce the noise-damage costs to £200–250 million, even under a high-growth scenario. On an annualized basis using a 3.5% annuity rate, the baseline noise-damage costs were about £11–14 million, growing to £20-26 under a high growth scenario. The average noise-damage costs around Heathrow are about £5,850 per household, although this ranges from £23,180 for the 230 homes exposed to noise levels greater than 72-dBA to £2,110 for each of the 36,000 households exposed to between 57- and 60-dBA of noise levels.

At the East Midlands airport, I found significantly lower noise-damage costs, or about £0.94–1.24 million in total under a 2005 baseline scenario with 57,400 total annual air transport movements. Under the baseline scenario, there were about 890 residents and 390 housing units exposed to noise levels above 57-dBA LEQ.

I also found that different factors embedded within meta-analyses and NDIs of previous noise studies (noise metric, threshold level, discount rates) all have large impacts on the NDIs as well as the damage costs. Because small changes in these assumptions can have big impacts on the final valuation, understanding these factors is crucial for proper benefit-transfer policy applications. Espey and Lopez (2000, p. 415) also distinguish homeowners' willingness to pay to avoid airport noise versus the average impact of noise on the market value of properties. As such, housing-price-based NDIs that describe noise damage costs as a percentage effect per DNL may even underestimate the actual welfare loss. Nevertheless, the calculation of these damage costs suggests that the noise-damage costs are of a large magnitude—especially relative to the greater regional benefits from aviation.

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Chapter 7

Conclusion

Aircraft noise conflicts continue to present significant challenges to policymakers and airport stakeholders. Indeed, the National Research Council (2003, p. 23) counted 4 national interest groups and 69 local community organizations in the United States that focus on airport noise issues. The role of airports in linking global economies and local communities requires policymakers to balance the economic demands for air transportation and regional growth while responding to the local needs of airport-area communities.

In this analysis, I highlight the interrelationships between airport flight operations and noise impacts on surrounding communities and between air transport industry and regional economic growth. I estimate the regional economic and catalytic impacts associated with the growth of the air transport industry under different airport growth scenarios at London Heathrow and the East Midlands airport and then calculate the noise-damage cost impacts under these same scenarios.

7.1 Summary of Results

First, I compare the noise-damage costs and economic impacts associated with aviation growth in the East Midlands region. To analyze the economic impacts of increased flights at the regional level, I use the REMI-ECOTEC model and focus on the impacts of the air transport industry on the rest of the economy. The REMI-ECOTEC model is an econometric input-output model, which uses neoclassical economic behavioral characteristics and fixed trade relationships to forecast changes in output, labor, capital demand, wages and prices, demographics, and market shares across different regions. The model also incorporates changes in labor- and commodity-accessibility to reflect agglomerative and dispersal economic relationships associated with urban density. Model parameters are calibrated using both national- and region-specific data on employment, wage rates, productivity, demographics, and growth rates from the UK Office of National Statistics, UK Actuary Department, Eurostat, and other sources.

Using this model, I test the impacts of changes to the economic output of the air transport sector and compare these scenarios against a baseline growth forecast. Under this baseline forecast, the total UK value-added grows at an average rate of about 1.4% per annum over the 25 years between 2005 and 2030. The value-added of the air transport sector grows at a faster rate during this same time period—about 2.2% annually, on average. The inputs used to model the direct, indirect, and induced economic impacts (changes in aviation output) as well as the catalytic impacts (changes in productivity or accessibility) for each growth scenario are shown in Table 7.1. For the changes in air transport sector output, I assume that the air transport growth is increasing or decreasing relative to the baseline scenario. I base the catalytic-related

Table 7.1: Aviation growth scenarios and economic model inputs

Scenario	Air Transport Growth (%)	Model changes relative to baseline in 2030		
		Air Transport Sector Output (£m)	Catalytic Impacts (%)	
			Total Factor Productivity	Commodity Accessibility
Low Growth	1.1	-120	0.078	1.1
Baseline	2.2	n/a	0.132	2.2
Medium Growth	3.4	+160	0.204	3.4
High Growth	4.5	+370	0.270	4.5

In 2002 £. N/A = Not applicable. Source: Author's calculations using REMI-ECOTEC 6.0

increases in productivity on analyses conducted by Oxford Economic Forecasting (2006a), and assume that each 1% increase in air transport growth is proportional to a total factor productivity increases at a ratio of 0.06%. As such a 4.5% increase in air transport industry output under the high-growth scenario is related to a 0.270 increase in total factor productivity. For the catalytic-related commodity access growth scenarios, I assume that accessibility increases at the same rate as the growth of the sector itself.

Under a high-growth scenario based on traffic projections by the UK Department for Transport, I find that the total economic impacts of additional air transport sector growth (4.5%) in the East Midlands are up to £510 million in total UK value-added per year by 2030. Of these impacts, about 30% (£160 million) are in the air transport sector in the East Midlands; while another 20% (£100 million) are in other industry sectors in the East Midlands. The remaining 50% of the impacts (£250 million) occur in other regions of the United Kingdom and in sectors other than the air transport industry.

These impacts are derived from economic accounts of supplies and purchases between different industry sectors and include the directly related spending and jobs in the air transport sector as well as the indirectly related supporting sectors needed to handle the extra £370 million in air transport industry output relative to the baseline scenario. The total output of the air transport sector in the East Midlands under this scenario in 2030 is over £900 million—a total increase of almost 70% relative to the baseline forecast of about £550 million in output. This forecast also includes the impacts from induced spending by households receiving income from jobs directly and indirectly supported by this extra activity. These impact forecasts also incorporate adjustments to the regional economy that would result from longer-term population changes and inter-regional trade. The labor and commodity accessibility increases the total value-added by about 7%; thus, most of the impacts are derived from the air transport sector supply-chain plus related household spending. I conclude that the air transport sector has wide economic linkages that extend far beyond the region.

In addition to these impacts from the growth of the air transport sector employment itself, I also consider the long-term catalytic impacts of air services on the enhanced productivity of the regional economy. Here, I take into account the notion that an increase in air accessibility can make businesses more productive—with the access to resources making them more efficient and enabling them to expand their market share. Oxford Economic Forecasting (2005, 2006a) and others have accounted for such catalytic impacts by looking at the relationship between increased business travel or air freight usage and total economic productivity growth. I apply these relationships to estimate the catalytic increases in total factor productivity under different air transport growth scenarios—an increase of up to 0.27% by 2030 under the high-growth scenario. These aviation-related increases in total factor productivity affect output in various sectors and then generate direct, indirect, and induced effects. Based on this, I find that the catalytic impacts from air transport growth on regional productivity under a high-growth scenario could be £510–540 million per year throughout the United Kingdom.

Using an alternative way of estimating these catalytic impacts and more liberal assumptions regarding changes to accessibility, I find that the catalytic impacts of enhanced accessibility to the air transport sector could potentially increase total regional value-added by £1.9–6.3 billion in value-added throughout the United Kingdom under a high-growth scenario. These impacts are based on reductions in the effective cost of air transport, and thus reflect increased utilization and efficiency of different sectors that rely on air transport. As such, these impacts also include the associated direct, indirect, and induced impacts of the increased activity in these other sectors. Although these alternative accessibility-based catalytic impact estimates require further study and analysis, they do show that there are much larger catalytic economic impacts from growth beyond the traditional measures of direct, indirect, and induced activity from the air transport sector itself.

Having identified the regional economic impacts from aviation growth, I use the Federal Aviation Administration Integrated Noise Model to calculate the changes in the airport noise levels associated with this growth. The flight assumptions used in the airport noise model are shown in Table 7.2. I then value these impacts in terms of noise-damage costs on housing prices, based on empirically observed relationships between noise levels and differences in housing prices around airports in the United States, Canada, and elsewhere. The underlying economic theory is that residents are fully mobile and maximize their personal welfare by capitalizing the health, annoyance, and other physical impacts of noise within their housing budgets. Assuming that people are fully aware of

Table 7.2: Aviation growth scenarios and noise model inputs

Scenario	East Midlands		London Heathrow	
	Annual Air Transport Movements	Growth vs. Baseline (%)	Annual Air Transport Movements	Growth vs. Baseline (%)
Baseline (2005)	58,000	-	456,000	-
Medium Growth	122,000	+110	551,000	+20
High Growth	262,000	+350	754,000	+ 65

Note: Air transport movement = one aircraft takeoff or landing. Source: CAA, BAA, NEMA

airport noise as they make their housing decisions, the differences in housing prices reflect the economic value of the noise impacts and thus incorporate the effects on health and education. These values are generally comparable to stated preference surveys and other methods that directly ask how people value aircraft noise impacts but are also based on housing prices (Kish, 2008, p. 22).

Also, this average NDI-based approach produces more conservative noise-damage cost estimates than an alternative method based on the marginal noise-damage costs from each additional aircraft operation. This latter approach will underestimate the total noise-damage costs at larger airports, such as London Heathrow Airport, because the marginal sound energy from each additional aircraft operation is much less than the average noise damage (Pearce and Pearce, 2000, p. 14).

At the East Midlands airport, the noise-damage costs would increase from £0.03–0.04 million annually under the baseline scenario up to £0.4–0.5 million under a high-growth scenario. Average airport-area noise levels above 57-dBA under this high-growth scenario would affect up to 10,000 residents and 4,000 households. The average total noise-damage cost per household is about £3,200, or about £110 annually. On an annual

Table 7.3: Regional economic impacts and noise-damage costs under an East Midlands high-growth scenario (4.5% annually)

Type of Impact	Impacts in 2030 relative to baseline scenario (£m) In-region impacts	Out-of-region impacts	Total UK-wide impacts
Direct, indirect, and induced economic impacts on regional value-added			
Air transport sector	150–160	5–10	155–170
Other sectors	95–100	225–240	320–340
Total impacts, all sectors	245–260	230–250	475–510
Catalytic economic impacts on regional value-added			
Productivity-based	170–230	310–340	510–540
Accessibility-based	650–2,210	1,260–4,090	1,900–6,300
Noise-damage costs	0.4–0.5	–	–

Noise-damage costs in 2005 £; others in 2002 £. Source: Author's calculations using INM 6.2 and REMI-ECOTEC 6.0
(eastmidsum)

per household per decibel basis and assuming a 3.0% discount rate and a 30-year amortization period, the average noise-damage costs are £45–60 (€58–77) under the baseline scenario and £50–66 (€64–85) under the high-growth scenario. For the East Midlands region, I conclude that the economic impacts from growth in the air transport sector far outweigh the noise-damage costs of that growth (Table 7.3).

I also analyze the noise-damage costs around the London Heathrow airport. The annual noise-damage costs at London Heathrow are £11–15 million under a baseline scenario and £20–26 million under a high-growth scenario. The higher annual noise-damage costs reflect the higher housing values and much more densely populated communities when compared with the East Midlands. To put this in a slightly different way, the baseline willingness-to-pay for a reduction in noise is about £65–86 (€83–110) per dBA per household per year.[1] This is higher than the per-dBA/household/year values that Kish (2008, p. 28) found in other studies, but reflects the more detailed noise-level and population data used here.

