
The Impact of Oil Prices on the Air Transportation Industry

Final Report

Prepared by:

John Hansman (PI), Dominic McConnachie and Christoph Wollersheim
Massachusetts Institute of Technology

Matthew Elke, **Mark Hansen (PI)**, Nathan Chan and Maxime Crépin,
University of California at Berkeley

and

Tao Li, **Everett Peterson (PI)** and **Antonio Trani (PI)**
Virginia Tech

National Center of Excellence for Aviation Operations Research

March 28, 2014

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Acknowledgements

The authors wish to thank David Chin, Thea Graham and Dan Murphy for providing funding and technical guidance in this project. This work is funded by the United States Federal Aviation Administration under contract with University of Maryland as part of the NEXTOR 2. Any opinions, findings, and conclusions or recommendations expressed in this report are those of the authors and do not necessarily reflect the views of the FAA.

Executive Summary

Oil price changes have increased during the past decade resulting in significant adaptations by airlines, air cargo carriers and general aviation users. For airlines, the volatility of fuel prices makes profitability difficult. For passengers, increased oil prices result in higher fares and the use of more affordable modes of transportation or the elimination of unnecessary travel. For general aviation users, higher fuel prices have driven the utilization of some sectors of the small aircraft fleet to record low levels. Overall, higher fuel prices have a negative impact on the U.S. economy.

This report represents an effort to measure the impact of oil prices to airlines, cargo operators and general aviation operators. The report includes an assessment of the impact of oil prices to the U.S. economy. Because every aviation stakeholder is unique, the assessments presented in this report rely on (1) analysis of operations data, (2) industry interviews and (3) modeling fuel price impacts to aviation operators and to the U.S. economy using statistical, econometric and general equilibrium models. The report is structured in five sections. Section 1 offers a brief introduction and describes the questions to be answered in the report. Section 2 contains an analysis of the impacts of oil prices to commercial passenger operations. Section 3 contains an analysis of the impacts of oil prices to cargo operations. Section 4 contains an analysis of the impacts of oil prices to general aviation operations. Finally, Section 5 discusses the oil price impacts to the U.S. economy. The findings of the report are summarized in the following paragraphs.

Airline Impacts and Findings

1) There is a strong correlation between airline mission fuel efficiency (ASM and RPM per gallon) and fuel price. There is ample evidence that airlines adopted new operational strategies to reduce total fuel burn for the same amount of traffic. However, investment in new aircraft appears to have slowed when fuel prices increased after 2004. This finding provides empirical evidence to the findings of Winchester et al. (2013) who argue that a climate policy could reduce investment in new aircraft. Therefore, during future fuel price increases, stakeholders could consider mechanisms to ensure airline investment in new aircraft.

2) Between 1991 and 2001, mission fuel efficiency remained relatively stable, while fleet fuel efficiency increased. This shows that during this period, even though airlines were improving their fleet performance, likely through new aircraft acquisition, the fleet was not operated optimally from a fleet fuel efficiency viewpoint.

3) It was found that mission fuel efficiency increases were driven, in part, by cruise speed reductions. The weighted average cruise speed reduction for U.S. airlines was measured to be 1.1% in the period between 2004 and 2011. During the same six-year period, jet fuel prices increased by 91%. This suggests that airlines adopted optimized cost index values given the dramatic changes in operating cost structure. Fuel cost as a percentage of total operating cost increased from around 15% to nearly 40% in 2011. A number of additional operational changes leading to increased fuel efficiency are identified through airline interviews. It was found that all airlines surveyed have fuel management programs, or are developing such a programs. Operational efficiency and finances are identified as the motivation of such programs.

4) Three fuel prices scenarios were projected to 2025. Fuel price increase was found to decrease airline traffic. The magnitude of the impact on airline traffic ranged between 0% (low high oil scenario) and 6.5% (high oil price scenario). Model results show important links in GDP and fuel price in relation to traffic. GDP growth can increase oil prices, but also dampen the impact of fuel price increase.

5) In terms of network and schedule, it was found that increasing fuel price may have slowed U.S. domestic capacity growth and reduced short stage length traffic between 2004 and 2007. However, there appears to have been little impact on network structure and airport connectivity. This was measured by calculating the Gini coefficient of the U.S. domestic network, and the degree of connectivity of U.S. domestic airports.

Air Cargo Carrier Impacts and Findings

1) In the past decade, air cargo carriers operating jet aircraft made a clear decision to modernize and increase the size of the aircraft in their fleets. This is clearly reflected in the traffic data for United Parcel Service (UPS) and Federal Express (FedEx). It cannot be shown with the data available or via statistical analysis, if these changes were in direct response to an increase in fuel price. However, given that the cost of jet fuel can easily exceed 25% of operating costs of an air cargo carrier, it is safe to assume that increases in fuel price were a major consideration by cargo carriers when making fleet renewal changes.

2) Fleet composition changes did not lead to major changes in the network structure for either UPS or FedEx. The minor spatial traffic level changes across each carrier's network segments, over time; indicates that both FedEx and UPS were able to make substantial fleet overhauls without having to adjust their network structures. Large air cargo carriers were able to integrate these larger aircraft, carrying more cargo, into their existing network structures.

3) The forecast produced in our analysis, shows that air cargo RTMs will increase substantially in the next decades, regardless of differences in GDP growth or fuel price changes. The salient issue is how much these traffic levels could change, given a particular GDP and or fuel price conditions. Furthermore, given the entrenched consistency of FedEx and UPS network structures, it is likely that the air cargo traffic growth will take place as an expansion of traffic along existing segment pairs, rather than a major reworking, and redirecting, of the cargo carriers' network structure.

General Aviation Impacts and Findings

1) A series of models were developed to estimate the impacts of oil prices to general aviation operations. Models developed include: a) an econometric airport-level demand model to forecast itinerant and local operations; b) a logistic airport-level market share model to predict the share of GA operations by engine type; c) a two-level GA demand distribution model to distribute operations among a set of airports; and d) econometric nationwide models to estimate the number of hours flown by GA engine type.

2) Using the airport-level demand models developed and given other factors fixed (including income), a 10% increase in fuel price would produce a 5.2% reduction in the number of local general aviation operations.

3) Using the airport-level demand models developed and given other factors fixed (including fuel price), a 10% decrease in per capita income would translate into an 11.1% increase in the fuel-to-income ratio and produce a 5.8% decrease in the number of local general aviation operations.

4) Using the airport-level demand models developed and given other factors fixed (including income), a 10% increase in fuel price would result in a 4.3% decrease in the number of itinerant general aviation operations.

5) Using the airport-level demand models developed and given other factors fixed (including fuel price), a 10% decrease in per capita income would translate into an 11.1% increase in the fuel-to-income ratio and produce a 4.8% decrease in the number of itinerant general aviation operations.

6) Considering the EIA 2012 oil price reference case scenario, the models developed predict a decline in total number of GA operations at a rate of 0.8% per year until the year 2015. The decline applies to the sum of local and itinerant operations for all GA aircraft.

7) Considering the EIA 2012 oil price reference case scenario, the models developed predict a modest growth of 0.9% and 1.1% for itinerant and local operations after the year 2016. At such growth rates, the recovery of total local GA operations is expected to reach year 2010 levels in the year 2023. It is important to mention that the more recent EIA 2013 trends would tend to accelerate this recovery by 5 years. This indicates that aviation activity as measured by GA local operations is very sensitive to fuel price forecasts.

8) While the general aviation trends in aircraft utilization have been in the decline in the past decade, there have been periods of time when the opposite trend has been observed. For example, in the period 1992-1999 a positive growth in GA operations was observed when the GDP grew by 32% (in constant \$2000 dollars) coupled with a very low fuel-to-income ratio. According to long-term economic forecasts (including those of EIA), the fuel-to-income ratio parameter is expected to peak in the year 2015 and then decrease modestly over time thus causing a potentially favorable trend for GA activity.

9) Under EIA reference oil price conditions, the projections of GA traffic activity presented in this report, are less optimistic than those presented in the FAA Aerospace Forecast 2013-2033. The study projects a weak recovery in GA operations after the year 2016 because the price of fuel compared to the per capita income ratio is expected to peak in 2015 based on EIA 2012 projections. New EIA oil price projections could accelerate the weak recovery by one year.

10) Nationwide models developed to evaluate the impacts of fuel price on GA aviation activity provide similar trends as those predicted using airport-level models. For example, a 10% increase in fuel-to-income ratio would yield a 2.4% reduction in the number of hours flown by piston-powered aircraft. Similarly, the same nationwide model predicts that a 10% increase in the fuel-to-income ratio would translate to a 0.8% decrease in hours flown by turboprop and turbojet aircraft nationwide.

Oil Price Impacts on the U.S. Economy

1) Without any improvements in fuel efficiency, a 45 percent cumulative increase in the real price of oil between 2010 and 2020, compared with the 2012 EIA reference oil price, would result in an 11 percent increase in air fares for domestic and international air passenger transportation and an 11.5 percent increase in the price of air cargo services. If air passenger and air cargo carriers respond to higher oil and fuel prices by reducing fuel consumption per unit of output (e.g., ASM for passenger carriers) by the levels estimated in Section 2 of the report, this would reduce the increase in air fares by 2.7 to 3.0 percent for passenger transportation and by 2.8 to 3.1 percent for air cargo transportation. Thus, changes in flight operations, such as cruise speed, and the use of more fuel efficient aircraft could lead to significant reduction in air fares in the face of much higher oil prices.

2) The reduction in airfares from increased fuel efficiency would not only benefit air carriers, but also industries related to travel and tourism. Without improvements in aircraft fuel efficiency, domestic leisure travel would decrease by 6.1 percent as the cost of travel (e.g., air fares, motor fuels) increase due to higher oil prices. Similarly, international leisure travel by U.S. residents would decrease by 6.5%.

3) By adopting strategies that improve fuel efficiency, the reduction in domestic leisure travel would be 0.2 to 0.4 percent less. While the change in domestic travel is small on a percentage basis, it represents a significant change given that U.S. residents spent \$427.7 billion on domestic travel and tourism in 2010. The specific industries most affected include accommodation; amusement, gambling, and recreation; travel agents; and performing arts.

4) Adopting strategies that improve fuel efficiency also have positive macroeconomic effects on the U.S. economy. Improvements in aircraft fuel efficiency lead real GDP to be between \$4.0 and 7.4 billion higher in 2020 when compared to an alternative with no improvement in fuel efficiency. Aggregate U.S. welfare, as measured by equivalent variation increases between \$15.6 and \$35.0 billion on a discounted basis between 2010 and 2020 for the alternatives with increases in fuel efficiency compared with the alternative with no increase in fuel efficiency.

1 Introduction

Jet fuel prices have significantly increased during the past decade resulting in fuel cost becoming the airline's primary operating cost. Similarly, fuel prices for general aviation users constitute between 25-45% of the life cycle cost of owning and operating a small aircraft. Figure 1-1 shows historic jet fuel prices between 1991 and 2012. Jet fuel prices for general aviation aircraft are typically twice the values shown in Figure 1-1. Jet fuel prices remained relatively low and stable between 1991 and 2004. Between 2004 and 2012 fuel prices significantly increased. Some forecasts show this trend continuing (EIA, 2012). Given that the air transport system enables economic growth and provides significant social benefit, it is important that policy makers and the industry are informed of past changes and likely future impacts driven by increased fuel prices. The prominence of this issue for policy makers is highlighted by the recent FAA Modernization and Reform Act of 2012, which explicitly requires the execution of a fuel price study (FAA, 2012). Further, future market-based carbon constraint policies may increase the effective price of jet fuel (Winchester et al., 2013). Understanding the operational impact of fuel price increase may inform such policies. This report explores how fuel price increases have changed the way airlines (cargo and passenger) operate, particularly during the 2004 to 2012 period. The report also provides some background and models to understand oil impacts to general aviation operations (Section 5).

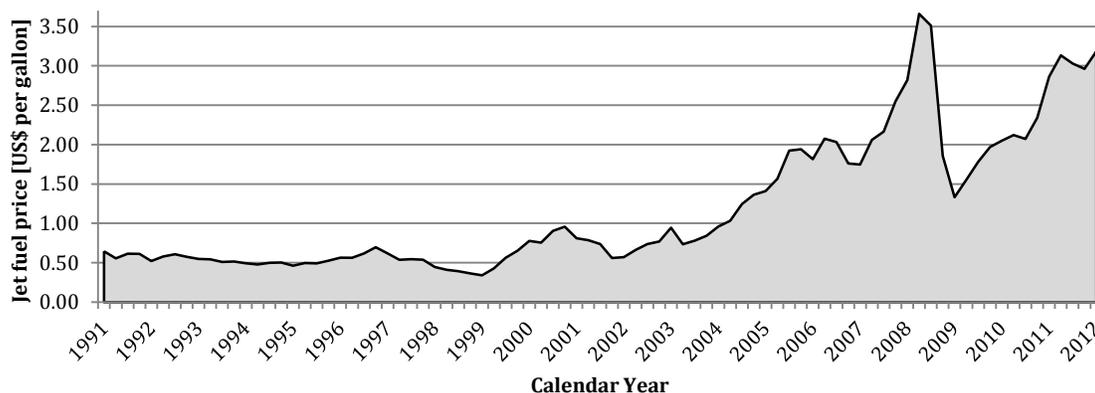


Figure 1-1 Jet fuel prices in the US between 1991 and 2012. (Data source: EIA, 2012).

This report approaches the fuel price issue using the following methodologies: (1) analysis of operations data, (2) industry interviews and (3) modelling fuel price impacts to aviation operators and to the U.S. economy using econometric and general equilibrium models. The report is structured in five sections. Section 2 contains an analysis of the impacts of oil prices to commercial passenger operations. Section 3 contains an analysis of the impacts of oil prices to cargo operations. Section 4 contains an analysis of the impacts of oil prices to general aviation operations. Finally, Section 5 discusses the oil price impacts to the U.S. economy. The report attempts to answer the following questions:

- What are the overall economic impacts of fuel price volatility and increases with respect to commercial aviation, which includes both passenger and freight, and general aviation?

- ⌘ How has the increase in fuel cost impacted air traffic control (ATC) operations and air traffic management (ATM) policies? Moreover, how does ATC/ATM management and industry standard operating procedures factor in the impact of fuel price? How are air navigation service providers (ANSP) held accountable?
- ⌘ What can the FAA do to help airlines and general aviation reduce fuel consumption? Policies? Procedures? Infrastructure investment?
- ⌘ How has the industry reduced fuel consumption to minimize rising costs? Which innovative energy augmenting procedures and policies has the industry adopted?
- ⌘ Are there any new and innovative measures not yet in place that can help the industry reduce fuel consumption?

2 Fuel Price Impact on Airline Operations

To understand the impact of oil prices on airline operations three complementary methodologies were used: (1) analysis of operations data, (2) industry interviews and (3) modelling fuel price impacts. For the analysis of operations data, four airline operational performance areas are explored and related to fuel price: fuel efficiency trends, fleet changes (i.e. fleet efficiency), operational changes (cruise speed), and network and schedule changes. For the industry interviews, structured interviews were conducted with fuel or operations department representatives from four major airlines. In order to get input from other carriers, 21 representatives from 19 airlines were surveyed. For the modelling of fuel price impacts, a partial equilibrium model called the Aviation Portfolio Management Tool for Economics (APMT-E) was used. APMT-E uses a fuel price scenario and compares impacts to a reference scenario. The APMT-E reference scenario largely follows International Civil Aviation Organization (ICAO) forecast for airline traffic to 2050 (ICAO, 2009). Three fuel price scenarios were developed with corresponding GDP forecasts: a high oil price scenario, a short term peak scenario and a climate scenario using a \$25/tCO₂ emissions allowance price (EIA, 2012). Scenarios are forecast to the year 2025.

This section investigates the relationship between fuel price and airline operations. Studies such as Babikan et al. (2002) have explored airline operational measures to reduce fuel burn. However, the relation to fuel price is not explored. Rutherford and Zeinali (2009) and Lee et al. (2001) show that airline fleets have become more efficient, although the rate of improvement has decreased. However, these authors track fleet fuel efficiency, which excludes ground operations, taxi and take-off. Azzam et al. (2010) explore network topology and fuel efficiency, but also do not relate this to fuel price.

Another string of literature comprises studies that use partial equilibrium models to examine industry-wide impacts of policy-related fuel price increases. Winchester et al. (2013) investigate impacts of a climate policy in the US and find evidence that such a policy could, under certain assumptions, slow down fleet renewal. In 2009, ICAO used a partial equilibrium model to determine how fuel price scenarios would influence airline demand and supply (ICAO, 2009). Other reports, such as Malina et al. (2012) focus on policy-related cost increases and implications for airlines and passengers. Morrison (2012) focuses on the fuel price question using a partial equilibrium model but limits the analysis to a parametric impact assessment.

The relationship between fuel price and airline operations between 1991 and 2011 was investigated. Operational optimization can increase airline fuel efficiency and therefore reduce unit fuel cost, leading to lower total fuel cost, for a set amount of traffic. Increasing fuel price could therefore provide a cost incentive to change operations. In this section three operational performance areas are studied: fuel efficiency, operations (cruise speed analysis) and network and schedule. Data was obtained from a variety of sources and is referenced where discussed.

2.1 Fuel Efficiency and Fuel Price

The relationship between airline fuel efficiency and fuel price was investigated. Fuel efficiency is an interesting metric to track in relation to fuel price because it links airline operations to airline fuel cost. This section tests the hypothesis that increasing fuel prices after 2004 are correlated to increased fuel efficiency.

In order to track fuel burn during all phases of flight, and therefore capture all means of fuel efficiency improvement, a metric called *mission fuel efficiency* is used. Mission fuel efficiency is the total number of ASMs or RPMs flown by an airline divided by total fuel consumption. Data was obtained from the Bureau of Transportation Statistics (BTS) Schedule T2 (US Department of Transportation, Bureau of Transportation Statistics, 2012a). The BTS data includes taxi, cruise, takeoff and landing phases of each flight. Table 2.2 contains definitions of mission fuel efficiency. RPM per gallon is related to ASM per gallon by load factor, a measure of the average number of passengers on an airline’s aircraft, divided by the average number of available seats on the airline’s aircraft.

Table 2.1 Fuel efficiency definitions.

Metric	Unit	Definition	Explanation
Mission fuel efficiency	ASM per gallon	System total seat miles flown divided by total fuel consumption	Fuel efficiency including ground operations, landing and takeoff
Mission fuel efficiency	RPM per gallon	System total revenue passenger miles flown divided by total fuel consumption	Fuel efficiency including ground operations, landing, takeoff and aircraft load factor
Aircraft fuel efficiency	ASM per gallon	Instantaneous ASMs per gallon in cruise at optimal velocity and altitude (1/SAR)	Direct measure of optimal technical performance of aircraft at cruise, where most fuel is burnt

This section tests the hypothesis that *mission fuel efficiency* is correlated to fuel price. Figure 2-1 shows mission fuel efficiency (both ASM per gallon and RPM per gallon) for the US fleet for all traffic between 1991 and early 2012 on a quarterly basis. Trends include:

- Between 1991 and 2012 US airlines achieved an annual RPM per gallon improvement of 2.27% p.a., achieving the International Air Transportation Association (IATA) goal of 1.5% p.a. RPM per gallon improvement (IATA, 2009).
- Between 1991 and 2001 fuel prices were relatively low and stable and mission fuel efficiency remained stable. However, RPMs per gallon fluctuated seasonally with passenger demand and had a general increasing because system average load factor increased from 0.58 to 0.76.
- Between 2001 and 2004 fuel price was relatively low and steady, mission fuel efficiency increased after 9/11 and RPMs per gallon increased after 9/11.
- Between 2004 and 2011 fuel price increased, mission fuel efficiency increased, RPMs per gallon continued to fluctuate seasonally with passenger demand and increased because system average load factor continued increased and mission fuel efficiency increased.

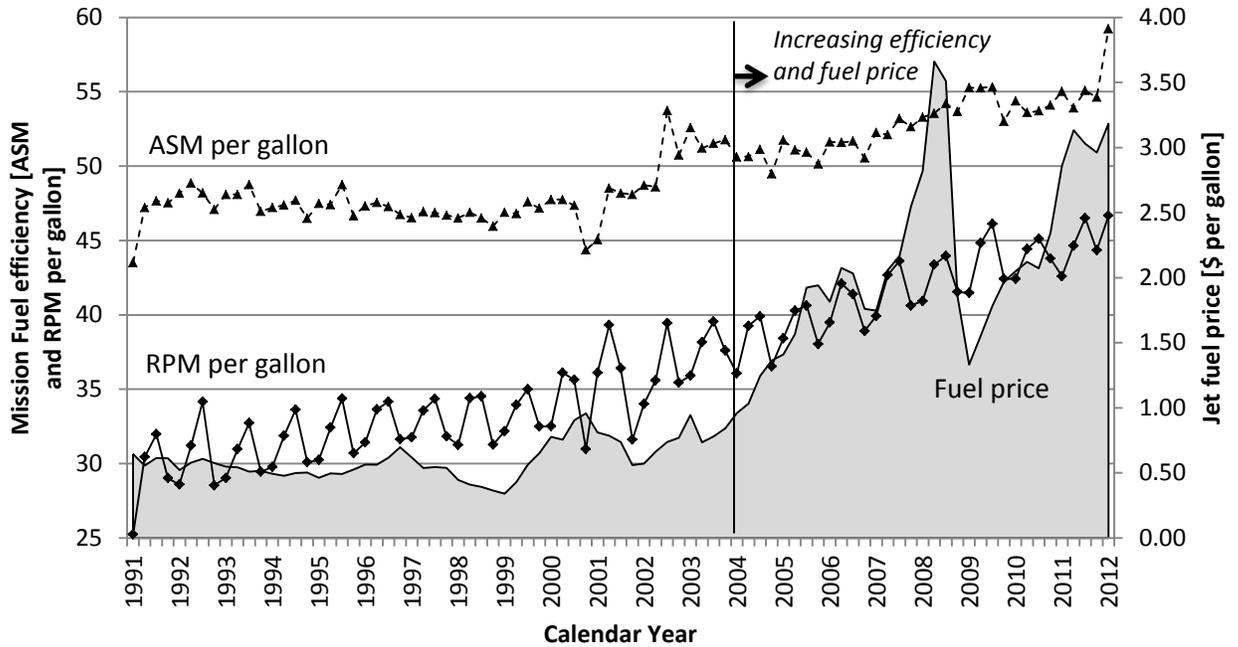


Figure 2-1 US system wide mission fuel efficiency (ASM and RPM per gallon) and fuel price. Quarterly data between 1991-2012. Data source: BTS Schedule T2 and EIA (2012).

In order to further clarify the relationship between fuel efficiency and fuel price, a regression analysis was performed using fuel price and mission fuel efficiency (both ASM and RPM per gallon). The data is plotted in Figure 2-2 with mission fuel efficiency on the y-axis and fuel price on the x-axis.