Although I do not explicitly compare the noise-damage costs to the regional economic impacts of the industry growth in the Greater London region, I note that these higher noise-damage costs are contrasted against an air transport sector that is also much larger in size: under the baseline year (2005), air transport in London is responsible for 43,000 jobs and £5.8 billion in value-added. In comparison, the East Midlands air transport sector has about 2,000 jobs and £230 million in value-added. Even under the baseline scenario, the economic impacts of the air transport sector far outweigh the noise-damage costs in Greater London.

I also look at the potential contributions of an advanced-technology, low-noise aircraft to the noise-damage costs at London Heathrow. Under a limited implementation scenario with only about 20% of the flights being operated by such low-noise aircraft, such an aircraft could reduce the noise-damage costs down to £14–18 million annually—about a third relative to the high-growth scenario. A more aggressive implementation scenario (30% of all flights) would reduce the annual damage costs to £7–9 million—about two-thirds below the high-growth scenario. When compared to the 2005 baseline instead of the high-growth scenario, low-noise aircraft would reduce the noise-damage costs by about 40% relative to the baseline levels while enabling aircraft traffic levels to grow by about 60%. Although the development costs for such a future aircraft are unknown,

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[1] Again, this assumes a 3.0% discount rate and a 30-year useful house life. I also note that the per-dBA willingness-to-pay per dB per household has a large distribution of values and ranges from a minimum of £43–£56 to a maximum of £157–206 (€55–71 to €201–263). The average household in the area with noise levels above 57-dBA contains 2.4 persons. Using a 3.5% annuity rate, the average willingness to pay is £45–59 or €58–76 per dBA per household per year.

this analysis shows that there is a measurable economic value from low-noise aircraft in terms of reduced noise-damage costs.

7.2 Contributions and Policy Implications

In this analysis, I develop a methodological framework to compare the regional economic impacts and noise-damage costs of aviation growth. I use the REMI-ECOTEC model to forecast the economic impacts of growth in the East Midlands air transport sector and the FAA Integrated Noise Model to model the noise impacts of additional flight operations at London Heathrow and East Midlands airports. In addition, I am one of the first analysts to consider and apply the long-term catalytic impacts of aviation on regional growth. Moreover, my use of industry-standard models and realistic scenarios makes this research methodology easily applicable by transportation planning stakeholders who focus on environmental and economic issues on a daily basis.

This comparison of the noise-damage costs and regional economic impacts within a single framework fills a significant gap in planning and transportation research. Although there is a long history of applied practice in the areas of both noise impact and economic analysis, integrating these areas within a single analytical framework has never been done before. By analyzing both impacts within a consistent framework, I give greater consideration to the larger context of community and the regional economy than has been done with traditional aviation cost-benefit and cost-effectiveness studies.

In analyzing the noise and economic impacts, I also note the similarities in the impact-chain methodologies (p. 63) used to analyze these two areas. As noise-damage-cost indices are either revealed through empirical data on housing prices or contingent-value surveys, economic impact models are derived and calibrated through economic data and spending/travel patterns. Recognizing these similarities can help bridge the intellectual and cultural gaps between engineers, planners, economists, and policy analysts.

My second contribution is in calculating the potential catalytic economic impacts from aviation growth at the regional level. I found that in the East Midlands, the catalytic impacts on productivity and accessibility are about equivalent to or larger than the direct, indirect, and induced employment impacts of the air transport industry itself. These catalytic impact forecasts are sensitive to the underlying productivity or growth assumptions, and increasing the productivity of a different-sized region (such as London) may have different catalytic impacts. Although these catalytic impacts need to be investigated further using different methodologies, their relative magnitude nevertheless indicates that air transportation can have a measurable impact at the regional level.

There are several policy implications of this research. First, the relatively low noise-damage costs in the East Midlands suggest that the use of economic instruments or compensation could be a viable strategy to decouple the local negative externalities of aircraft noise from the positive economic benefits of aviation growth. Without downplaying the importance of aircraft noise to local communities surrounding major airports, the relatively small magnitude of the noise-damage costs compared to the economic impacts indicates that there is a solution space within which policymakers can solve airport noise conflicts.

Furthermore, the relatively low magnitude of the noise-damage costs compared to the air transport sector and catalytic economic impacts supports airport development as part of a regional economic development strategy. Although I did not frame this analysis as a means to evaluate competing development strategies, which may have potentially higher-yielding economic impacts than growth of the air transport sector itself (AirportWatch, 2006), I note that that relative prices and wages within the REMI model do account for such economic-displacement effects. Moreover, economic growth has historically occurred at least in parallel with increases in air traffic, and increased aviation demand (and increased noise) should at least be expected as regional economies grow over time.

I also note that these economic impacts are based on relatively conservative forecasts embedded within the model itself. The REMI-ECOTEC model assumes an overall baseline economic growth rate of about 1.8% on average for the entire UK economy between 2005 and 2010, and 1.4% between 2005 and 2030. In contrast, the HM Treasury (2006) forecasts a medium-term economic growth in the 2006 to 2011 period of about 2.75% in GVA.[2] While the REMI-ECOTEC forecast includes demographic trends and economic migration components, which may not be captured by other forecasters, its relatively conservative forecast suggests that it may even underpredict the economic impacts of the aviation sector presented here.

Finally, there is growing recognition that transportation or infrastructure improvements can have long-term catalytic impacts on economic productivity, which are in addition to the traditional direct, indirect, or induced household spending impacts. Analysts and policymakers commonly discuss the concept of such impacts in order to justify airport expansion schemes, but very few have quantified these catalytic effects under specific

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[2] The 2.75% growth rate is for non-oil GVA. The GVA growth including oil is 2.4% per annum. Other forecasters predict growth rates of about 2.6% to 2.9%.

aviation growth scenarios. Modeling the catalytic relationships between economic growth and transportation improvements requires further methodological development, but understanding the relatively large magnitude of these impacts should help to call attention to the importance of these impacts for policymaking purposes. It could be argued that only the catalytic effects should be considered in policy analyses, because these impacts are what differentiates between regions and alternative public investment over the long-term. This would also be consistent with the derived-demand hypothesis, which suggests that the economic impacts of the transportation industry itself are irrelevant because transportation has no value other than the activities derived at either end—the large size of the air transport sector itself, notwithstanding.

7.3 Future Research

Through the course of this analysis, I identified a number of areas where further research could improve the modeling of the relationships between aviation growth, noise-damage costs, and economic impacts. Due to the limitations of previous hedonic-price studies on noise and housing prices, my noise-damage cost calculations are based on average NDIs and assume a constant relationship between noise levels and housing prices. Because of the logarithmic form of noise metrics (a +10-dBA change represents a doubling in perceived noise), this may understate the noise-damage costs where there are significant changes in flight operations against a low background noise level, such as would occur in the communities around the proposed third runway at London Heathrow airport. This may be less important in other areas where there are only marginal changes to flight operations and high overall background noise levels (Wadud, 2008, p. 12).

Nevertheless, integrating more detailed noise-level data into hedonic-price studies may enable the estimation of elasticities for noise-damage costs at different noise levels and housing-price ranges.

With regard to the estimation of catalytic economic impacts, more detailed studies are needed to quantify the relationships between air transport accessibility and changes in regional and metropolitan productivity. Such extensions could include: (1) conducting detailed empirical analysis of the inter-regional variations in productivity or investment at the regional level, (2) developing models that control for other economic productivity impacts, and (3) using improved metrics, such as origin-demand flows rather than passengers per GDP for capturing air travel demand. Issues of magnitude and marginal impacts also apply to understanding the economic catalytic relationships. The catalytic economic impacts associated with a doubling of flights at a smaller airport may also have a different impact than when compared to a large airport like London Heathrow, especially when such an airport already has a high degree of network centrality within the global air transportation system (Guimera et al., 2005).

Further study and testing of the inter-regional components of the REMI-ECOTEC model is also needed to refine its use in accessibility-based catalytic impact studies. A good definition of aviation accessibility should be feasible and applicable using origin-demand revenue passenger-mile (RPM) data—similar to the way in which vehicle-miles traveled (VMT) and vehicle-hours traveled (VHT) are used to study changes in surface transportation access. Moreover, there may be other ways of estimating the long-term catalytic impacts of transportation. Malina et al. (2008) conducted a contingent-value survey of businesses to derive the catalytic impacts based on the willingness-to-accept the closure of a local airport. Perception is an important component of strategic location and economic development, and quantifying such concepts within economic forecasting and policy models is an interesting prospect.

Finally, there may be other dimensions to the catalytic impacts beyond increases in productivity and economic output at the regional level and metropolitan levels. I hypothesize that there are measurable socio-economic catalytic benefits that reflect the long-term impacts of leisure passenger air travel on livability. Air accessibility–including both the level of service provided as well as the relative cost of these services–can improve the quality of life by enabling outbound tourism as well as social and professional networks. These networks and tourism opportunities enhance "global livability" and can shape economic migration and industrial productivity—especially for consulting and other service industries. In the REMI model, such qualitative attributes are reflected as the "compensating differential" of a region—the difference in productivity and wages between regions (Greenwood et al., 1991). Qualitative surveys and other social science methods may reveal how global mobility and connectedness now shapes personal and firm-level location decisions, travel patterns, and regional economic activity.

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Appendix A

Simplified Input-Output Analysis

Analysts primarily use input-output accounting frameworks for short-term impact studies due to the limitations of constant technology assumptions, but also use them as the basis for longer-term dynamic forecasting and environmental impact models. Under an input-output framework, analysts conceptualize the economy as a set of interdependent industries and activities, each of which requires the productive output of the others as input to its productive process (Greenberger et al., 1976, p. 89). The simplifying assumption is that the ratios of one industry's inputs to its outputs—the technical coefficients—are fixed. Using this framework, analysts can infer the changes in technology, labor force, or government spending by estimating their effects on production coefficients and reworking the matrix calculations (Greenberger et al., 1976, p. 90). Analysts can then generalize and extend these models into a dynamic framework by the addition of capital stock, inventories, and capacity-building activities.

I use a simplified static economic impact model to illustrate the impacts of aviation growth through the rest of the economy. I use the input-output and flow data from REMI to create a basic model, and then enhance this model by adding import data. I then construct a model using the base UK 2002 input-output data. I apply the methodology developed by Schaffer (1999) using a basic endogenous household model to look at the direct, indirect, and induced economic impacts of an investment in aviation. Short-term, localized economic impacts are commonly estimated using input-output multiplier models due to their simplicity. In this way, the flows of dollars from an exogenous shock can be traced as they circulate through an economy.

Table A.1 shows a simplified input-output table for the United Kingdom in 2002, with intermediate and final demand components along with value-added. The rows represent the total purchases (or demand) of a particular sector by other sectors. Columns represent the total purchases of other sectors by a particular sector. The column total is the total purchases by an industry, as well as the total value-added. The total purchases and value added are used to produce the industry's output. The row total is the total intermediate and final demand of a particular industry or commodity.