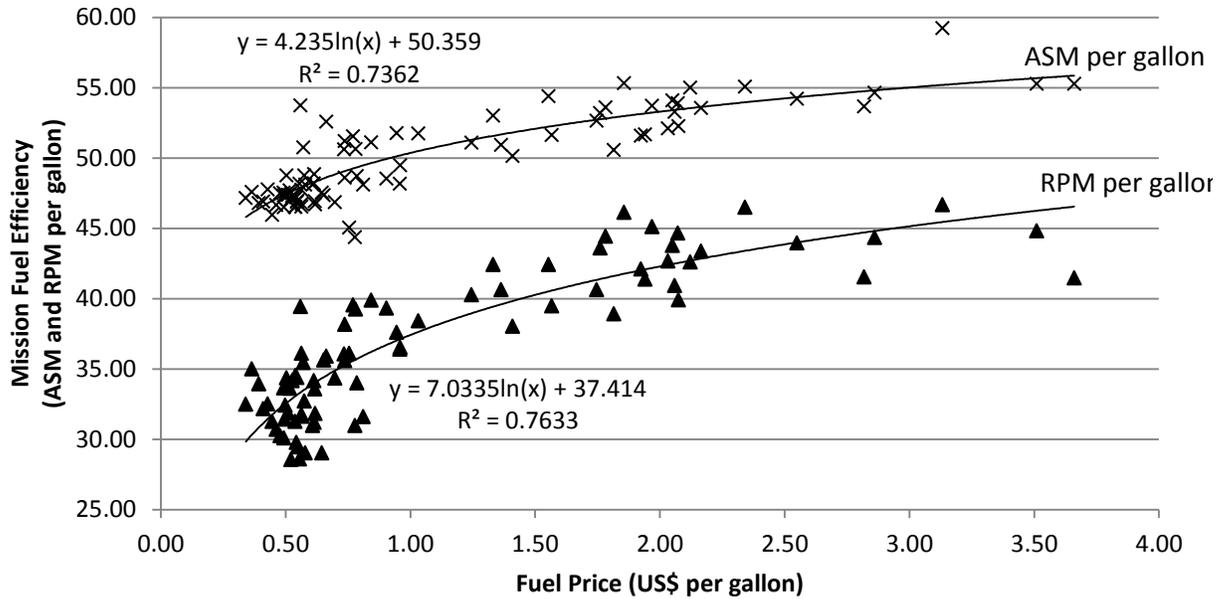


Figure 2-2 US system wide mission fuel efficiency (ASM and RPM per gallon) (y axis) versus fuel price (x axis). Quarterly data between 1991-2012. Data source: BTS Form 41 Schedule T2.

Each point in the chart is a quarter of a year between Q1 1991 and Q1 2012. A least squares error approach was used to find the best-fit model relating fuel price to mission fuel efficiency. Best fit of mission fuel efficiency versus fuel price was found when mission fuel efficiency was shifted by three quarters of a year into the future for a given fuel price. This suggests that after an increase in fuel price, airlines take three quarters of a year to change operations to achieve increased fuel efficiency. The correlation coefficient, r^2 , is 0.73 and 0.76 for mission fuel efficiency, ASM per gallon versus fuel price and RPM per gallon versus fuel price, respectively. This is a reasonably good correlation, meaning that fuel price can account for much of the variability in observed airline fuel efficiency. These models are shown in Equations 2.1 and 2.2.

$$\frac{ASM}{gallon_{Q+3}} = 0.74 \ln P_Q + 50.36 \quad (2.1)$$

$$\frac{RPM}{gallon_{Q+3}} = 7.03 \ln P_Q + 37.41 \quad (2.2)$$

This section has established that there is a reasonably good correlation between airline mission fuel efficiency and fuel price. This supports the hypothesis that fuel price and mission fuel efficiency increased after 2004 because of increasing fuel prices. The following sections investigate fleet renewal and cruise speed reduction as possible explanations for increased mission fuel efficiency after 2004. For the rest of this report, mission efficiency refers to ASM per gallon.

2.2 Fleet Composition Change

In order to understand the increase in observed mission efficiency after 2004 (shown in Figure 2.2) this section explores US airline fleet composition change between 1991 and 2011 as a possible cause. Airlines could increase mission fuel efficiency by improving the efficiency of operations such as single engine taxi or optimized cost index. Alternatively newer, more fuel efficiency aircraft could be used to

improve mission fuel efficiency. In order to monitor technological changes in aircraft, this section uses a metric called *fleet fuel efficiency* which is the number of seat miles travelled per gallon of fuel by an aircraft at optimal altitude and velocity. Fleet fuel efficiency is defined in Table 2.1. Fleet fuel efficiency is inversely proportional to aircraft Specific Air Range (SAR). Because this metric does not include operational factors such as taxi, landing, tack-off and load factor, it allows a direct measure of technical performance of the fleet at cruise, where most fuel is burned¹.

Fleet composition change is measured by evaluating the weighted average optimal performance characteristics of aircraft in the fleet. Optimal performance characteristics determine aircraft fuel efficiency in cruise at optimal altitude and velocity. As fleet composition changes, the weighted average optimal performance characteristics of the fleet changes, and therefore fuel efficiency.

Fleet fuel efficiency, in year n is calculated as shown in Equation 2.3, where y is aircraft type, SAR is aircraft specific air range in miles travelled in cruise at optimal speed and altitude per gallon of fuel consumed and S is the average number of seats on aircraft type y .

SAR and seating data for the US fleet was obtained from Piano-X aircraft performance database (Piano, 2012). US system ASMs flown by aircraft type was obtained from BTS, Form 41, Schedule T2 (BTS, 2012). The weighted average fleet fuel efficiency in each year was calculated until seat miles flown captured 99% of total seat miles flown in a given year².

$$\text{Fleet fuel efficiency}_n = \sum_{\%ASM=0}^{\%ASM<0.99} \left\{ \%ASM_{y,n} * \frac{1}{SAR_{y,n}} * 1/\overline{S_y} \right\} \quad (2.3)$$

Lee et al (2001) find that fleet fuel efficiency has improved between 1.2 to 2.2% per year. Therefore if an airline increases the proportion of new aircraft in its fleet, it can be expected that fleet wide fleet fuel efficiency should improve. Similarly, grounding or retiring older, less efficient aircraft could also improvement in system fleet fuel efficiency. Yearly fleet fuel efficiency between 1991 and 2011 is plotted in Figure 2-3. For comparison, yearly mission fuel efficiency is also plotted.

¹ Fleet fuel efficiency is inversely proportional to the metric energy intensity, used in the academic literature (Lee et al., 2001 and Babikan et al., 2002). Energy intensity uses the units joule per available seat kilometer. This report renames this metric as aircraft fuel efficiency and uses the unit ASM per gallon to be consistent with the operations literature and airline practice.

² In Form41 data, each year between 30 and 40 aircraft flew more than 99% of ASMs while more than 200 aircraft flew 100% of ASMs. Most of these tail-end aircraft were either non-fixed wing, or small propeller aircraft. We therefore summed to 99% instead of 100% because of lack of specific air range data, and the very small impact these aircraft had on optimal energy usage.

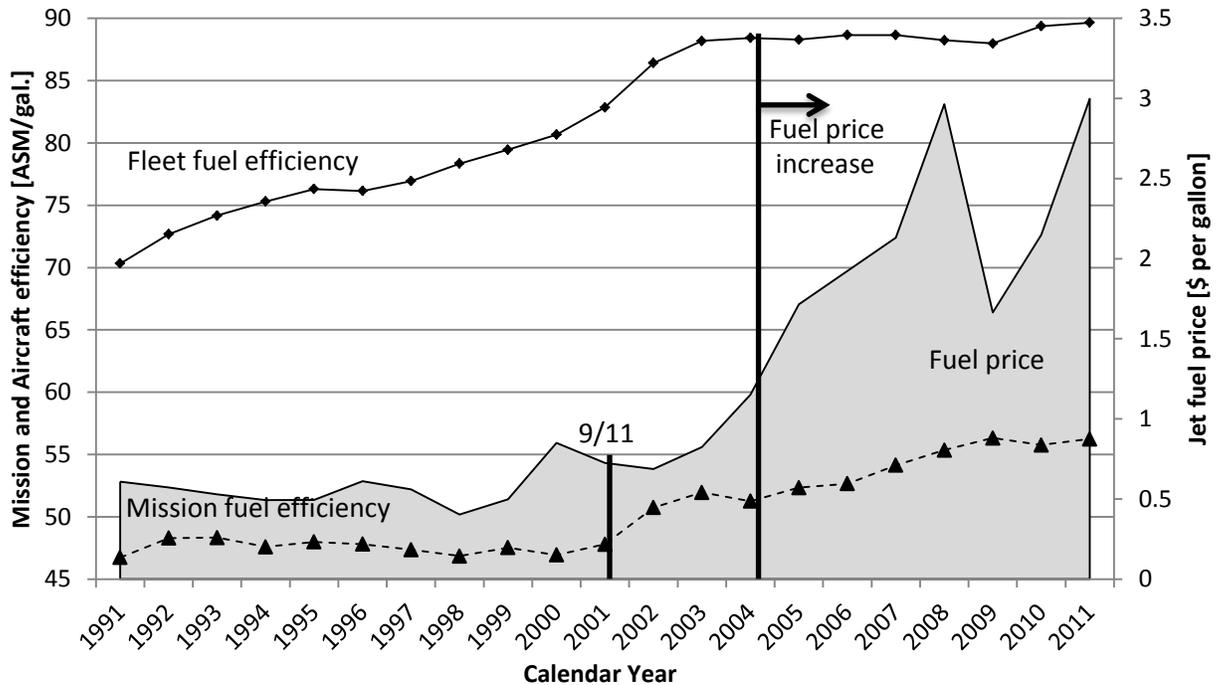


Figure 2-3 Mission and aircraft fuel efficiency and fuel price. Data source US DOT Form 41 via BTS, Schedule T2, EIA (2012), and aircraft performance data from PIANO-X (Piano, 2012).

Several trends can be observed in Figure 2-3.

- Between 1991 and 2001: mission fuel efficiency remained relatively stable, while fleet fuel efficiency increased. This shows that during this period, even though airlines were improving their fleet performance, likely through new aircraft acquisition, the fleet was not operated in a way which utilized the increasing fleet fuel efficiency. This could be explained by the relatively low and steady fuel price during this period. For example flying faster than the optimal fuel burn velocity saved time, at the cost of burning more fuel.
- Between 2001 and 2003: mission fuel efficiency and fleet fuel efficiency both increased suggesting major shifts in airline fleet composition after 9/11.
- After 2004: mission fuel efficiency began to increase, although fleet fuel efficiency remained steady.

As discussed in the previous paragraphs, increase in fuel price is correlated to increase in mission fuel efficiency. However, the above results, shown in Figure 2-3, suggest that airline investment in aircraft performance, as shown by fleet fuel efficiency decreased after 2004. A reason for this observed trend could be that high fuel prices limit airline capital investment capacity. Evidence for this conclusion exists in the literature. Winchester et al. (2013), using a partial equilibrium model of the airline industry, forecast that climate policy, which effectively increases the price of jet fuel, would result in a less efficient fleet relative to a reference scenario. The above finding provides empirical evidence for the trend of a slowing in fleet fuel efficiency when fuel prices increase.

The following section investigates ways airlines changed operational behavior to increase mission efficiency. In particular changes in cruise speed are explored.

2.3 Cruise Speed Change

The previous section established that when fuel price increased after 2004, the rate of technological efficiency improvement decreased, while mission fuel efficiency improved. In order to understand the ways airlines increased mission fuel efficiency, this section explores reductions in cruise speed as a possible explanation.

When an aircraft flies faster than its optimal cruise speed at a given altitude, it burns more fuel than optimal speed and altitude (Boeing, 2012). Historically commercial aircraft have flown faster than fuel-efficient optimal speed because of the value of time related cost. Lovegren (2011) estimates U.S. domestic aircraft fly approximately 8% faster than cruise optimal fuel burn rate. An explanation of this behavior is the value of time. Flying faster reduces time related cost, at the trade-off of increased fuel cost. Airline cost index, the ratio of fuel cost and time cost, captures this trade-off. The cost index trade-off calculation is implemented in most flight management systems, given an airline's time cost and fuel cost on a particular route and aircraft type.

The average U.S. carrier, domestic service, filed ground speed was compared between the periods 1st October 2004 to 30th September 2005 and 1st January 2011 to 31st December 2011. Between these periods, jet fuel price increased by 91%, providing a natural experiment to test the hypothesis that a fuel price increase will result in cruise speed reduction. Data for this analysis was obtained from the Enhanced Traffic Management System (ETMS) database (FAA, 2009) which contains daily average filed ground speed by aircraft type and airline.