Table A.1: 2002 simplified input-output table

Sector	Agriculture and Mining	Manufacturing	Utilities and Construction	Retail Services	Hotels and Restaurants	Other Transport	Air Transport	Basic Services and Telecom	Nonbasic Services	Households and Personal Consumption	Other Final Demand	Exports	Total Demand and Exports
Agriculture and Mining	4.0	19.5	10.6	0.8	1.0	0.2	0.0	0.6	0.5	11.9	0.9	16.1	66.0
Manufacturing	6.1	131.1	22.4	21.8	14.1	9.6	2.1	25.0	37.7	207.4	53.8	175.1	706.1
Utilities and Construction	1.6	8.6	55.2	3.6	0.7	1.8	0.1	7.9	17.8	21.67	82.3	0.8	202.1
Retail Services	3.1	45.7	7.1	8.8	6.5	3.0	0.4	11.0	14.1	110.9	15.3	1.9	227.8
Hotels and Restaurants	0.1	0.8	0.4	2.0	0.3	0.4	0.2	2.2	1.5	67.3	0.0	5.4	80.6
Other Transport	1.1	10.3	1.3	23.5	1.2	21.0	1.5	8.6	5.7	16.5	1.1	6.3	98.1
Air Transport	0.2	0.7	0.1	0.5	0.1	0.4	0.5	2.4	0.4	11.0	0.0	4.5	20.7
Basic Services and Telecom	6.5	34.9	15.0	36.5	7.0	14.1	2.6	157.3	54.5	98.3	19.1	60.3	506.1
Nonbasic Services	1.2	7.6	8.1	15.1	1.2	4.6	0.5	17.0	39.1	139.3	210.4	3.2	447.2
Households + Labor Value Added	6.1	110.3	33.4	71.1	20.9	28.9	3.2	146.6	166.1	19.8	0.0	0.2	606.6
Capital Value Added	21.6	104.2	46.5	42.3	18.5	8.4	2.7	98.9	106.3	4.5	-	-	454.0
Imports	15.1	232.4	0.7	2.0	9.2	6.2	6.8	28.9	3.3	0.2	-	-	304.8
Total Output and Imports	66.7	706.0	200.6	227.9	80.6	98.5	20.7	506.5	447.1	708.7	383.0	273.7	3,720.1

Data in Billions of 2002 £. Note: In most cases, row sums should equal the column sums, but there are slight discrepancies here due to missing data.
Author's calculations from UK ONS 2004 Blue Book Data

This table is based on the 53x53-sector sector direct requirements table which is embedded into the REMI-ECOTEC model. The direct requirements table shows the total intermediate and final purchases per unit of output—essentially showing the share of inputs from each of 53 sectors that go into producing a single unit of output. To convert the direct requirements into a transactions table that shows the flows of activity between industries, I multiply each share by the total output from each sector. I then transform this 53x53-sector table into a consolidated 9x9-sector table that includes air transport and hotels/restaurants as separate categories.

In order to include the induced economic impacts due to household spending, I also calculate the total wages/salaries and final consumption for each of the consolidated 9 sectors. REMI-ECOTEC provides the total final personal consumption expenditures for each of 12 categories, such as food, clothing, or other goods and services. To close this model with respect to the amount of personal consumption expenditures on wages and salaries, I use the portion of household expenditures that is included within the output of the services industry (service activities and private households with employed persons—such as in the employment of maids or babysitters). Table A.2 shows the simplified input-output table, with intermediate and final demand components along with value-added.

Using the new consolidated transactions table (9x9-sector + households), I also create a new direct requirements table (A-matrix) by dividing each column by the total output of each consolidated industry. I then create a new total requirements table by subtracting this A-matrix from an identity matrix (with ones along the diagonal and zeros elsewhere) and then taking the inverse of the (I-A) matrix to directly calculate the impacts. I incorporate data to close the model with respect to households, using personal

Table A.2: Comparison of simplified models showing total multiplier and Leontief inverse impacts from a £100 stimulus in air transport sector (in £)

Model basis	Type I (Household Exogenous)		Type II (Household Endogenous)	
	Multiplier (6 rounds)	Leontief Inverse	Multiplier (6 rounds)	Leontief Inverse
REMI	117.0	119.0	365.6	476.0
REMI with Imports	145.1	145.3	201.3	210.8
UK I-O data (with Imports)	168.0	168.5	280.1	316.2

Author's calculations from REMI-ECOTEC UK version 6.0 and ONS data

(iocomparison)

consumption expenditures along with wage and salary data by industry (instead of labor value-added data) in order to close the model with respect to households. I determine the household expenditures on wages by using the portion of nonbasic services that goes towards other households or service organizations (UK sectors 122/123).

Using this simplified input-output model of the United Kingdom, I illustrate an example of how £100 million of exogenous sales in the air transport sector filters through the rest of the economy. Figure A-1 shows that the initial expenditure in the air transport sector leads to about £54 million in sales through the first round of spending—primarily through people employed in the air transport sector, and through intermediate expenditures in the services and manufacturing sectors. Retail and hotels/restaurants increase as a proportion of total sales in the second round of spending, especially as workers employed by the other industries receive their wages and salaries. In this simplified example with endogenous household spending, the initial £100 million in the air transport leads to total economic impacts of about £330 million as the money circulates through the economy. Schaffer (1999, p. 35) notes that in most cases (97%), such models close after 6 rounds of spending.

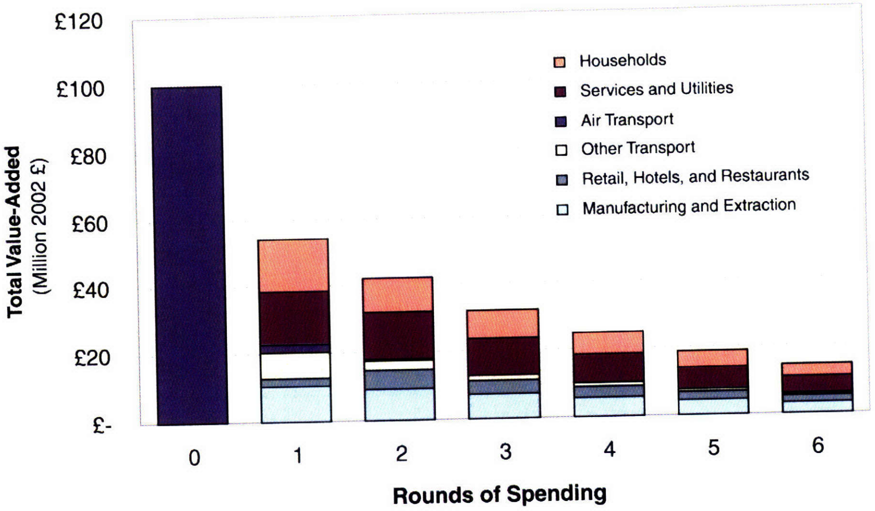

Figure A-1: Impact of a £100 expenditure in air transport.

I evaluate this model by comparing the results from a multiplier analysis with six rounds of spending (as shown in Figure A-1) with a more traditional Leontief inverse model. Although the Type I models with households exogenous matched reasonably well, the Type II multiplier model with households endogenous does not close after 6 rounds—and thus did not match the Leontief inverse solution. Because Schaffer (1999, p. 24) keeps imports as part of the incomes quadrant (III) rather than in consumption (quadrant I), I attempted to improve the model fit by including imports as part of the total output. Imports added as much as 40-50% to the total output of each sector group. Including imports improved the performance of the Type I (endogenous household) multiplier model when compared to the Leontief model, and it converging after 6 rounds of spending. The inclusion of imports also improved the performance of the Type II multiplier model relative to the model without imports, although it still did not completely converge within 6 rounds of spending. I also applied this methodology using the 2002 UK input-output table in order to replicate the results produced using the data from the REMI model. The total impacts predicted by the Type II multiplier model (households endogenous) were less than the Leontief model, and the solution did not converge after six rounds of spending.

Overall, the inclusion of import data appears to improve the results of impact analyses greatly, although both the models still do not fully converge after 6 rounds of spending. The lack of convergence between the multiplier model and the Leontief inverse model may not necessarily be important, but it shows that something is missing from the model. In general, it appears that the REMI data are more conservative than the UK input-output data. The REMI and UK data are relatively close in value, except for the manufacturing sector, where the values are much larger in REMI than in the UK data set. Imports are much larger in the REMI model than in the UK data. These basic models show the strong direct and indirect linkages between air transport and manufacturing, basic services (including telecom), and other transport. There are also large induced effects with other service industries and households.

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Appendix B

REMI-ECOTEC Model Testing

Here in Appendix B, I describe the baseline control forecast in the REMI-ECOTEC model in more detail. I also compare this forecast to other models, and conduct a number of sensitivity tests in order to illustrate the model dynamics.

B.1 REMI-ECOTEC Baseline

This baseline forecast provides a reference with which to analyze the various policy scenarios that I test—such as changes in aviation output or the regional accessibility of different commodities. The baseline forecast also highlights the different structural differences between the regions, and also the key trends over time. I start by describing the general indicators of the regions, including population, employment, economic output (Gross Value Added (GVA)), and productivity.

In Table B.1, I show the population, employment, and regional value-added in 2005 and 2030. I also show the average annual percentage growth over the 25-year period in each of these areas. In 2005, there were about 7.5 million persons in the Greater London region in 2005, with another 8.1 million in the rest of the South East, and 4.3 million in the

Table B.1: Baseline model: population, employment, and value-added, 2005-2030 by region

Metric	Region				UK Total
	Greater London	South East	East Midlands	Rest of UK	
Population (000s)					
2005	7,490	8,110	4,330	40,060	59,980
2030	8,100	8,620	5,280	43,140	65,130
Annual growth (%)	0.31	0.24	0.79	0.30	0.33
Employment (000s)					
2005	4,040	3,720	1,770	17,090	26,620
2030	4,350	3,770	1,810	17,000	26,930
Annual growth (%)	0.29	0.05	0.10	-0.02	0.05
Regional Value-added (£m)					
2005	212,600	168,300	66,800	655,300	1,103,000
2030	308,400	229,400	88,600	859,400	1,485,900
Annual growth (%)	1.47	1.23	1.12	1.08	1.18

In 2002 £. Annual growth rates are averaged over the 25-year period. Source: Author's calculations from REMI-ECOTEC UK Version 6.0

East Midlands. Overall, the total UK population increases from about 60 million persons in 2005 to 65 million in 2030—an average increase of 0.33% per annum on average. Population growth is slightly less in the Greater London and Southeast (0.31% and 0.24% per annum, respectively), while the population of the East Midlands increases from 4.3 million to to 5.2 million people—about 0.79% per year.

Greater London had about 4.0 million jobs in 2005, while the East Midlands had about 1.7 million jobs. The average growth in employment between 2005 and 2030 for the UK was about 0.05%. Employment grows faster in London (0.28% per annum) and the East Midlands (0.10% per annum). In the East Midlands, the relatively low population growth relative to the change in employment in the East Midlands suggests that the residents are commuting to jobs in other regions, such as Birmingham, Manchester, or London.

The total UK GVA is £1.1 trillion in 2005, and increases to £1.4 trillion by 2030. The GVA in London is £212.6 billion in 2005, while the East Midlands GVA is £66.8 billion. The long-term economic growth is 1.5% in London and 1.1% in the East Midlands–with a UK total average growth rate of 1.2%.