Figure 2-4 shows a particularly clear example of an airline reducing cruise speed between 2004/2005 and 2011. The data shows Southwest Airline's B737-300 fleet filed ground speed, averaged on a daily basis. Yearly fluctuations are related to seasonal changes. Between 2004/2005 and 2011, jet fuel prices increased by 91%, while Southwest Airline's B737-300 fleet average filed ground speed decreased by 1.6%. Given a reciprocal relationship between speed and fuel burn, this could translate into more than 1.6% reduction in fuel burn over this period.

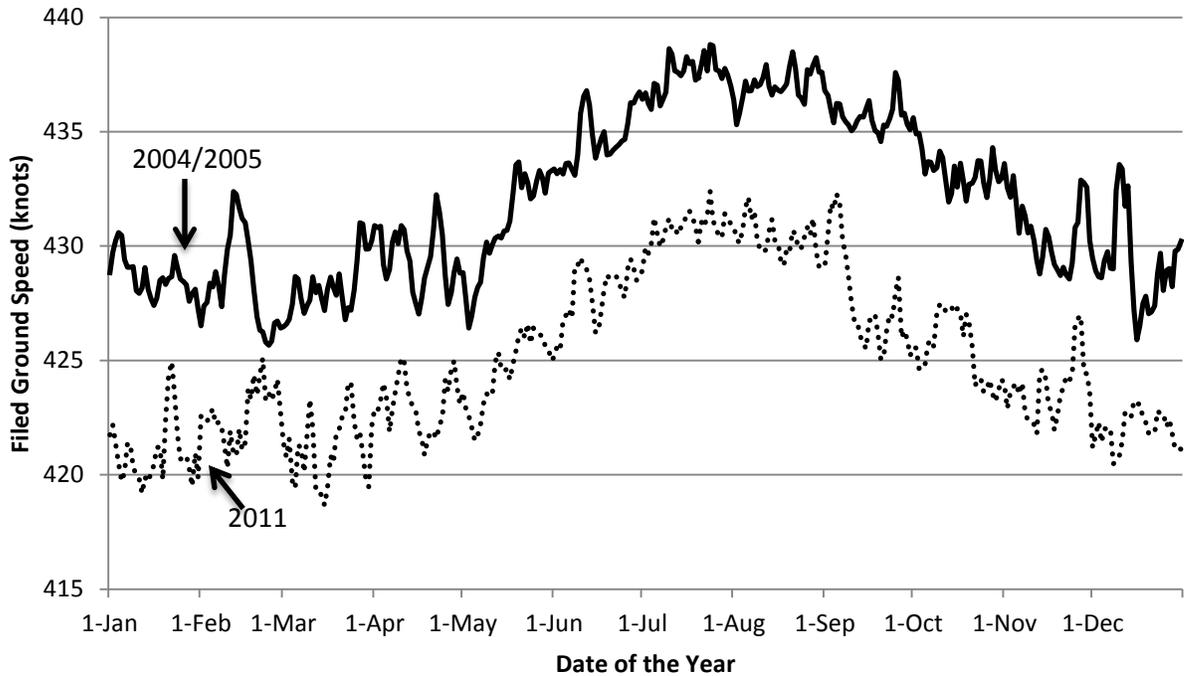


Figure 2-4 Southwest Airlines B737-700 speed comparison between 2004/2005 and 2011. Data Source: FAA Enhanced Traffic Management System (ETMS, 2012).

This analysis was extended to seven major US airlines: Southwest, Airtran, Continental, Delta, Jet Blue, America West and American Airlines³, representing 26% of total US ASMs flown in 2004. Only aircraft types present in the fleet in both 2004/2005 and 2011 were included in the analysis. For America West, only aircraft in the fleet after the merger with US Airways were used. A weighted average cruise speed was calculated by multiplying the percentage change in filed ground speed for an aircraft type by the number of operations performed by that aircraft type, divided by total airline operations. All aircraft types were summed to get an airline weighted average change in filed ground speed. Results are plotted in Figure 2-5 for the seven airlines, and the system weighted average.

³ These were airlines for which we could obtain filed ground speed data

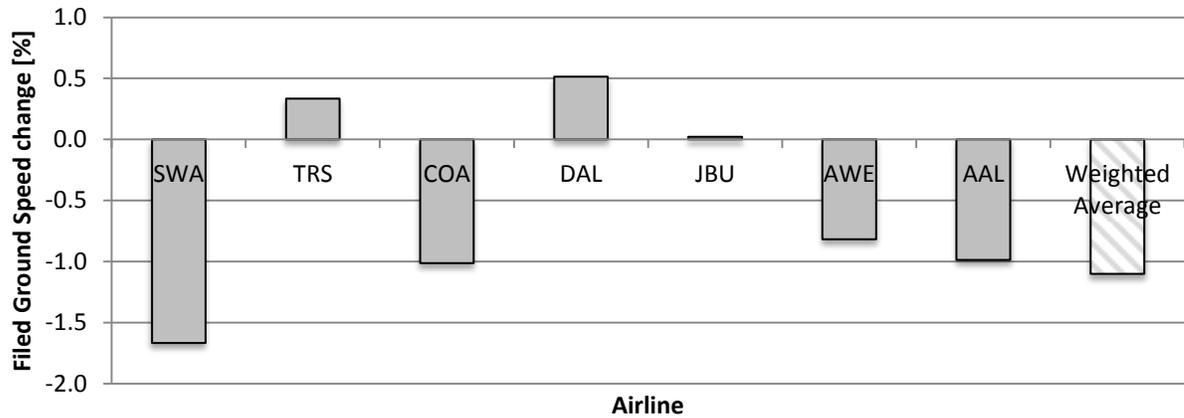


Figure 2-5 Average percentage change in cruise speed changes for seven U.S. airlines and the system weighted average between the period 2004/2005 and 2011. Data Source: FAA ETMS (2012).

The weighted average cruise speed reduction for these seven airlines was 1.1% between the 2004/2005 and 2011. During this six-year period, jet fuel prices increased by 91%. This section has established that part of the observed increase in mission fuel efficiency after 2004 was because aircraft were being flown closer to the optimal cruise speed. The following section explores changes in airline network and schedules.

2.4 Network and Schedule Change

This section explores the impact of increased fuel price on airline network and schedules. In particular impact on capacity, stage length and network structure are examined. Figure 2-6 shows U.S. domestic capacity (ASM) and traffic (RPM) between 1995 and 2011. The source of data used in Figure 2-6 was obtained using BTS form 41, schedule T2. This chart shows evidence of fuel price increase impacting capacity growth between 2004 and 2007.

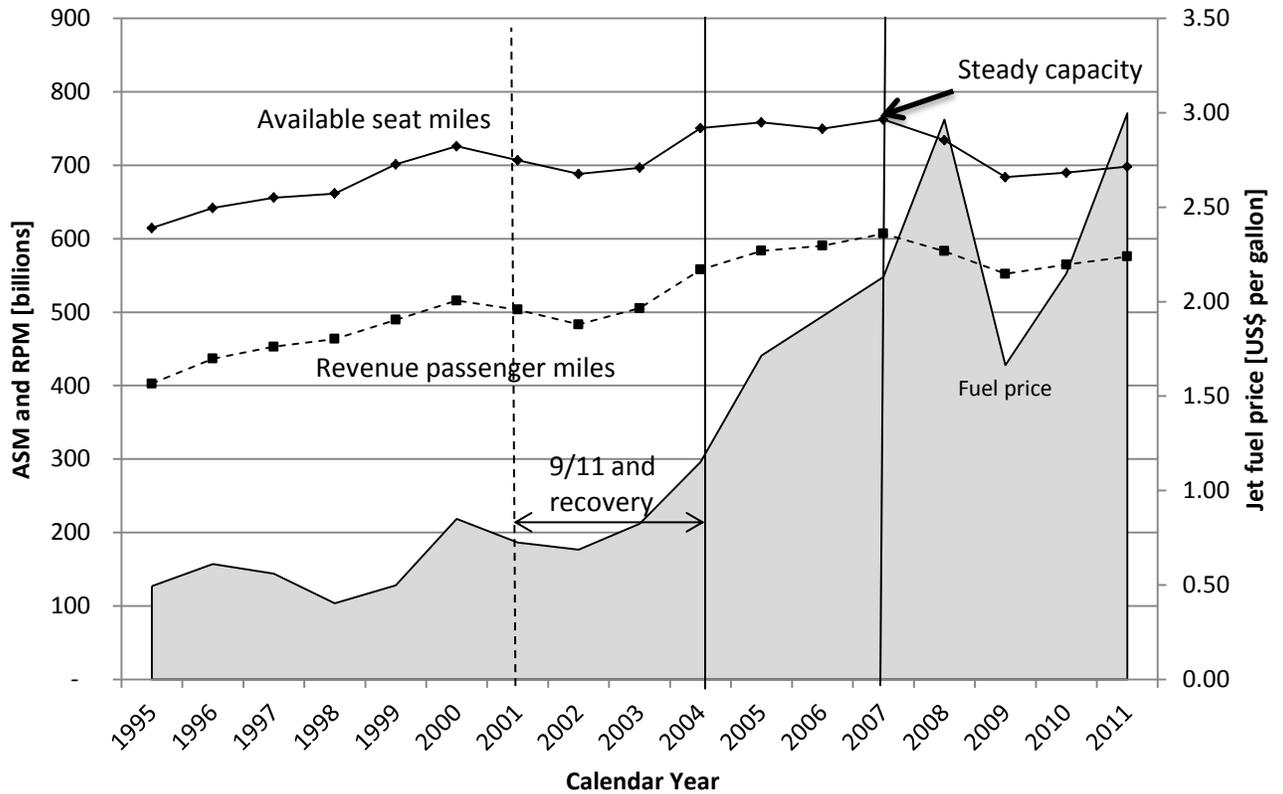


Figure 2-6 U.S. domestic ASM and RPM and fuel price. Data source: BTS Form 41 Schedule T100 and EIA (2012).

By 2004, the industry appears to have recovered from 9/11. Both ASMs and RPMs had increased to above pre-9/11 levels. Further, RPMs normalized by GDP, as shown in Figure 2-6, had increased to pre 9/11 levels of around 45 RPMs per \$1000 of GDP. However, although the industry appeared to have recovered from 9/11 by 2004, ASMs did not increase between 2004 and 2007. This was evident, even though U.S. GDP grew significantly by 7.8% and RPMs by 8.8% between 2004 and 2008, ASMs only grew by 1.6% as shown in Figure 2-7. Between 2004 and 2007, jet fuel prices increased by 85%. This evidence suggests that airlines restrained capacity growth between 2004 and 2007 because of increased fuel prices.

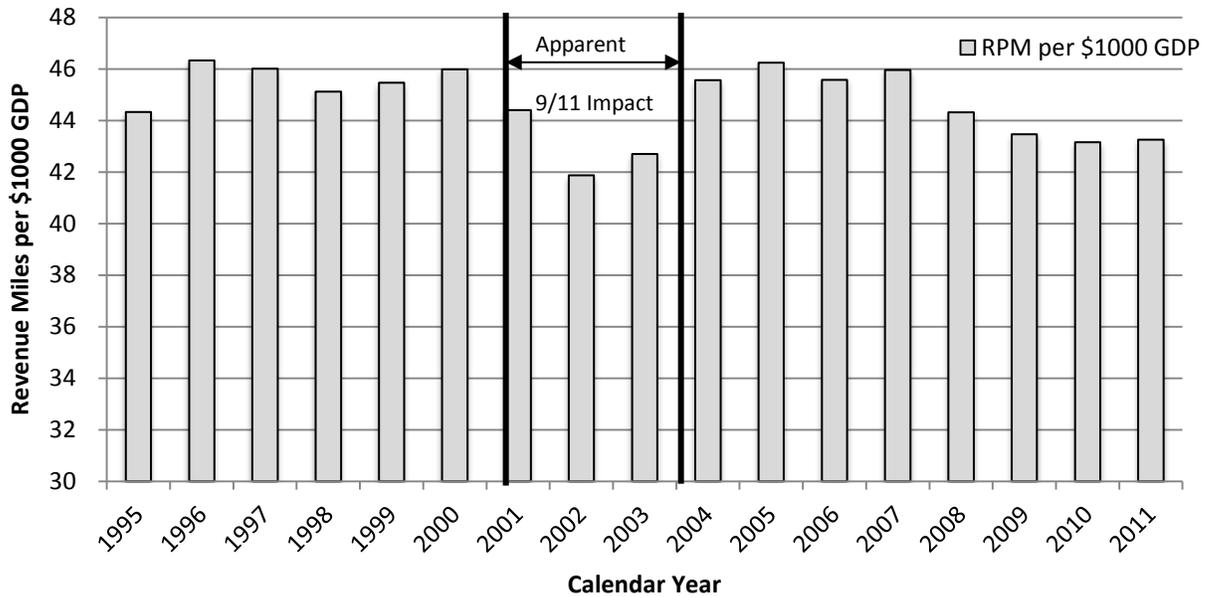


Figure 2-7 U.S. Domestic traffic normalized by U.S. gross domestic product (GDP). Data source: BTS Form 41 Schedule T100 and EIA (2012).

2.5 Stage Length and Network Structure

This section explores the impact of fuel price increase on airline network structure. Between 2003 and 2011, there has been a significant decrease in traffic on relatively short stage lengths. Figure 2-8 shows passengers by stage length for the U.S. domestic and international market. The chart shows that stage lengths of less than 500 miles were most significantly impacted, decreasing by 6.31% between 2004 and 2011. All other stage length categories grew during this period, except the category 1500-1999 miles, which decreased by 2.97%. In 2011, for the first time between 1995 and 2011, an equal number of passengers were moved on the stage length category of 500-999 miles as the less than 500 miles stage length category.

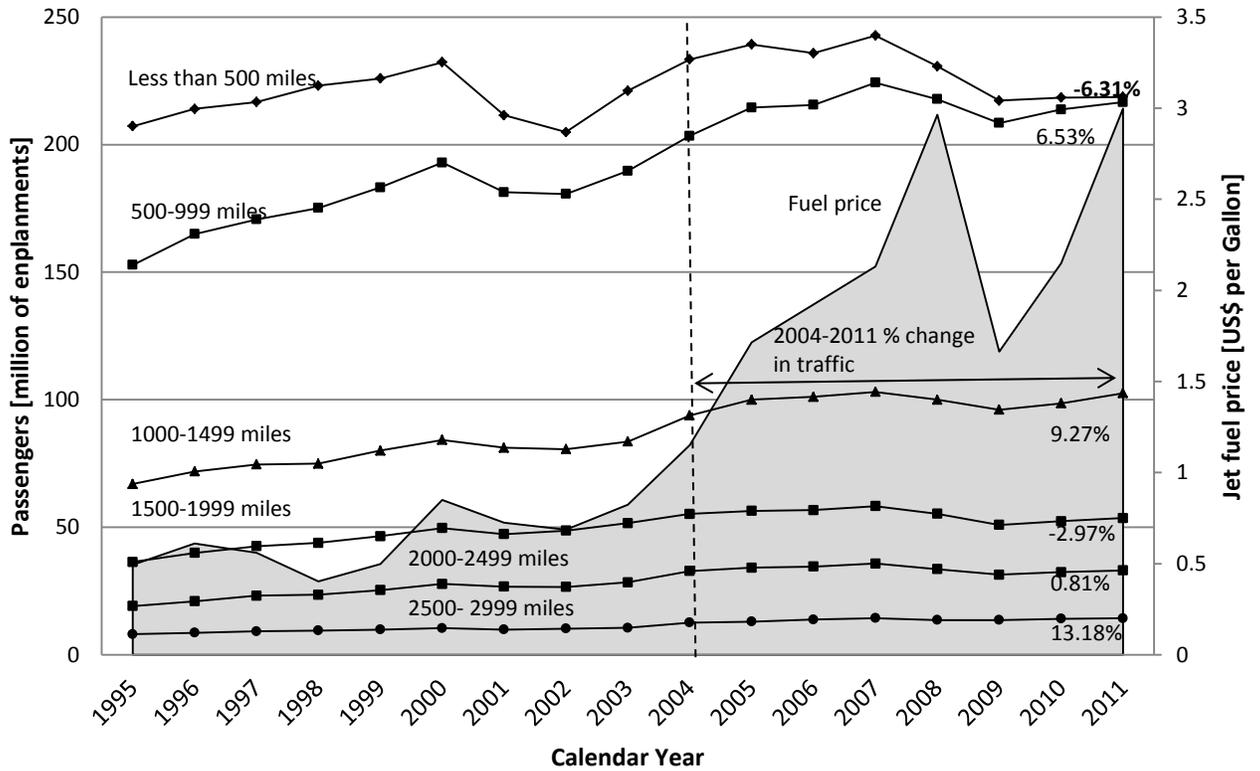


Figure 2-8 U.S. domestic and international passenger enplanements. Data source: BTS Form 41 Schedule T100 and EIA (2012).

Although shorter stage lengths appear to be most impacted, analysis of BTS T100 data (BTS, 2012c) suggests that the structure of the U.S. domestic network remained largely unaffected from increasing oil prices. To measure network structure changes, Gini coefficient, G , of the U.S. domestic network, is calculated, as shown in Equation 2.4 and plotted in Figure 2-9. The Gini coefficient is a measure of network eccentricity. A coefficient of 1 would be a perfect hub and spoke network, and a coefficient of 0 would be a perfect point-to-point network. A coefficient in-between would be a mixture of these two network types. In Equation 2.4, y is the number of seats per week at airport i or j , and n is the number of airports in the system. U.S. airports that are not connected to the U.S. domestic network were excluded.

$$G = \frac{1}{2n^2\bar{y}} \sum_i \sum_j |y_i - y_j| \quad (2.4)$$

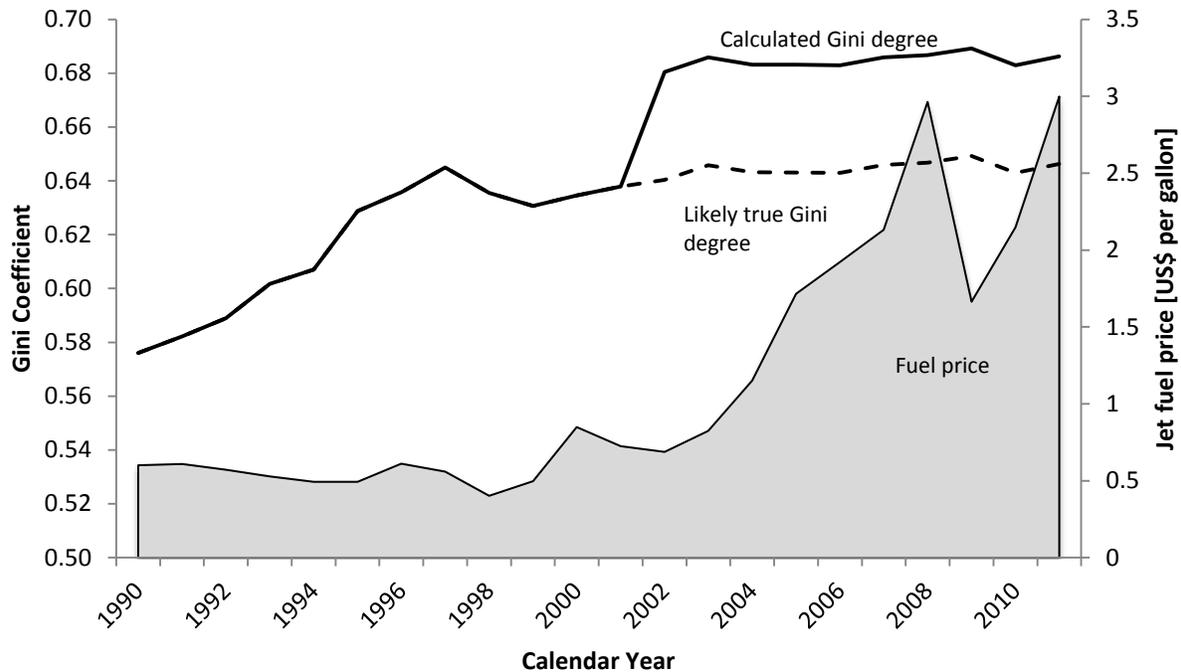


Figure 2-9 Gini coefficient change. Data source: BTS Form 41 Schedule T100 and EIA (2012).

Figure 2-9 shows that after growth in hub strength until 1997, the U.S. domestic network has remained at a relatively high but constant level of eccentricity and does not appear to have been impacted by increasing oil prices.⁴

Further, smaller airports do not appear to have lost much connectivity to the U.S. air transportation system. Connectivity of an airport is the average number of flights needed to reach any other airport in the system. BTS Form 41 schedule T2 data was used to calculate the connectivity of U.S. domestic air transportation system. Categories are based on FAA definitions of Large, Medium and Small hubs, as well as Non-hub and Non-primary airports⁵. Large hubs are the most connected needing on average 1.75 flights to reach any other airport in the system in 2011. Medium airports required on average 2.12 flights, small 2.29, non-hub 2.49 and non-primary 2.74 in 2011. Figure 2-10 shows connectivity between 1991 and 2011. There appears to be little change in airport connectivity, and no obvious relation to fuel price.

⁴ The large increase in Gini coefficient between 2001 and 2002 is because of changes in airline reporting categories. In 2002 small carriers were included in T100 data. The dashed line in Figure 2-10 shows the likely true Gini coefficient after 2001.

⁵ FAA defines hubs as: Large, more than 1% of annual passenger boardings. Medium, At least 0.25%, but less than 1%. Small At least 0.05%, but less than 0.25% Non-hub: More than 10,000, but less than 0.05 Non-hub: At least 2,500 and no more than 10,000.

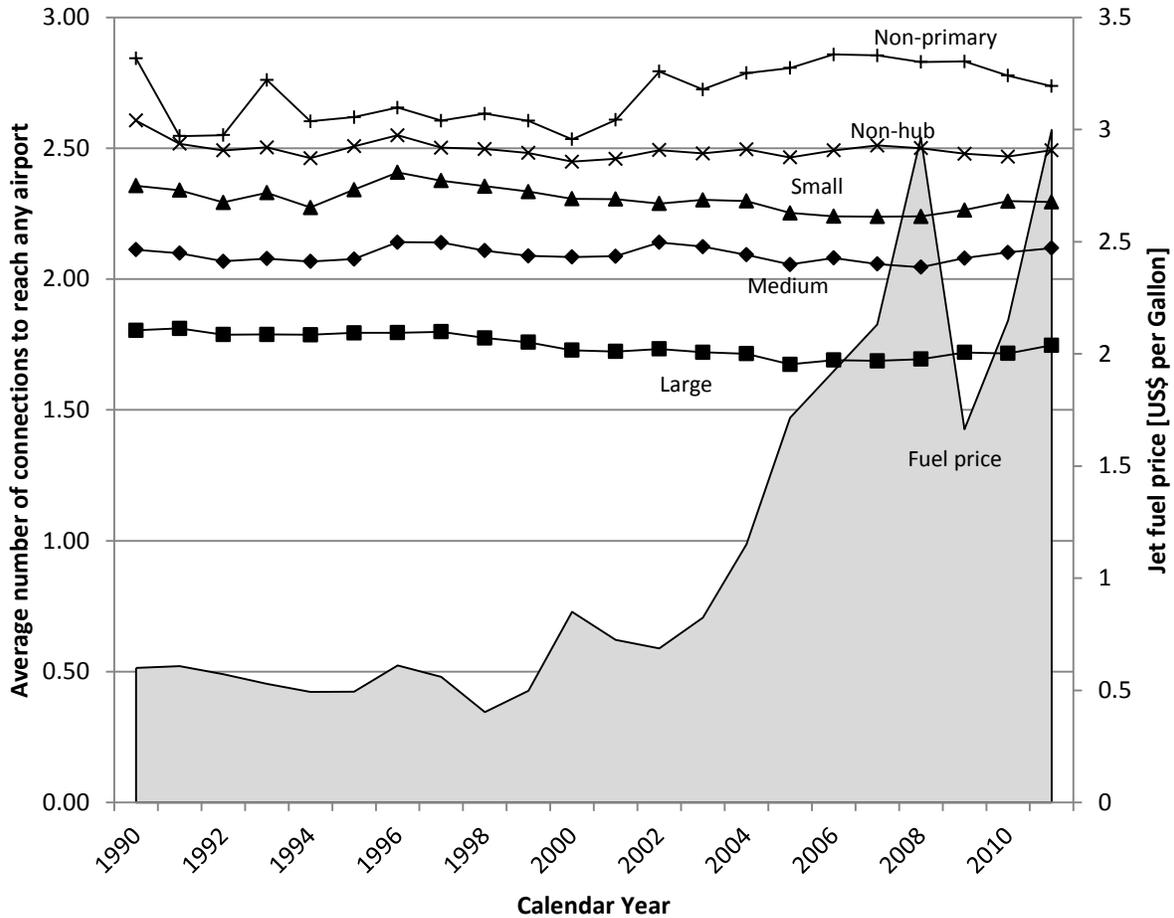


Figure 2-10 Network connectivity change. Data source: BTS (2012) T100 and EIA (2012).