I also focus on a more detailed analysis of economy activity at the sector-level. I adapt the concept of economic base analysis to analyze the impacts of professional services—a much larger sector than manufacturing and one of the key users of aviation services. I focus on a subset of professional services that are primarily export-oriented industries. This is referred to as the basic sector. The nonbasic sector focuses on production linkages through different industries within a region (Bendavid-Val, 1991, p. 87). Table B.2 shows exports as a percentage of total output for service sectors in the

Table B.2: Exports as percentage of total regional output for Basic and Nonbasic Sectors - East Midlands Baseline, 2005

Basic Sectors	Exports (%)	Non-basic Sectors	Exports (%)
Financial Activities	63.1	Education	39.0
Post and Telecom	53.1	Equipment Rental	17.8
Research and Development	48.8	Real Estate Activities	14.8
Other Business Activities	25.6	Other services, Households	13.4
Computer and Related	23.4	Public Admin and Defense	7.3
Banking and Finance	19.1	Membership Organizations	6.7
Insurance and Pensions	16.9	Sewage and Refuse	4.3
Culture and Sport	15.1	Health and Social Work	3.8
Basic Average	33.1	Nonbasic Average	13.4

In 2002 £. Source: Author's calculations from REMI-ECOTEC UK version 6.0

East Midlands. On average, about 33% of all output for the basic sectors are used for exports, while about 13% of all non-basic sectors goes towards output.

Table B.3 shows the share of value-added in each sector in 2005, while Table B.4 shows the average annual growth in regional value-added by sector between 2005 and 2030. The air transport sector accounts for 1.5% of the total value-added in London, but only 0.2% in the the East Midlands. Throughout the UK, the sector accounts for 0.6% of the total value-added. Despite being a relatively small industry, however, air transport is forecast to be one of the fastest-growing sectors through 2030—with an average growth rate (2.25%) over 1 percentage-point higher than that of the UK average growth (1.18%).

Interregional trade and global exports are shown in Table B.5, and indicates that the United Kingdom had a net trade deficit of about £31 billion in 2005. The relative regional competitiveness is shown in Table B.6, while labor competitiveness is shown in Table B.7. The real relative wage rate takes into account the average wage rates by industry and the cost of living in region, including taxes and housing prices, and is shown as a percentage

Table B.3: Breakdown of value-added by sector, 2005

Percent Share (%)	Region				UK Total
	Greater London	South East	East Midlands	Rest of UK	
Agriculture and Mining	1.2	1.9	1.7	3.3	2.6
Manufacturing and Fuel	8.3	17.0	29.6	23.8	20.1
Utilities and Construction	5.2	7.4	8.5	8.3	7.6
Retail Services	9.4	12.2	11.6	11.0	10.9
Hotels and Restaurants	4.3	3.8	3.5	3.7	3.8
Other Transport	4.1	3.8	3.8	3.4	3.6
Air Transport	1.5	0.8	0.2	0.3	0.6
Basic Services and Telecom	37.0	26.8	16.6	19.2	23.6
Nonbasic Services and Households	29.1	26.4	24.4	27.1	27.2
All Sectors	100.0	100.0	100.0	100.0	100.0

Source: Author's calculations from REMI-ECOTEC UK Version 6.0

Table B.4: Average annual growth in regional value-added by sector, 2005-2030

Average annual percent growth (%)	Region				UK Total
	Greater London	South East	East Midlands	Rest of UK	
Agriculture and Mining	0.83	0.51	0.16	0.52	0.53
Manufacturing and Fuel	0.83	0.66	0.44	0.46	0.52
Utilities and Construction	1.19	0.96	0.87	0.79	0.88
Retail Services	1.43	1.30	1.30	1.21	1.26
Hotels and Restaurants	1.65	1.59	1.58	1.54	1.57
Other Transport	1.75	1.61	1.50	1.48	1.56
Air Transport	2.28	2.25	2.26	2.21	2.25
Basic Services and Telecom	1.59	1.35	1.41	1.36	1.43
Nonbasic Services and Households	1.46	1.38	1.56	1.32	1.37
All Sectors	1.47	1.23	1.12	1.08	1.18

Source: Author's calculations from REMI-ECOTEC UK version 6.0.

Table B.5: Regional exports, 2005

	Region				UK Total
	Greater London	South East	East Midlands	Rest of UK	
Net UK Regional Exports (£Bn)	46.2	2.2	-8.0	0.0	n/a
Net Global Exports (£Bn)	-5.8	-4.0	-2.3	-19.0	-31.1
Imports / Demand (%)	27.9	37.5	49.6	14.9	14.5
Exports / Output (%)	35.0	37.2	45.8	14.1	13.3

In 2002 £. Source: Author's calculations from REMI-ECOTEC UK version 6.0

Table B.6: Relative regional competitiveness - Private non-farm industries, 2005

	Region				UK Total
Percent Share (%)	Greater London	South East	East Midlands	Rest of UK	
Composite Price	0.795	0.990	1.024	1.054	1.000
Composite Input Costs	0.777	0.991	1.026	1.061	0.995
Delivered Price	0.953	1.013	0.996	1.009	1.000
Cost of Production	0.946	1.023	0.991	1.011	1.000
Labor Intensity	0.919	0.968	1.025	1,939	1.004

Source: Author's calculations from REMI-ECOTEC UK version 6.0

relative to the national average. The compensating differential is the amount of expected income in area relative to the national average that will keep net economic migration at zero: if the value is greater than one, then the area is considered to be amenity poor and requires higher expected income and vice versa (Miller and Ervin, 2004). Together, the relative wage rate and the compensating differential help to determine economic migration.

Table B.7: Regional labor competitiveness, 2005

Percent Share (%)	Region				UK Total
	Greater London	South East	East Midlands	Rest of UK	
Compensating Differential	5.765	0.996	0.534	0.769	0.996
Real Relative Wage Rate	1.201	1.070	0.973	0.943	0.995
Non-farm Average Annual Wage Rate (nominal £)	28,369	24,830	21,009	20,691	22,456
Labor Productivity (2002 £)	100,753	89,364	76,058	76,485	81,940

Source: Author's calculations from REMI-ECOTEC UK version 6.0

B.2 Comparison with other models and forecasts

Economic forecasts can differ due to modeling methodologies and data, and can even vary over time. The GLA analyzes several independent economic forecasts for London before publishing its own official forecast. These forecasts include Cambridge Econometrics (CE), The Centre for Economic and Business Research (CEBR), Experian Business Strategies (EBS), and Oxford Economic Forecasting (OEF) (Greater London Authority Economics, 2006, p. 3). Figure B-1 shows historical data and forecasts for regional GVA from several different sources: CE, REMI-ECOTEC, the ONS, Eurostat, and GLA Economics. The REMI-ECOTEC forecasts for value-added are much higher for London than CE, ONS, and Eurostat, but are similar to the other forecasters for the East Midlands.

While the various forecasters predicted annual growth rates in 2008 of 3.0% to 4.2%,[1] for example, the GLA's official estimate was 2.8% (Greater London Authority Economics, 2006, p. 19). The GLA also refines its forecasts several times a year—taking into account updated data and changing conditions. A comparison of different GLA

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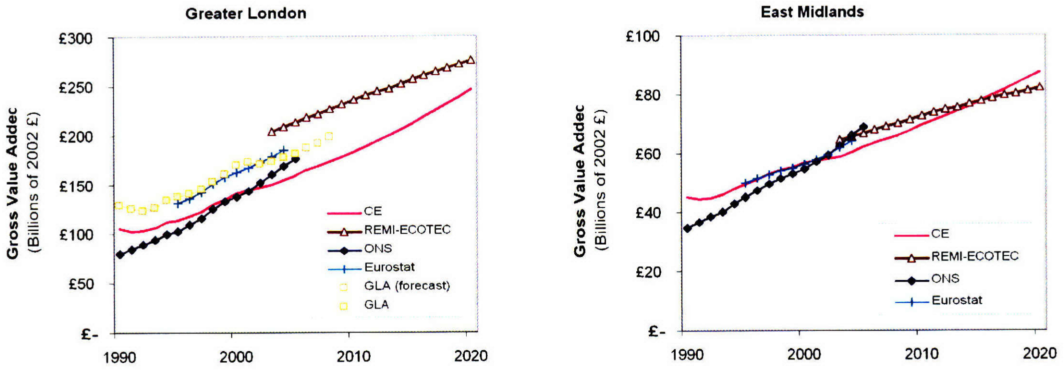
[1] Consensus average of 3.5%



(a) Greater London

(b) East Midlands

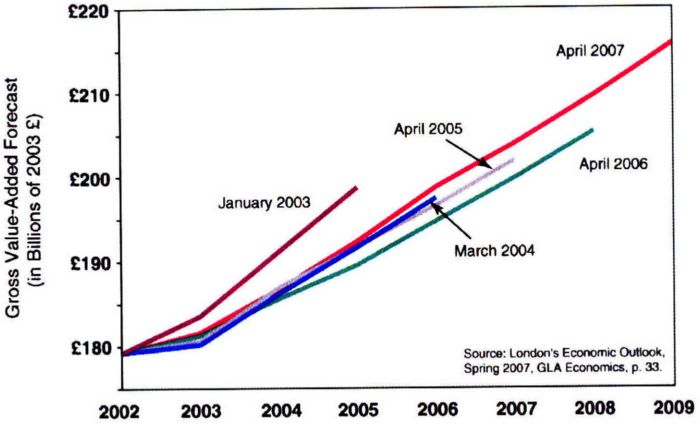
Figure B-1: Comparison of data and forecasts: Cambridge Econometrics, REMI-ECOTEC, UK Office of National Statistics, and Eurostat.

forecasts are shown in Figure B-2. In January 2003, for example, the forecast growth rate for 2005 was 4.0%. By March 2004, that had declined down to 2.9%, and by Aprill 2005 was at 2.6%. The final GLA published growth rate for 2005 was 2.1% (Greater London Authority Economics, 2006, pp. 18-33).

B.3 Model Testing

While the model structure and its underlying data are as crucial to the REMI-ECOTEC model as any other methodology, the selection and manipulation of its various policy variables is also a key step in the policy analysis. Here, I describe a number of sensitivity tests to explore the functionality of the model and how policy variables are applied within its fixed structure. I focus on the sensitivity of key policy variables in the REMI-ECOTEC model most relevant to regional air transportation policy assessment.

My sensitivity tests are centered around three main areas: (a) how the overall REMI-ECOTEC model forecasts compare to other standard regional economic methodologies;



Source: GLA Economics

Figure B-2: Comparison of London GVA Forecasts: 2003-2007

(b) more detailed analysis of the interactions between regions and industries in the model; and (c) differences in how several specific policy variables are manipulated in order to simulate a particular economic phenomenon.

B.3.1 Alternative Methodologies

First, I compare the performance of the standard REMI model with other traditional methodologies such as input-output, endogenous household, and Computable General Equilibrium (CGE) models. Standard input-output and endogenous household models are similar to the RIMS II and IMPLAN models that are widely used in the United States. I simulate these different methodologies by selectively turning off different components of the REMI model. These model settings are shown in Table B.8. In these series of tests, I use a one-time increase (10%) in air transport industry sales in the East Midlands, and compare the differences in the resulting forecasts and the regional control.

I expect that the input-output and endogenous household models would produce forecasts that are lower than those from the REMI-ECOTEC standard model due to the lack of investment and accessibility-related productivity. The REMI-ECOTEC model should also produce different regional distributions of activity than the CGE-type model, because its regional allocation is based on an economic theory (accessibility) rather than econometric (statistical) relationships. While the total cumulative impacts are less than the CGE model, the impacts should be potentially greater in regions where there is agglomeration.