2.6 Limitations of Results

There are several limitations of the above analysis. Primarily, fuel price is only one factor which influences airline fleet choice, operations and network structure and schedule. For example, GDP is a large factor determining airline traffic, schedule and network. Gillen et al. (2002) report income elasticity of air travel at 1.4, meaning GDP growth can have a greater impact of traffic than fuel price change. Traffic is driven by shock events such as 9/11 or the 2008 financial crises. Also, airlines don't necessarily pass on the cost of fuel price increases in the short term. Nevertheless, it is possible to observe general trends in airline operations that provide evidence of airline responses. Combining this data with industry interviews strengthens observations made in this section. The following section presents the results of airline interviews.

2.7 Understanding Fuel Price Impacts Through Airline Interviews

In order to understand how airlines responded to increased fuel prices after 2004, structured interviews were conducted with fuel or operations department representatives from four major carriers (three US and one European) and survey response was recorded from 21 representatives from 19 additional carriers of varying operational sophistication and geographic location. Industry interviews and surveys provide complementary insight to the operations data collected and analyzed in the previous sections. Interview questions were structured around (1) organizational structure change, (2) impact on fleet, (3) impact on operations and (4) impact on schedule and network. The same set of questions was used for each airline, listed below:

- 1. Has the organizational structure of your airline changed in response to increasing fuel prices (i.e. have you created a Fuel Efficiency or similar department)?*
- 2. Have you retired aircraft or added aircraft for because of increased fuel prices?*
- 3. Has your airline implemented any operational strategies (e.g. APU runtimes, single engine taxi, etc) to reduce fuel burn. If so what are they and how effective have they been?*
- 4. Have there been any changes in flight planning regarding fuel efficiency? Have there been any schedule or network changes driven by fuel efficiency considerations?*

Interview responses do to not necessary reflect official airline policy or practice, nor do they provide a comprehensive response of these airlines to increased fuel prices. However, they do provide insight into different operational mechanisms used by airlines to reduce fuel cost. The primary aim of the survey was to understand the extent and motivation of airline fuel efficiency.

2.7.1 Airline Interview Response

Table 2.2 summarizes airline interview results. Airline responses to each topic are ranked on a scale of 0 to 3, as shown in the table key, where 0 means the program does not exist, and 3 means the program exists and is a priority for the airline. A “-“ indicates topics not discussed. Key insights from the interviews are discussed below.

2.7.2 Organizational Structure

All airlines interviewed have some form of organizational structure response to increased fuel prices. The extent of this response varied. The most active response was the creation of dedicated fuel efficiency departments. Two airlines responded in this form, both these airlines formed these groups in 2009/2010, with current group size of between four and seven members. One airline further broke down fuel efficiency tasks into: in-flight efficiency, ground operations efficiency and program planning and efficiency of flight. The other two airlines had collaborative teams comprised of members from multiple departments, who met on a schedule to discuss and plan fuel efficiency measures.

2.7.3 Fleet Efficiency

All four airlines said that fleet modernization through engine and aircraft replacement is the best way to improve fuel efficiency. All airlines were currently in the process of modernizing their fleets to some degree. However, all airlines said that the high cost of fleet modernization limited the extent of action. Three airlines said that aircraft were/ or had been retrofitted with winglets to increase fuel efficiency. One airline said that fuel burn savings from winglets was about 3% for longer flights and 2% for shorter flights. One airline had implemented as Boeing’s performance improvement package. This package includes flight optimization such as drooped ailerons, vortex generator improvement and RAM air system

improvement. It was estimated to improve fuel efficiency by about 1%. Two airlines said that any mechanical measure that increases fuel efficiency is easier to implement, and therefore can result in higher fuel savings, than measures that require behavior change. For example winglets lead to a guaranteed 2-3% fuel savings, while APU usage or single engine taxiing require ground crew and pilot behavior change to achieve fuel savings.

Table 2.2 Interview summary of results.

Airline Fleet	A	B	C	D
Fleet Modernization	***	***	***	**
Fleet Modification: winglets	**	-	***	***
Fleet Modification: other	***	-	-	-
Operational Measures				
Cost Index Adjustments	**	**	*	***
Tugs	**	**	**	**
Single Engine Taxi	**	***	-	-
APU	**	**	**	**
Engine washing	***	**	-	**
Weight reduction: water	***	-	0	***
Weight reduction: seats	***	**	***	-
Weight reduction: other	***	**	-	***
Tankering	-	**	**	-
Reduce contingency fuel	***	*	-	***
Fuel tracking	***	***	***	***
Performance monitoring	***	***	-	-
Schedule/ Network				
Precise scheduling/ routes dropped	3	2	3	-
Schedule timing change because of CI	-	-	-	3
Increased use in regional carriers	-	2	0	-
Key: - not discussed, 0 does not exist, * exists little activity, ** exists active, *** priority for airline				

2.7.4 Operational Measures

All airlines use the cost index to optimize the trade-off between fuel cost and time cost. However, sophistication and extent of the use of the cost index varies widely. For example, one airline implemented a step change to cost index across their entire fleet in a given year when fuel prices began to rise after 2004. This airline was traditionally adverse to new technology, but increasing fuel prices were part of a change in strategy, which included enabling traditionally disabled auto-throttles.

Another airline made far greater use of cost index adjustments to cruise speed. The airline calculates cost index for individual flights, calculated by dispatcher software. Pilots can change the cost index setting if they need to, depending on factors such as weather and take-off delay. Passenger booking information for ongoing flights is provided to flight crew through ACARS and a decision can be made about cost index.

A third airline said that although cost index was a priority, accurate cost index calibration was a challenge. For example, the quantification of delay costs had been inaccurate, impacting cost index calibration. This airline was looking to provide cost index information on a flight level of granularity to pilots. This airline noted that the realized benefits cruise speed reduction was often lower than the modeled savings. For example aircraft mixes at congested hub airports can be a significant factor when deciding whether to increase/decrease cruise speed. Different descent speeds of aircraft can cause issues for air traffic control (ATC). Often, ATC will speed up the slowest aircraft, which minimizes benefits of a slow descent.

Finally, one airline said that they consider a wider range of factors when quantifying the simple equation of time versus fuel cost. For example, they fly old B737-300 or 400 which fly slow compared to B737 NG. However, they need to remain competitive with other airlines who fly the B737 NG, and so they fly their old B737-300/400s faster than optimal cost index.

2.7.5 Tugs

Fuel use during taxi is one of the areas that airlines can increase fuel efficiency. Taxing can be done by aircraft engines, trucks or electric motors on aircraft. One airline was testing all three methods. In particular, they were using electric taxi-bots, which can be controlled by pilots. This airline was also testing using electric motors attached to the landing gear of aircraft. This method has the advantage of decreased engine use, at the cost of increased flight weight.

Another airline is using tugs to reduce taxing needs. For example, when aircraft go into maintenance, or need to be moved between terminals. A third airline had converted ground equipment from diesel to electric to reduce fuel use.

2.7.5.1 Single Engine Taxi

Three airlines had implemented single engine taxiing policy. The fourth airline said that it was looking to implement single engine taxi policy. Two airlines noted the difficulty of enforcing and monitoring single engine taxi policy. The reason for this is because pilot contracts with airlines often limit access to pilot specific performance data, which includes specific thrust settings.

2.7.5.2 Auxiliary Power Unit

The auxiliary power unit (APU) provides backup power to aircraft, and is used primarily when aircraft are parked on the ground. APUs provide power for aircraft instruments, heating and cooling and for starting turbine engines. APUs use between 0.8% and 3.5% of fuel use at cruise (USFAA, 1982, 1995). An alternative to APU usage is for an aircraft to use ground supplied power and conditioned air. However, ground power is not available at all airports (aircraft often require a 400Hz power supply), and has an associated cost of installation or rent.

While all airlines interviewed made use of APUs, the extent of this use varied. One airline said that policy stipulates ground power must be plugged in within 1 min of arrival at gate. While they said that

this policy worked well at their hub airports, it was more difficult to achieve at other airports. The airline also said that ground power is not always included in airport contracts. This can make ground power more expensive than APU usage in some instances. At other times, the quality of the ground supply is not trusted, so APUs are used. In conclusion, they said that APU cost had to be carefully weighed against savings. Another airline said that prior to 2008 or 2009, pilots only used APU. Since then, ground power is used when possible. Each service is either a gate service or not. If it is a gate service airport, the pilot comes in and uses ground power.

The other two airlines said that although they made use of ground power when they could, they had problems negotiating with ground crews and pilots to change behaviour. One of these airlines said that they are beginning to track APU fuel usage data.

2.7.5.3 Engine Washing

Engine washing involves using hot high pressure water to clean residue from aircraft engines. Engine washing reduces exhaust gas temperatures (EGT). Three airlines said that they have active engine washing programs.

One airline said that they perform regular engine washing, done by either Pratt & Whitney, or in house. They said that a reduction of about 10 degrees F can be achieved. They said that for every degree F drop in EGT they expect to save a certain amount of fuel per flight. With a freshly washed engine, the overall savings are about 0.1-0.2%. They said that this was therefore a very cheap and effective measure to increase fuel efficiency.

The other two airlines said that they both have engine-washing programs. One airline installed the program in 2009. This topic was not discussed with the fourth airline.

2.7.5.4 Weight Reduction

Reducing aircraft weight reduces aircraft fuel consumption. All airlines were taking advantage of weight reduction measures to reduce fuel burn. For example, water usage in flight is an area identified as a potential area for savings. Two airlines had very active water reduction programs. One of these airlines has a system to calculate water needed for a flight based on factors such as stage length and load factor. Flight crews get an ACARS message with water needed for the next flight. The pilot enters this value into the flight management system, and water is filled up to that level. The other airline found that for long haul, wide-body flights, the ~400 gallons that were carried on wide body aircraft (for washing hands and flushing toilets) were not entirely used. This airline there also developed a formula for water loading that is a function of load factor and length of flight. They also physically capped the capacity of some of their water tanks. A third airline said that they had looked into water usage reduction, but had decided that customer satisfaction was more important.

Another way to reduce weight is to replace aircraft seats. One airline said that this often has a dual purpose, in that weight is reduced and available seats on an aircraft can be increased which increases potential revenue per flight. Two other airlines had also converted to lighter “slim-line” seats on many aircraft.

Airlines had adopted many other forms of weight reduction. For example one airline had reduced the number of magazines on each aircraft, and made sure they paid for their weight in fuel. They had also provided incentives to caterers to reduce weight. This airline said that although weight reduction fuel efficiency measures are often minor measures, even a 2kg savings on a flight it is huge in an airline with

more than 1000 flights per day. Another airline had also introduced a number of weight reduction measures. For example, if an aircraft didn't fly over water, all watercraft equipment was removed. This airline also removed its GTE air phone system, which led to a weight reduction of between 80 and 100 pounds. Stow bins had been replaced by lighter ones. Further, all paper-based Jeppesen charts were replaced by iPads (which also had other operational advantages). For this airline's B777, it was estimated that the weight reduction program saved a total of 700 lbs. For some fleets, the program even led to a 10-15% weight reduction. Another airline had a similar range of weight reduction measures. For example it had removed ovens on flights that don't need heated food, and everything that went onto the aircraft, such as magazines, needed to pay its way in fuel. This airline added, which was reiterated by a second airline, that they only do measures that reflect positively on safety, benefit customer, and cover the cost.

2.7.5.5 Tankering

Tankering is the practice of purchasing excess cheaper fuel at an origin airport to save fuel cost for the next leg of a flight. Airlines may practice tankering when fuel price difference between two airports outweighs the cost of carrying extra fuel weight. Two airlines said they actively practice tankering to reduce fuel costs. This topic was not discussed with the other two airlines.

2.7.5.6 Contingency Fuel

Contingency fuel is fuel carried, in excess of trip fuel, to deal with any unplanned events such as delays, storms etc. Better planning and information can mean less contingency fuel is likely to be needed. Three airlines said that they had implemented measures to reduce contingency fuel reserves. For example, at one airline, the amount of contingency fuel used to be 20 minutes or 5%. This was reduced to 3% as long as potential en route alternate is available and as long as weather at end alternate is good. The same airline is trying to reduce extra fuel/ discretionary fuel by giving flight crew better information en route. For example pilots are given information of the extra fuel of flights between the same city pair and aircraft type during the last 24 months. The tool is situated in flight software and gives the mean and 95th percentile fuel use statistics. This airline's strategy is to give pilots as much information as possible. The airline said that for pilots, fuel is like insurance, they take extra fuel to deal with uncertainties in flight. The more fuel, the less they care if uncertainties like traffic or weather come up. For the pilot, carrying more fuel means less stress. This airline also was attempting to increase the accuracy of the zero fuel weight calculation. This airline found that pilots would take more fuel than they needed because they would only get weight info late. The solution was to give pilots a software window to see window of latest zero fuel weight.

2.7.5.7 Fuel Data Tracking

Fuel tracking is the process of collecting, storing and validating fuel data. To monitor fuel efficiency improvements, it is essential that airlines have the necessary data to determine improvement. All airlines had data tracking systems, although the complexity of each system varied. For example, one airline only uses data from fuelling companies of fuel going into aircraft, the information of how much fuel is in the aircraft and how much fuel is left on aircraft on unblock from ACARS. However, they are working in a project to quantify fuel burn in flight. Another airline said that the collection of digital flight data that includes metrics including the use of reversed thrust on long runways and flaps deployment was done for their express units but not for mainline units because of pilot union concerns. Finally, another airline said that they began to collect fuel and other data in 1999, which had made a huge difference to airline operations. They don't track fuel by city pairs, but on more global averages over time by region by fleet

type. This airline said that they had signed up with outside vendor who has expertise and tool to drill down into data. They will look into planned fuel versus actual fuel.

2.7.5.8 Fuel Hedging

Fuel hedging in its most simple form is the practice of purchasing future fuel at today's prices. One of the airline said that their airline did not hedge because of the high risks of hedging in the wrong direction (fuel prices decrease when you pay a high price today). Another airline said that they practiced fuel hedging, but not to outdo the industry, but to smooth out volatility in fuel prices.

2.7.5.9 Timing of Operational Changes

When fuel prices increase, airline response measures take different lengths of time to be effectively implemented. This point was highlighted by two airlines. For example, one airline said that in the shorter term, flight operations changes are made. In the longer term, fuel prices will impact fleet management. This airline said that in terms of cost index changes, if large fuel prices happen over a short period of time, schedules have to be changed to take into account the delay from flying slower. This usually has to wait until the next season, because schedules cannot easily be changed in the same season. Another airline said that in the shorter term, fewer flights are operated. In the longer term, emphasis is placed on new fleet acquisition.

2.7.5.10 Schedule and Network

Fuel price increases can change airline schedules and networks. Airlines discussed some of these impacts and they are summarized in the following sections.

2.7.5.11 Precise Scheduling/Routes Dropped

One airline said that increased fuel costs have changed the way that their airline schedules routes. They said that originally, their airline had high fixed costs and low variable costs. Therefore if it was possible to schedule a flight, it should be done, even if revenue was low. They said that example of such low revenue flights are early morning and late night flights. They said that now that fuel prices have increased, they schedule for high variable cost. Therefore early morning and late night flights are not necessarily tagged onto a schedule. This airline called this trend precise scheduling. They gave the example of Allegiant Air, which only flies when there is high revenue. This airline had also dropped some point-to-point flying because of the fuel issue. In particular, point-to-point flying between secondary airports has been impacted. Another airline said they had had a similar impact on schedules, where revenue marginal routes were dropped when fuel prices increased. However, this airline said that there was no clear pattern of routes being dropped.

A third airline said that they also dropped routes. However, this airline said that they did not only focus on fuel. For example, if they could cover costs through belly freight, then they would keep a route open.

2.7.5.12 Schedule Timing Change Because of Cost Index

Increased fuel cost can lead to airlines flying slower because of changes to the fuel cost/time cost calculation, or cost index. One airline said that changes in cruise speed because of fuel price increases changes average expected time of arrival. The airline said that in the short term they leave schedules unaltered. However, in the longer term, schedules and published times are changed.

Another airline said that they have a team who goes through the published schedule, and identify tight block times, where pilots have to fly fast and burn a lot of fuel to be on time. These block times are made longer. A third airline said that their scheduling was done using historic data, not ideal trajectories.

2.7.5.13 Increased Use of Regional Carriers

One airline said that if a route was not profitable (which could be driven by high fuel cost relative to route revenue), they delegated the route to regional carriers.

2.7.6 Survey

In order to gain understanding from additional airlines of their response to fuel price increases, a survey was conducted with response from 21 representatives from 19 carriers of varying operational sophistication and geographic location. World regions covered include Asia, Africa, Europe, Middle East, North America and South America. The primary aim of the survey was to understand the extent of fuel efficiency programs, and motivation for such programs. The survey formed part of a wider IATA survey with which one of the authors of this report was involved. A summary of responses is shown in Table 2.3. Percentages can add up to more than 100% because airlines could respond to more than one answer for each question.

The survey results show that the majority, 50%, of airlines have a very active fuel management program, with other airlines are either developing or have limited fuel management. There were no airlines without a fuel management program. In terms of motivation for fuel efficiency, operational and financial considerations trumped environmental concerns. For 90% of airlines fuel efficiency is considered an operational objective. For 73%, it is considered a financial objective, while for 50%, it is considered an environmental objective. In terms of fuel management measures, consumption, efficiency and financial trumped environmental impact. However, most (62%) airlines answer that environmental and emissions control is a priority. Therefore although environmental concerns are important to the airlines surveyed, when it comes to fuel efficiency, consumption (operations) and therefore fuel price, is a more important factor.

These findings suggest fuel efficiency is important for airlines, but is motivated by financial and operational concerns as opposed to environmental concerns.

Table 2.3 Survey responses from 21 representatives from 19 carriers.

1. Our airline	Number	Percentage
has a very active fuel management program	11	50%
has a limited fuel management program	4	18%
has no coordinated fuel management program	0	0%
is working to develop a fuel management program	9	41%
2. Environmental Impact and Emissions control		
are priority objectives for our airline	13	62%
do not influence fuel related operations within our airline	6	29%
are rarely discussed within our airline	4	19%
3. For our airline, Fuel Efficiency is considered		
An operational objective	20	90%
A financial objective	16	73%
An environmental priority	11	50%
not routinely discussed	0	0%
4. Our airline's Fuel management measures/KPI's are focused on		
Consumption	15	68%
Efficiency	18	82%
Environmental impact	4	18%
Financial	12	55%
Other	1	5%

2.8 Modeling Fuel Price Impacts on Commercial Aviation

2.8.1 Assumptions

Fuel price scenarios were projected out to 2025 and the impact on the US air transportation system was explored. Fuel price and GDP scenarios were adapted or directly applied from the US Energy Information Administration (EIA, 2012). The impact of these fuel price and GDP scenarios on a reference scenario, based largely on ICAO/GIACC (2009), was assessed.

The relationship between air-travel price increase and resulting decrease in demand is well documented. For example Kincaid and Tretheway (2007) conduct a meta-analysis of air transport price elasticity and find values ranging between -0.36 on Trans Pacific (North America – Asia) to -1.96 on Intra Europe routes. This means that for a fare price increase of 10%, traffic will decrease by between 3.6% and 19.6%. Fuel price increases passed through to fares can lead to such an increase in the price of air-travel, and result in decreased demand. Factors determining traffic decrease include traveler type (business or leisure) and route category (domestic or international).

The air transport system response to fuel price increase is modeled using the Aviation Portfolio Management Tool for Economics (APMT-E). APMT-E is one of a series of models developed by the FAA and the Partnership for Air Transportation Noise and Emissions Reduction Center of Excellence. The model has been used in support of ICAO/GIACC (2009) and ICAO/CAEP (2010) and is outlined by MVA Consultancy (2009).

APMT-E is a partial equilibrium model based largely on the price elasticity relationship discussed above. Fuel price and reference scenario demand are exogenously input into the model. Demand is determined in part by GDP activity and translated into traffic using the income-elasticity relationship discussed in Gillen et al. (2002).

APMT-E is a global model that determines operations for country pair-stage length combinations. The model identifies 23 route groups (e.g., North Atlantic, Domestic US, North America-South America), nine distance bands (e.g., in kilometers, 0-926, 927-1,853, and 6,483-8,334), ten aircraft seat classes defined by the number of available seats (e.g., 0-19, 20-50 and 211-300) and two carrier types (passenger and freight). In APMT-E, airlines can respond to fuel price increases by raising prices (and flying less) and, when purchasing new aircraft (which are combinations of airframes, engines and seat configurations), selecting more fuel efficient alternatives. The model is calibrated using 2006 data, shown in Table 2.4.

Aviation operations are determined by, in each period, retiring old aircraft based on retirement curves. The surviving fleet is then compared to forecast capacity requirements to determine capacity deficits by carrier region, distance band and carrier type. Potential new aircraft are selected from a set of predetermined technologies and are evaluated by calculating the operational costs (including fuel, depreciation, finance and maintenance costs, and route and landing charges) per seat hour over the life of the aircraft. Once new aircraft are purchased to meet fleet deficits and added to the surviving aircraft, the fleet is deployed across schedules and operating costs are calculated. Assuming a constant cost markup, airfares and demand are then calculated. Differences between actual demand and demand forecast at the beginning of the period are used to update the demand projection for the next period. Figure 2-11 is a flow chart depicting the model's yearly solving process.

Table 2.4 APMT-E model data sources.