The total net increases in regional value-added between 2005 and 2030 for the different scenarios and regions of impact are shown in Figure B-3. While the input-output-type model generated total impacts about 21% less than those forecasted by the complete REMI dynamic model, the endogenous household model and the CGE-type models increased total GVA by 12% and 6%, respectively. I note that this comparison does not take into account the alternative baselines which underlie the different model scenarios; these alternative baseline forecasts (input-output, etc...) differ from the REMI standard baseline—and thus produce different impacts over time. The dynamic, interregional linkages in the REMI model do show up in this test; while the East Midlands had changes that were relatively consistent with the baseline model (-11% to +1%), the Greater London and the remaining UK regions had differences as much as negative -38% or 44%.

Table B.8: REMI-ECOTEC model settings used to generate alternative methodology comparisons

	REMI-ECOTEC Standard	Input-Output (Type I)	Input-Output w/ Endogenous Households (Type II)	Instantaneous Market Clearing Wages/Prices (CGE)
Wage response to market conditions	•			•
Labor intensity response to relative factor costs	•			•
Property income response to pop'n	•			•
Transfer payment response to pop'n	•		•	•
Local consumption response to income and prices	•		•	•
Investment stock adjustment	•			•
Government spending response to pop'n	•		•	•
Government spending response to real wages and unemployment	•			
Composite price response to access and production costs	•			
CIF price response to transportation and production costs	•			
Trade flows with endogenous supply	•	•	•	•
Migration equation (2001 version)	•			•
Commodity access index	•			
Labor access index	•			
Housing price equation	•			•
Demand price elasticities	•			•
Wage equation coefficients	•			•

Unused Features: Alt migration equation 1993 version; Alt investment response to the level of activity; Alt instantaneous market clearing wage; Alt trade flows with historic supply; Alt demand price elasticities; Alt wage equation coefficients
Source: REMI-ECOTEC UK version 6.0

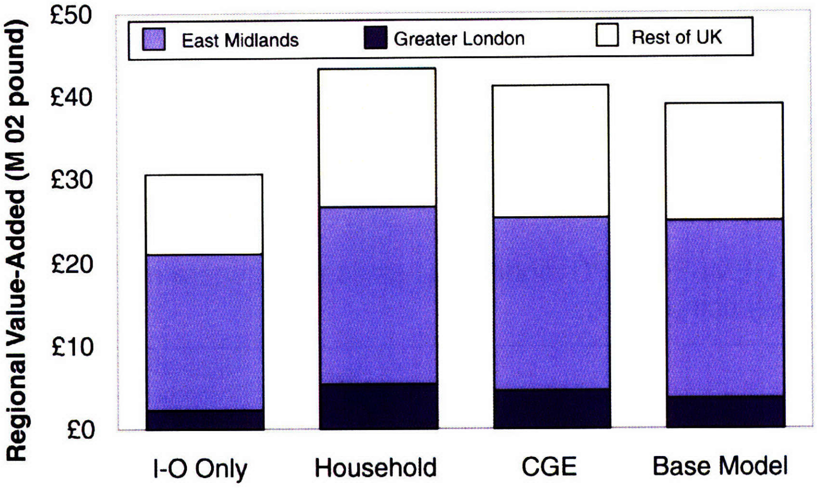


Figure B-3: Impact of 10% increase in air transport sales in the East Midlands under alternative methodologies

B.3.2 Effect of Investment and Intermediate Inputs

One of the unique features of the REMI model is that it uses adjustments to capital stock investment in order to further refine the flows of economic activity between regions. These relationships are based on traditional Cobb-Douglas production functions for labor and capital. I expect that investment is probably a minor part of the economic impacts for small, short-term shocks, but should have a larger role in the longer-term impacts. Similarly, the increase in sales/exports without employment, investment, and wages probably should not produce major differences in the forecasts in heavily capital-intensive industries such as air transport.

In order to examine the contribution of investment and intermediate inputs, I use several policy variables that enable the suppression of the investment, intermediate inputs, or employment effects that are generated by an increase in industry sales. These policy variables are typically used when increased industry sales are not expected to affect the industry—perhaps when there is excess production capacity or some other constraint on industry expansion.

Isolating the contribution of investment using these variables is conceptually different than comparing it with the CGE-type model studied previously, because the impacts of investment and intermediate inputs still occur elsewhere in the region. Here, I am concerned with identifying the impacts of investment and intermediate inputs (or lack thereof) due to the shock. For the sensitivity tests, I use a one-time, £31.5 million exogenous increase in air transport industry sales (equivalent to 10%) and nullify the same amount.[2]

Figure B-4 shows the difference in total regional value-added (2005-2030)—again, associated with a roughly 10% increase in air transport industry sales. The total increase in GVA in 2006 associated with the increased aviation sales is £48.4 million under the baseline REMI-ECOTEC model. Nullifying the investment reduces the total impacts on regional GVA by about 2% (£1.1 million). The intermediate impacts have a much bigger impact on GVA, and they reduce the total impacts by about 55% (£26.5 million). Including industry sales but without employment, investment, and wage effects has a net effect of reducing the impacts by 43.0% (£39.7 million) relative to the baseline scenario. In this case, the intermediate effects are significant—much greater than the total impacts themselves–and are much greater than investment.

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[2] The specific policy variables are: (a) Nullify Investment Induced by Industry Sales / International Exports; (b) Nullify Intermediate Inputs Induced by Industry Sales / International Exports; and (c) Industry Sales / International Exports Without Employment, Investment, and Wages (amount). These impacts are entered as monetary units rather than percentage shares due to the limitations of the policy variables.

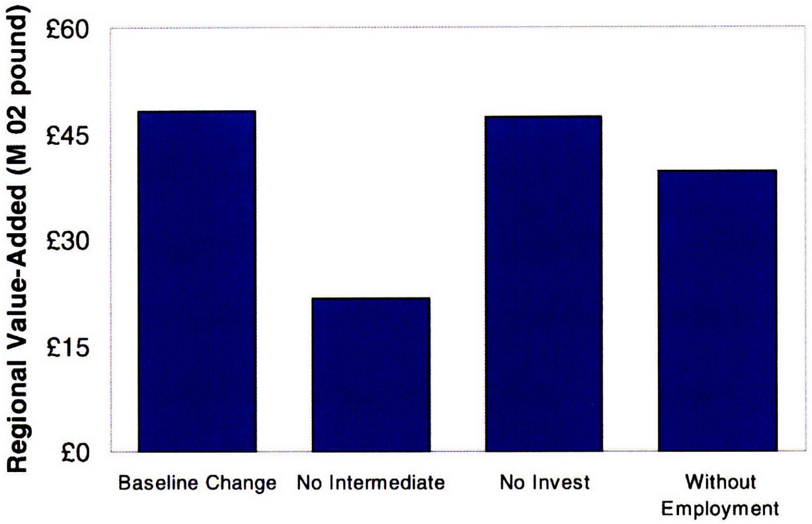

Figure B-4: Comparison of total impacts without intermediate inputs, investment, or employment effects

B.3.3 Regional Response Speed

Another distinguishing characteristic of the REMI model is that it uses different response speeds (to economic shocks) in order to affect the interregional flows—thus reflecting the stock-and-flow relationships for investment and population. In contrast, CGE-type models require all markets to clear simultaneously. Here, I conduct several sensitivity tests in order to understand whether or not the regional responses are sensitive to different sizes and timings of exogenous shocks. As the size of the shock increases (and for a longer-time), I expect the East Midlands to be able to capture a larger part of the total activity—thus drawing more business from the other regions and creating larger impacts. Due to the regional scale of the REMI model and the small relative size of the air transport sector in the East Midlands, it should be more sensitive to larger shocks than to smaller shocks.

I compare the basic impacts from an exogenous 10% increase in air transport industry sales in the East Midlands for 1-, 5-, and 10-year time periods. I also look at

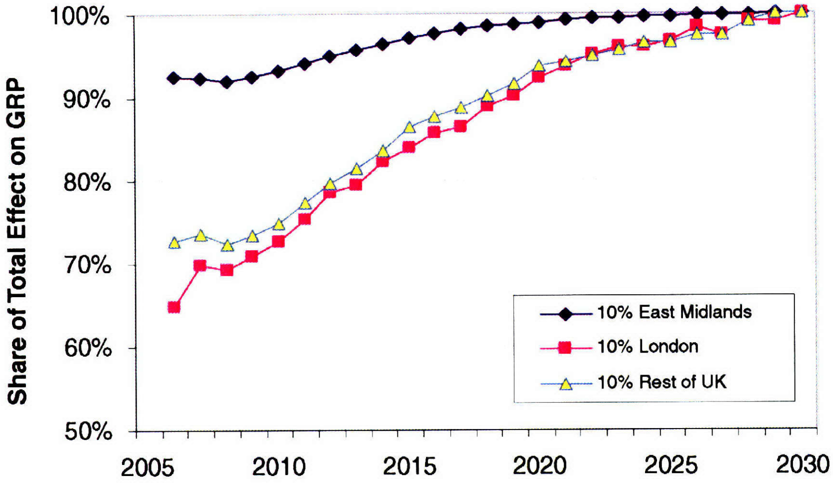

Figure B-5: Cumulative economic impact from 10% increase in exogenous air transport industy sales on GRP by region

a series of one-time shocks in a range of sizes up to 20%. Figure B-6 shows linearly increasing impacts due to increasing magnitudes. The total regional GVA share for the East Midlands ranges from 48% to 54% of the total impacts under the different scenarios.

Figure B-5 shows the cumulative effect of the shock over time in terms of total GRP. In the East Midlands, over 90% of the economic impacts are seen immediately in 2006, while the total impact is felt by 2020. The economic impacts in London and the rest of the United Kingdom from this shock accrue much more gradually, where only about 65%-75% of the total economics impacts initially occur in the year of the shock, with it reaching 100% by 2030.

B.4 Model Inputs

Table B.9 shows the policy variable settings which were used to generate the results in Chapter 4 and 5.

Table B.9: Air transport growth scenarios inputs

Variable: Industry Sales / Int'l Exports (share)
Detail: Air transport
Units: Proportion

Year	Scenario		
	Low	Medium	High
2003	0.000	0.000	0.000
2004	0.000	0.000	0.000
2005	0.000	0.000	0.000
2006	-0.009	0.012	0.027
2007	-0.018	0.023	0.055
2008	-0.027	0.035	0.082
2009	-0.036	0.047	0.110
2010	-0.045	0.059	0.137
2011	-0.054	0.070	0.164
2012	-0.063	0.082	0.192
2013	-0.072	0.094	0.219
2014	-0.081	0.105	0.246
2015	-0.090	0.117	0.274
2016	-0.099	0.129	0.301
2017	-0.108	0.141	0.329
2018	-0.117	0.152	0.356
2019	-0.127	0.164	0.383
2020	-0.136	0.176	0.411
2021	-0.145	0.187	0.438
2022	-0.154	0.199	0.465
2023	-0.163	0.211	0.493
2024	-0.172	0.223	0.520
2025	-0.181	0.234	0.548
2026	-0.190	0.246	0.575
2027	-0.199	0.258	0.602
2028	-0.208	0.269	0.630
2029	-0.217	0.281	0.657
2030	-0.226	0.293	0.684

Source: Author's calculations using REMI-ECOTEC UK version 6.0

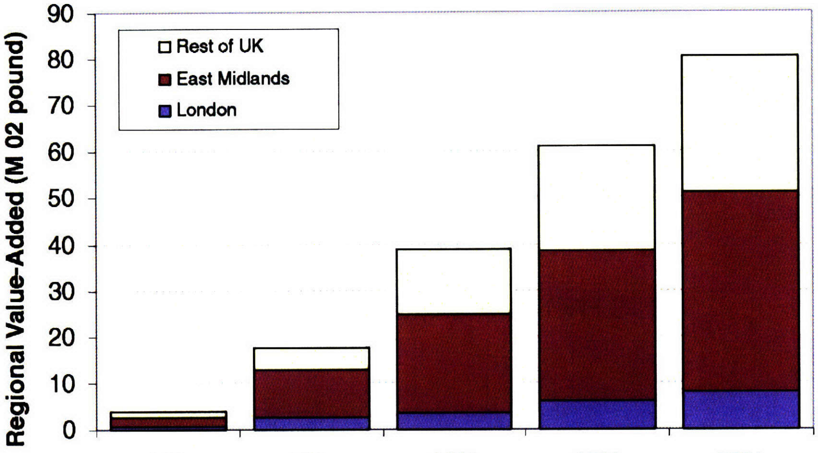

Figure B-6: Magnitude and region of impact

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Appendix C

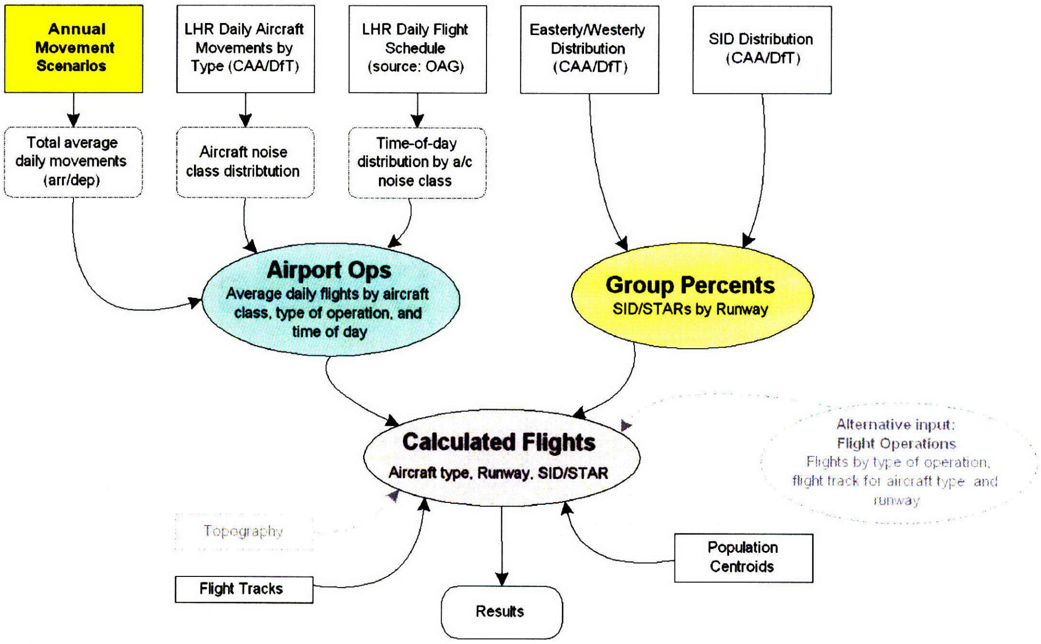
Airport Noise Model Details

C.1 Noise Model Assessment

My main criteria for evaluating the performance of the noise models was the relative size of the 57-dBA 16-hour daytime L_{Aeq} noise contours. This is primary noise contour that is currently used in the UK for policy-making purposes, although the EU is requiring its member states to produce noise contours using the L_{DEN} and L_{night} metrics, which do account for evening and nighttime weighting (Bickerdike Allen Partners, p. 10). I compared the baseline forecasts against existing noise models published by the CAA and the East Midlands Airport (EMA). Although the results from the CAA's ANCON2 model for Heathrow are not directly comparable to my INM study, other analysts have developed similar INM models for the proposed third runway at Heathrow and the East Midlands.

I also tested the effects of different model variables on the size of the 57-dBA contour, including aircraft noise class groupings, time-of-day, aircraft takeoff weights, flight tracks, and terrain. In general, my overall objective was to create models that were as close as possible to existing published models, but yet that remained parsimonious and credible. The results of the sensitivity studies are shown in tables C.1, C.2, and C.3.

Figure C-1: Integrated noise model inputs



In general, terrain reflectivity and departure track dispersion had very small effects (less than 1%) on the size of the 57-dBA contours. The differences in time-of-day distributions for arrivals and departures had slightly larger effects (slightly greater than 1%) on the size of the noise contours. Different assumptions for average aircraft trip distances and alternative takeoff operational profiles also had small effects on the noise contours. Although incorporating these assumptions into the model created larger contours which were closer in size to those determined by the CAA, they add complexity and uncertainity to the model. As such, I removed them from the final noise models. When I expanded the model database to include 20-21 aircraft models, the effects on the size of the contours were much greater—shrinking the contours at Heathrow and enlarging the contours at Nottingham.[1] I also note that small changes in the size of the

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[1] Higher takeoff wights might also be assumed due to full passenger loads and fuel tankerage. Using the OAG schedule data, I had initially found the actual average stage length for Class 3 (narrowbody) aircraft flights was about 490 nautical miles (Profile Stage 1), but I tested the effect of increasing this average distance to 1000-1500 miles (Profile Stage 3).

Table C.1: Heathrow sensitivity tests

Model Run	Area (km^2)	Pct Chg vs. Base (2004)	Remarks
2004 Actual	117.4	base	16 hour daytime
L632 Base	88.4	-24.7%	5 classes, terrain
L632_NT	89.1	-24.1%	5 classes, no terrain
L632TX_NT	89.1	-24.1%	5 classes, track dispersal
L632D_NT	72.9	-37.9%	Detailed - 20 aircraft
L632M_NT	90.3	-23.1%	Day-night mix
L632SA_NT	90.0	-23.3%	Longer Class 3
L632M_SA_NT	91.2	-22.3%	Day-night mix and longer class 3
L632T7_NT	82.1	-30.0%	Replace 767s with 777s

Source: UK DfT, INM 6.2

Table C.2: Heathrow - third runway sensitivity tests

Model Run	Area (km^2)	Pct Chg vs. Base (2004)	Remarks
Baseline	28.0	base	16 hour daytime
ThirdRwy_NT	35.0	+25.1%	no terrain
ThirdRwy_FR	31.1	+11.1%	Flight operations
ThirdRwy_FR_NT	31.4	+12.0%	Flight ops, no terrain
ThirdRwy_FR_ICAO_NT	34.9	+24.5%	ICAO departures
ThirdRwy_TRK_FR	31.1	+11.2%	Track dispersion

Source: UK DfT, INM 6.2

noise contours often did not result in large changes to the population or dwelling unit counts, and that this was considered when selecting the final models.

Because my modeling objective is to focus on the overall effects of traffic growth as well as to match published contours as much as possible, I selected final models at Heathrow and Nottingham with a reduced number of aircraft types and without the more complex arrival/departure time-of-day operation distributions.

Figure C-2 shows a comparsion of my INM baseline noise contour for Heathrow versus the 2005 actual contours for Heathrow. Table C.4 shows a comparison of the

Table C.3: East Midlands airport sensitivity tests

Model Run	Area (km^2)	Pct Chg vs. Base (2004)	Remarks
2005 Actual	12.1	base	16 hour daytime
A80	9.0	-6.0%	Base
A80_NT	9.4	-1.7%	No Terrain
A80TX	8.9	-7.0%	Dispersed tracks (rough)
A80TX_NT	9.3	-2.8%	Dispersed tracks, no terrain
A80S	8.6	-9.6%	Revised stage lengths
A80D	13.2	+38.0%	Detailed - 21 aircraft

Source: East Midlands Airport, Bickerdike Allen Partners, INM 6.2

contour areas and population. The baseline SAI contours are -7.0% to -24.1% smaller in size than the 2004 actual contours. There are slightly larger differences in the population counts–about -9.5% to -30.8%. The CAA notes that there is typically a 20%-30% difference between INM noise contours and ANCON2 due variations in aircraft types, departure flight trajectories, and terrain data. As such, my model falls well within the range of expected performance.

For the third runway at Heathrow, my model generated a contour that was about 11.1% larger than Casella Stanger's INM runs. The key factors influencing these differences might be the precise location of the flight tracks, runway location, and flight profiles–but these differences can not be resolved with the readily available data.

My final model for Nottingham generated a 57-dBA contour that was about 1.7% smaller than contours produced by Bickerdike Allen Partners. A comparision of these two models is shown in Table C.5.

Table C.4: Heathrow model comparision: CAA 2004 Actual vs. SAI INM model

Contour	Land Area (km^2) CAA 2004	Land Area (km^2) 632NT	Land Area (km^2) Difference	Population CAA 2004	Population 632NT	Population Difference
57 dBA	117.4	89.1	-24.1%	239,700	176,650	-26.3%
60 dBA	66.7	53.0	-20.6%	105,300	91,060	-13.5%
63 dBA	40.3	34.0	-15.6%	55,900	46,256	-17.3%
66 dBA	24.4	20.3	-17.0%	21,000	18,995	-9.5%
69 dBA	13.3	10.9	-17.9%	5,700	4,173	-26.8%
72 dBA	6.5	6.0	-7.0%	1,500	1,038	-30.8%

Source: UK DfT, INM 6.2.

Table C.5: Nottingham model comparision: BAP 2005 Actual vs. SAI INM Model

Contour	Land Area (km^2) BAP 2005	Land Area (km^2) A80_NT	Land Area (km^2) Difference	Dwelling Units BAP 2005	Dwelling Units A80_NT	Dwelling Units Difference
57 dBA	9.54	9.382	-1.7%	303	388	-14.5%
60 dBA	5.48	5.120	-6.6%	181	129	43.1%
63 dBA	3.08	2.874	-6.7%	130	0	-0.8%
66 dBA	1.79	1.720	-3.9%			
69 dBA	1.11	1.219	9.8%			
72 dBA	10.71	0.888	25.1%			

Source: UK DfT, BAP, EMA, INM 6.2.

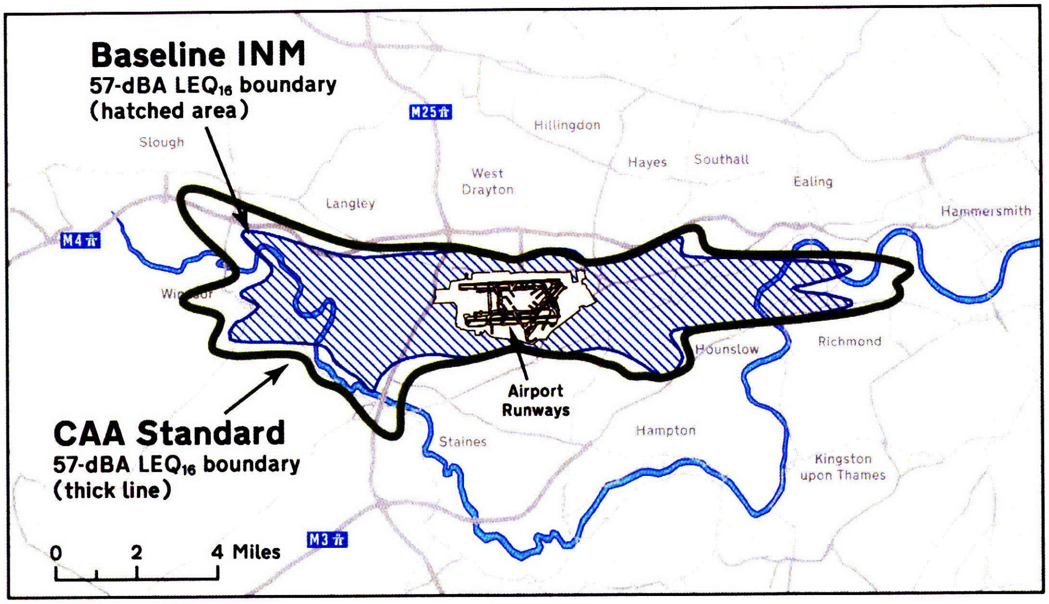


Figure C-2: Comparison of 57-dBA LEQ contours in INM and ANCON2.

C.2 SAX Noise Model Development

Darius Mobed developed the MATLAB codes to generate the NPD curves using input data and codes from Dan Crichton, Jim Hileman, and David Tan. Table C.6 describes the process used to calculate the NPD curves, while Table C.7 shows the settings used in the noise model.

Table C.6: Methodology used to derive the noise-power-distance curves

1. For each flight condition, choose what noise sources are contributing to the noise (Table C.7) and apply appropriate hemispheres
2. For each x position on the ground (given) calculate the height, angle pitch, and velocity correction.
3. Determine the noise from each hemisphere and propagate to the X position.
4. Sum up all the effects of the individual noise hemispheres and obtain the total aircraft sound pressure level at a certain velocity.

Source: Mobed et al. (2006).

Table C.7: Noise hemisphere settings

	Approach	Cutback	Sideline
Shielding	-	-	-
Fan Forward	yes	yes	yes
Fan Rearward	yes	yes	yes
Compressor	-	-	-
Turbine	yes	yes	yes
Core	yes	yes	yes
Jet	yes	yes	yes
Airfoil	yes	yes	yes
Wingtip	yes	yes	yes
Aileron - 1 degree	yes	-	-
Aileron - 5 degree	-	-	-
Undercarriage	yes	-	-
Roughness	-	-	-
Swirl tube 1	-	-	-
Wwirl tube 2	-	-	-

Source: SAI team

To examine the sensitivity of the NPD calculations, Mobed et al. (2006) also calculated the NPD curves at the SAX measurement points and speeds as well as at the INM reference points. Based on the INM technical guidance, the noise-power-distance curves are supposed to be generated at a reference speed of 160 knots (296 km/h or 82.3 m/s) and at 1000-feet altitude (304.8 m). In contrast, the SAX flies at 120 knots (222 km/h or 61.7 m/s) on approach or departure. Also, the SAX sideline measurement point is at 308 feet (93.8 m), while cutback occurs at 1094 feet (333.4 m). The SAX approach point is measured at 394 feet (120 m). The SAI noise assessment conditions were converted to the INM reference speed and altitude. Because the INM reference altitude is higher (1000' versus 394' at approach or 308' at cutback), the resulting effect should make the NPD curves quieter than the SAI predictions. But the INM reference speed is faster than the SAX approach/takeoff speed (160 knots instead of 120 knots or 222 km/h), the NPD curves should be noiser (more engine power).

For the approach condition, the NPD curve at the INM reference condition is initially about 2 dBA lower than the SAI approach speed/altitude. The SAI curve falls off rapidly, though, and then ends up about 10-11 dBA lower than the INM curve. On average, the SAI curves difference is about 8 dBA less than the INM curve. For the sideline takeoff condition, the difference between the INM and SAI curves is much smaller-with the SAI curve about 3-dBA less than the INM curve, on average.

The approach, cutback, and sideline curves are shown in Figures C-3, C-4, and C-5, with the respective takeoff and approach curves for a 767-300 shown for comparison. On approach, the 767 NPD curves ranged from 99 down to 57 dBA, while the SAX curves are 58 to 12 dBA. In general, these curves are about 33-46 dBA quieter on approach and 36-55 dBA quieter on departure. These differences between the NPD curves for the 767 and the SAX40 ranged in the order of about 30% to 80%. In contrast, the EPNL calculations showed that the SAX40 was about 25-30% quieter than the 767-300, with about 24-29 EPNdB differences in noise levels.

In general, the use of the SAI reference speed/altitudes produced slightly lower (quieter) NPD curves than at the INM conditions. The INM reference conditions thus produce curves which more closely match the expected noise signature-closer to those of existing 767-300 aircraft. I selected the INM reference conditions as a conservative modeling decision. Table C.8 summarizes the single-event sound levels for the Boeing 767-300 and the SAX-40.

INM uses three main types of data in modeling aircraft noise, including (1) NPD curves, (2) aircraft noise spectral class profiles, and (3) thrust/flap coefficients. While the SAI team was able to generate NPD curves for the SAX-40, the spectral class

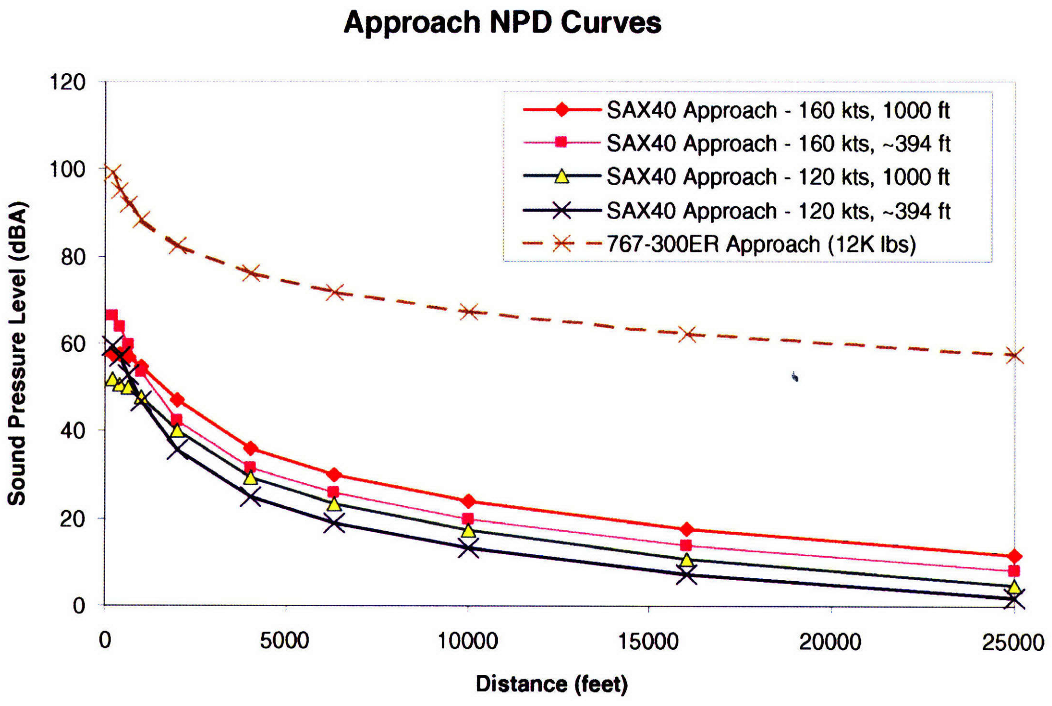


Figure C-3: Noise-Power-Distance curves for SAX-40 and Boeing 767 (Approach).

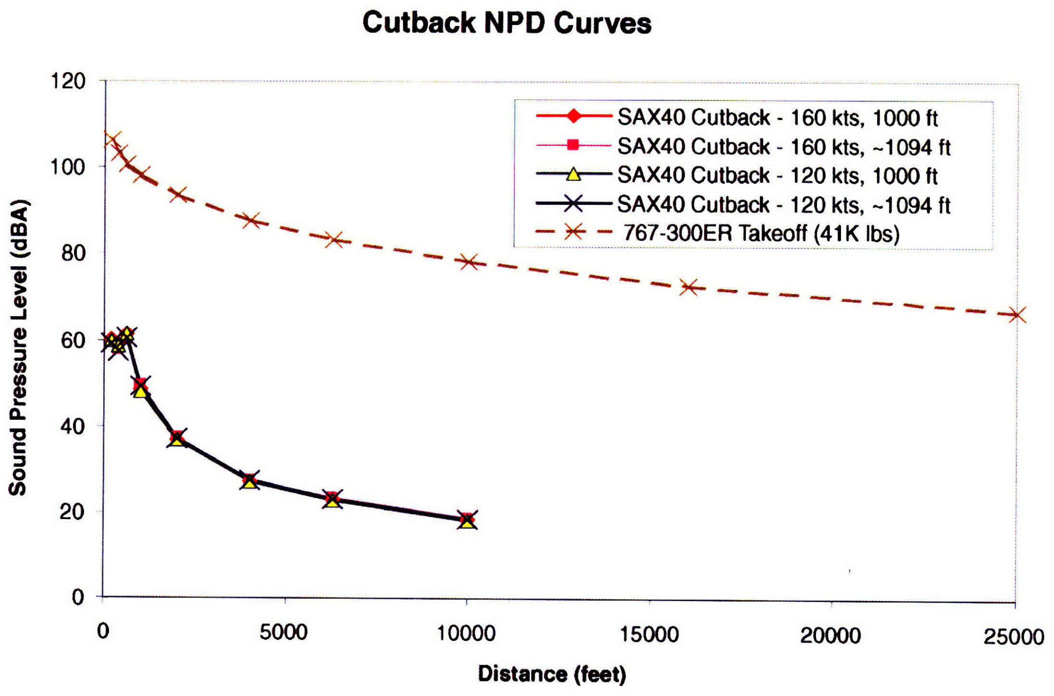


Figure C-4: Noise-Power-Distance curves for SAX-40 and Boeing 767 (Cutback).

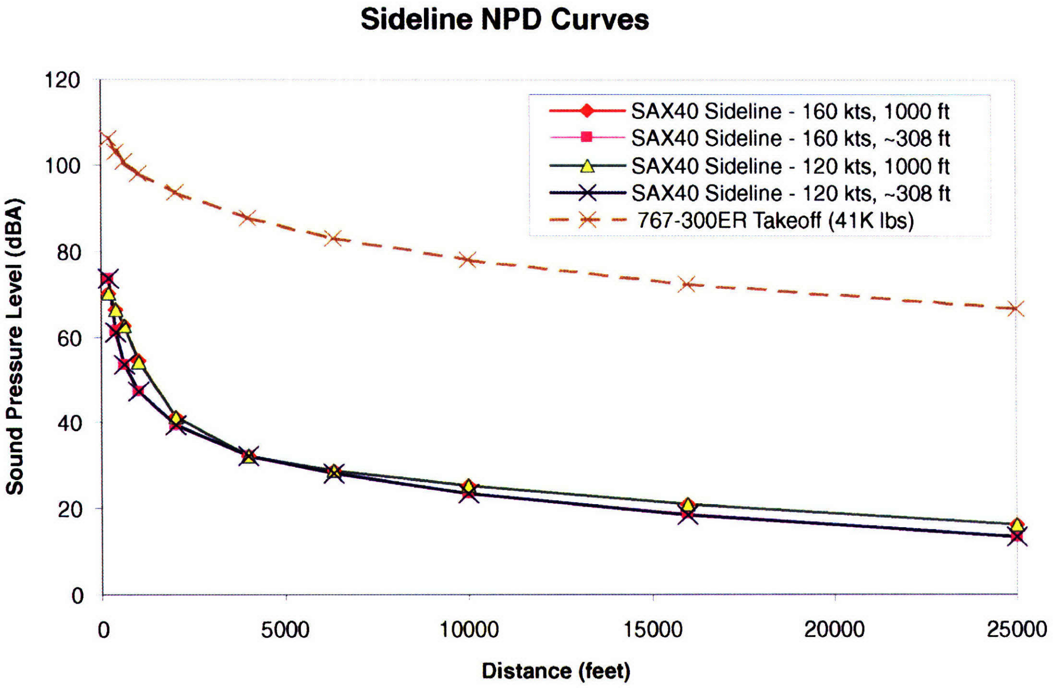


Figure C-5: Noise-Power-Distance curves for SAX-40 and Boeing 767 (Sideline).

Table C.8: Comparison of SAX-40 and B767 SEL noise levels in dBA

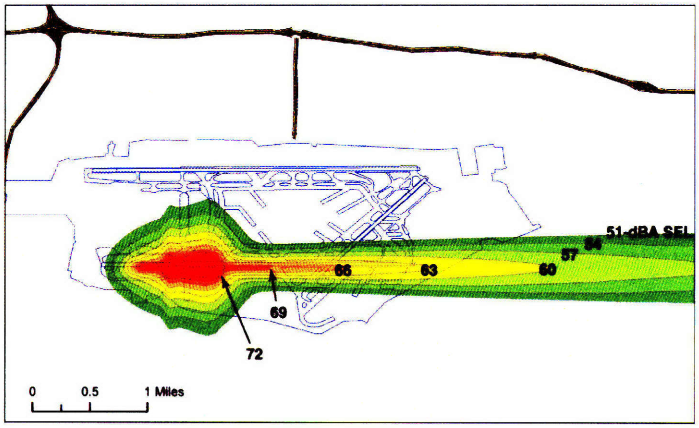
	Approach	Sideline	Cutback
B-767-300/300ER (dBA)	99.2	95.9	93
SAX-40 (dBA)	72.6	66.8	69.2
Difference (dBA)	26.6	29.1	23.8
Percentage (%)	-26.8	-30.4	-25.6

Source: Author's calculations from FAA AC-36H, SAI Team profiles are produced by the FAA and was thus not available. The blended fuselage-wing configuration of the SAX-40 should produce a spectral profile which was radically different from existing tube-and-wing aircraft in terms of how the noise eminates from the aircraft. Instead, I used the profile for a typical commercial jet airliner with high-bypass turbofan engines. Although not ideal, this represents a limitation of this analysis. Finally, the data to produce thrust/flap coefficients for the SAX were also not available, I circumvented this limitation by using fixed-point flight profiles. Analysts use this technique in modeling certain aircraft types (such as the MD-11) where thrust coeffients are not available. In doing so, I was also able to take into account the steep approach and unusual departure thrust cutback levels.

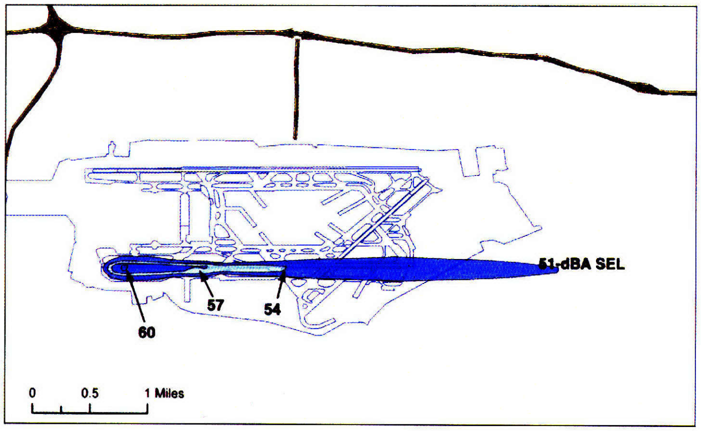
Figure C-6 shows the single-event contours. It compares an initial noise model based on a 20-dBA reduction from a 767, and the final curves used for the SAX-40. While the noise levels are almost unrealistically low, it essentially reflects a conservative assumption that the SAX-40 would not generate noise levels above the ambient urban noise at the airport perimeter.

C.3 Flight Operation Inputs

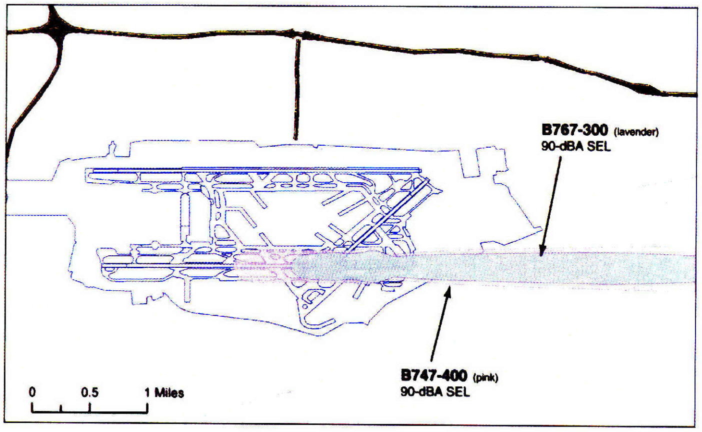
Tables C.9 through C.16 describe the actual flight inputs used to model the different scenarios at London Heathrow and the East Midlands airports by time-of-day and aircraft.



(a) Initial SAX noise levels based on 767 minus 20-dBA.



(b) SAX noise levels based on SAX-40 NPD curves.



(c) Noise levels for Boeing 767-300 and 747-400 (90-dBA SEL).

Figure C-6: Comparison of SAX noise levels (initial and final model) with Boeing 767-300 and 747-400.

Table C.9: Baseline (2005) flight departures by aircraft type and time-of-day, London Heathrow airport model

Aircraft Type	Period			Total
	Day	Evening	Night	
Dash-8	4	1	0	5
737-700	316	87	17	420
767-300	83	20	11	114
747-400	47	17	17	81
747-200B	2	1	0	4

Note: Same inputs used for arrivals. Source: Author's calculations based on CAA, BAA, OAG, and ACARS (Bowler, 2008) data

Table C.10: Medium-growth scenario flight departures by aircraft type and time-of-day, London Heathrow airport model

Aircraft Type	Period			Total
	Day	Evening	Night	
Dash-8	5	2	0	6
737-700	379	114	16	509
767-300	98	24	16	138
747-400	73	16	13	102

Note: Same inputs used for arrivals. Source: Author's calculations based on CAA, BAA, and OAG data

Table C.11: High-growth scenario flight departures by aircraft type and time-of-day, London Heathrow airport model

Aircraft Type	Period			Total
	Day	Evening	Night	
Movements on Existing Runways				
737-700	318	96	14	427
767-300	135	33	22	189
747-400	99	22	17	139
Movements on Third Runway				
Dash-8	6	2	0	8
737-700	201	60	9	270

Note: Same inputs used for arrivals. Source: Author's calculations based on CAA, BAA, and OAG data

Table C.12: Advanced-technology, low-noise aircraft Phase 1 scenario flight departures by aircraft type and time-of-day, London Heathrow airport model

Aircraft Type	Period			Total
	Day	Evening	Night	
Movements on Existing Runways				
737-700	318	96	14	427
SAX-40	135	33	22	189
747-400	99	22	17	139
Movements on Third Runway				
Dash-8	6	2	0	8
737-700	201	60	9	270

Note: Same inputs used for arrivals. Source: Author's calculations based on CAA, BAA, and OAG data

Table C.13: Advanced-technology, low-noise aircraft Phase 2 scenario flight departures by aircraft type and time-of-day, London Heathrow airport model

Aircraft Type	Period			Total
	Day	Evening	Night	
Movements on Existing Runways				
737-700	318	96	14	427
SAX-40	234	55	39	328
Movements on Third Runway				
Dash-8	6	2	0	8
737-700	201	60	9	270

Note: Same inputs used for arrivals. Source: Author's calculations based on CAA, BAA, and OAG data

Table C.14: Flight departures by route, percentage share, London Heathrow airport model

Departure Route	Existing Runways (%)				Third Runway (%)	
	9L	9R	27L	27R	8L[2]	26R
WOB/BPK	-	8.5	17.4	17.4	8.5	34.7
DVR/DET	-	3.8	8.7	8.7	3.8	17.3
MID[1]	-	2.3	7.8	7.8	2.3	15.5
SAM[1]	-	2.3	-	-	2.3	-
CPT	-	2.1	-	-	2.1	-
CPT/SAM	-	-	6.7	6.7	-	13.5
Subtotal	-	19.0	40.5	40.5	19.0	81.0

[1] Assumes 50/50 split between aggregated MID/SAM departures (6.7%), as published by CAA.
[2] Assumes Cranfield Agreement does not affect new runway. Source: Author's calculations based on CAA, BAA, and OAG data

Table C.15: Flight departures by route, percentage share, East Midlands airport model

Departure Route	Runways (%)	
	9	27
DAVENTRY	19.0	44.8
DAV2	1.7	-
TRENT	-	25.0
TRENT2	3.5	-
POLE	6.0	-
Subtotal	30.2	69.8

Source: Author's calculations based on NEMA, CAA, BAA, and OAG data

Table C.16: Baseline (2005) flight departures by aircraft type and time-of-day, East Midlands airport model

Aircraft Type	Period			Total
	Day	Evening	Night	
Baseline				
Dash-8	3.5	0.8	1.4	5.7
737-700	42.3	9.0	11.5	62.8
767-300	3.8	1.1	4.2	9.1
MD-11 (GE)	0.5	0.2	1.3	2.0
747-200B	0.1	0.0	0.3	0.4
Medium-growth				
Dash-8	7.3	1.6	2.9	11.8
737-700	88.6	18.9	24.1	131.5
767-300	8.0	2.2	8.7	19.0
MD-11 (GE)	1.4	0.5	3.2	5.1
High-growth				
Dash-8	15.8	3.5	6.2	25.4
737-700	190.0	40.5	51.7	282.1
767-300	17.2	4.8	18.7	40.7
MD-11 (GE)	3.0	1.1	6.9	11.0

Note: Same inputs used for arrivals. Source: Author's calculations based on CAA, BAA, OAG, and NEMA data