Data Type	Data Source
Operations	Based on 2006 COD (26.5 million operations, reduced to 4,000 schedules -- combinations of country pairs and stage lengths)
Fleet	ICAO's Campbell Hill Fleet database with 309 aircraft types
Aircraft Utilization	FESG fleet by seat class
Crew costs	Average crew cost data for 31 generic airframe types obtained from Form 41 PS2
Maintenance costs	Average cost data for 31 generic airframe types from Form 41 PS2 (with age related function to increase by aircraft age)
Capital costs	Data published by AVMARK for a wide range of airframe types and average ages
Landing costs	Based on unit airport charges by region data from ICAO
Route costs	Based on ICAO data for air navigation charges per available seat km for reporting airlines
Volume related costs	Trends in revenues and expenses data from scheduled airlines of ICAO contracting states
Price Elasticities	Kincaid / Tretheway (2007) for all 23 route groups
Income Elasticity	Gillen et al. (2002)
Source: Based on MVA consultancy (2009)	

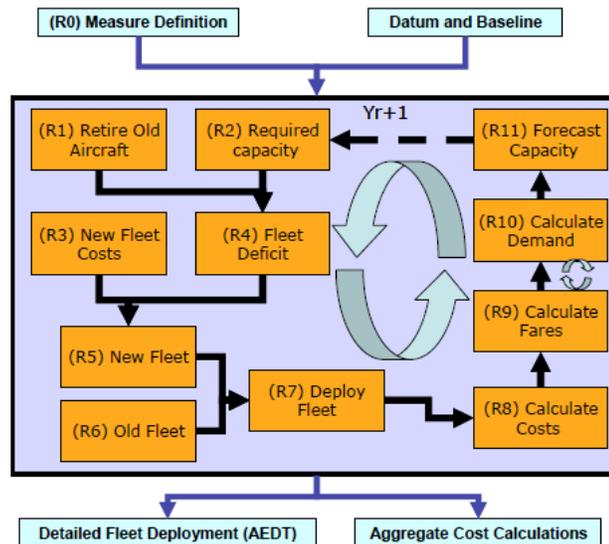


Figure 2-11 APMT-Economics flow chart. Source: MVA Consultancy (2009).

APMT-E projects a policy scenario and compares it with a reference scenario. Our APMT-E reference scenario largely follows ICAO/GIACC (2009). Traffic and fleet forecasts are from the Forecast and Economic Analysis Support Group (FESG) at the International Civil Aviation Organization (ICAO),

adjusted by the short term FAA Terminal Area Forecast (TAF). Aircraft fuel efficiency rises by 1% per year. Airspace management improvements driven by NextGen High Density Analysis are implemented in the US and airspace management advances in the rest of the world follow those in the US with a five-year lag. These improvements result in a reduction in detours in the US of 3% in 2015 and 10% in 2025, and in the rest of the world of 3% in 2020 and 10% in 2030. Load factors, average stage lengths and aircraft retirement schedules are consistent with FESG forecasts for the eighth meeting of the Committee on Aviation Environmental Protection (CAEP/8).

2.8.2 Scenarios

In order to understand potential future impacts of high and volatile fuel prices three scenarios were forecast: a *high oil price scenario* from EIA (2012) a *climate scenario* using a \$25/tCO₂ emissions allowance price EIA (2012) and a hypothetical *short-term peak* scenario replicating the increase in fuel price before, and fall after, the 2008 oil price spike. Scenarios are forecast to 2025. Table 2.5 shows scenario assumptions and forecasts and Figure 2-12-Figure 2-18 show the temporal profile of each scenario. Figure 2-12 and Figure 2-13 show fuel price projections and Figure 2-14 and Figure 2-15 show GDP projections.

Table 2.5 APMT-E Scenario Assumptions.

Scenario	Oil/Jet Fuel Price Assumption	2012-2025 Jet Fuel Price Growth Rate	GDP Assumption	2012-2025 GDP Growth Rate	Source
Reference	Oil price rises from \$100/barrel in 2012 to \$121/barrel in 2025	1.53%	Strong non-OECD growth, avg. OECD growth	2.75%	EIA AEO 2012
High Oil Price Scenario	Oil price rises to \$175/barrel in 2013, gradual rise thereafter	2.20%	Stronger non-OECD growth economic, oil supply inaccessible	2.87%	EIA AEO 2012
Climate Scenario	CO2 price of \$25/ton applied in 2013 to all sectors. Price rises by 5% p.a. thereafter	1.84%	Carbon price has negative impact on economy	2.70%	EIA AEO 2012
Short Term Peak Scenario	Jet fuel price follows trend of 2005 to 2009 between 2013 and 2017	1.53%	Same as reference	2.75%	Hypothetical

The *reference* scenario uses EIA (2012) fuel price and GDP data, and assumes an annual growth in fuel price and GDP of 1.53% and 2.75% respectively. The *high oil price scenario* and *climate scenario* use the corresponding EIA (2012) GDP forecast. In the *high oil price scenario* oil price increases are driven by high demand side activity (economic growth). In the *climate scenario* oil price increases are driven by an effective carbon price. Economic activity slows relative to the *reference scenario*. The *short-term peak* scenario uses EIA (2012) *reference* GDP forecasts because this is a hypothetical scenario. GDP was translated into traffic change using the income elasticity relationship from Gillen et al. (2002) of 1.4.

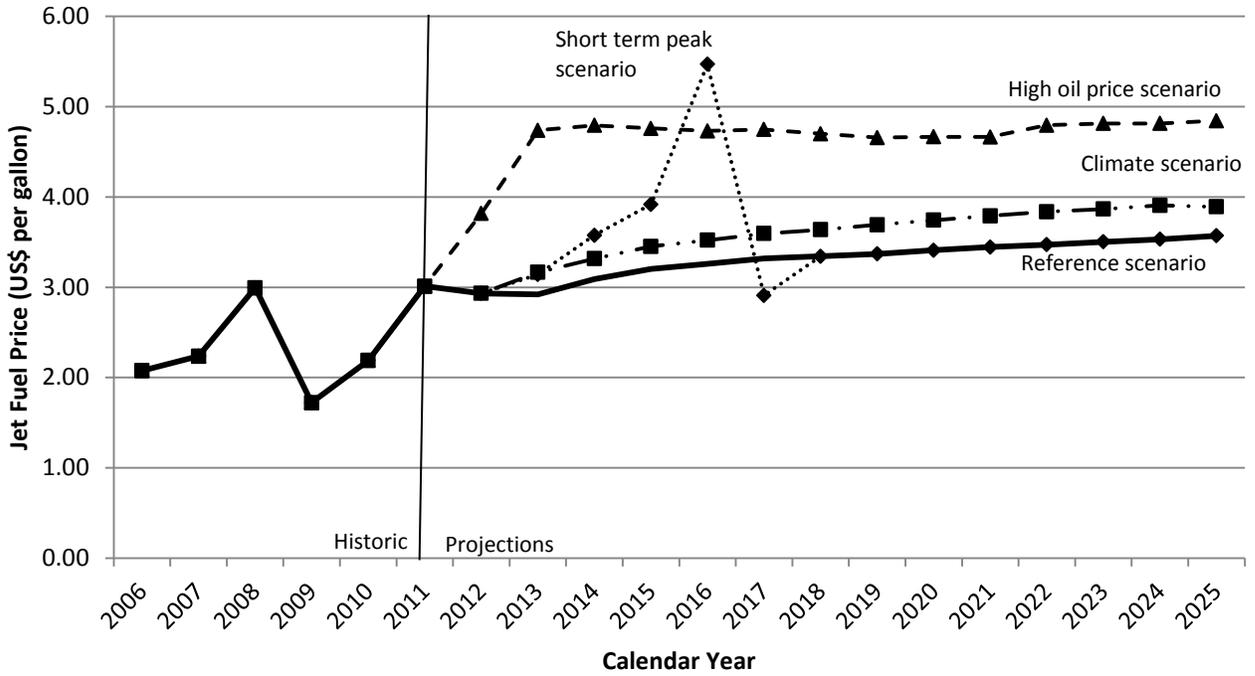


Figure 2-12 Fuel price projections to 2025 (EIA, 2012).

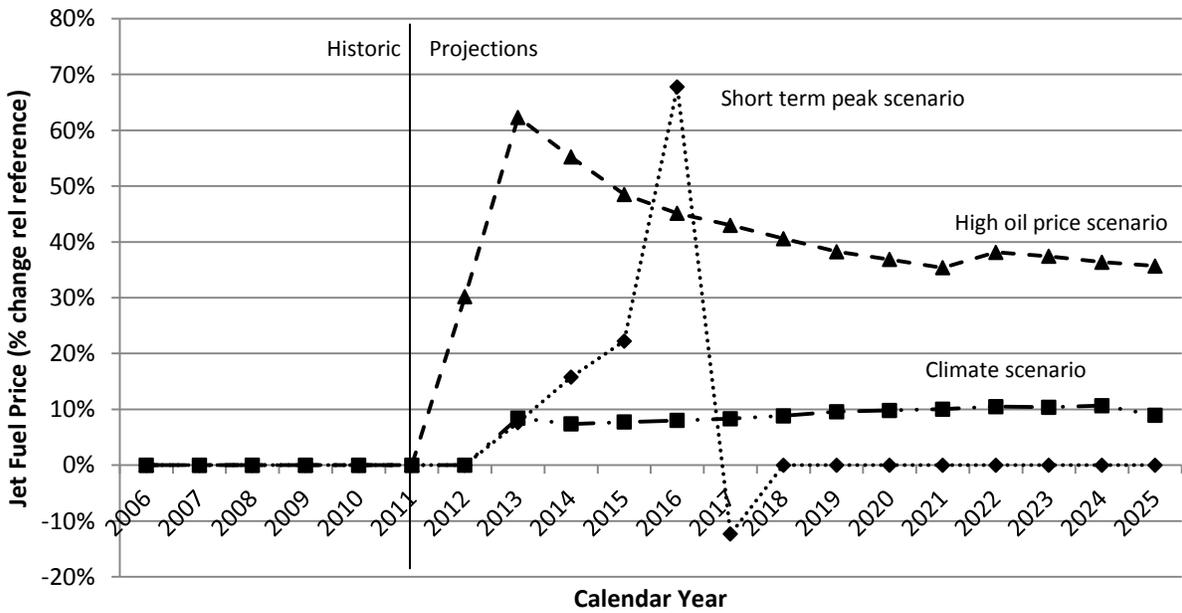


Figure 2-13 Fuel price projections, percentage change difference relative to the reference scenario (EIA, 2012).

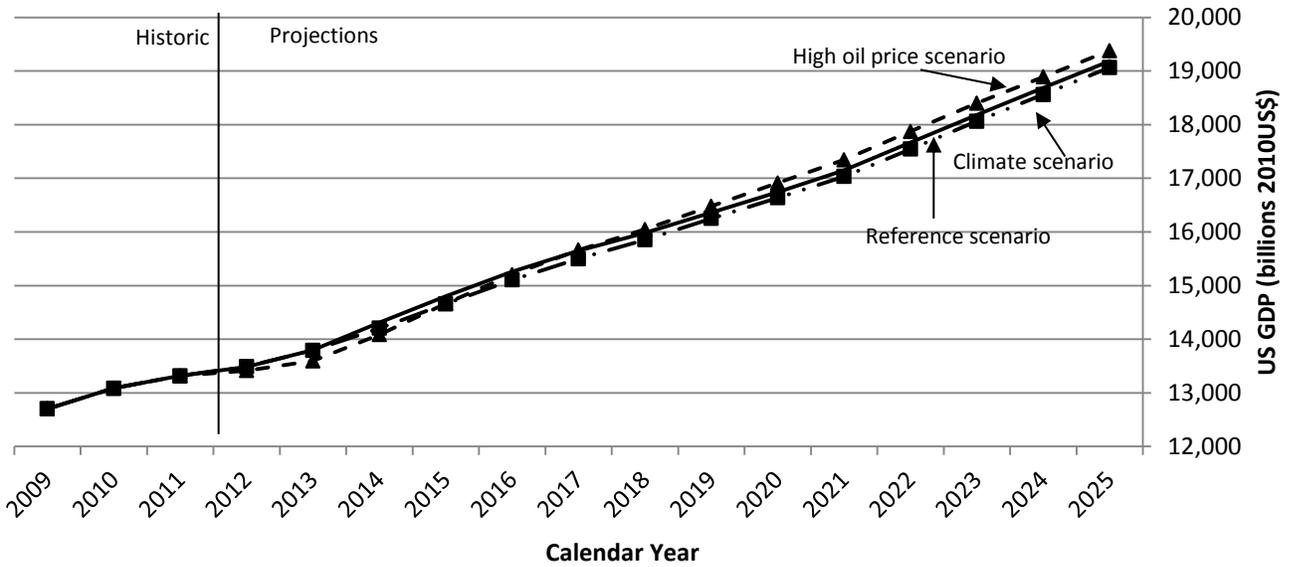


Figure 2-14 GDP projections to 2025 (EIA, 2012).

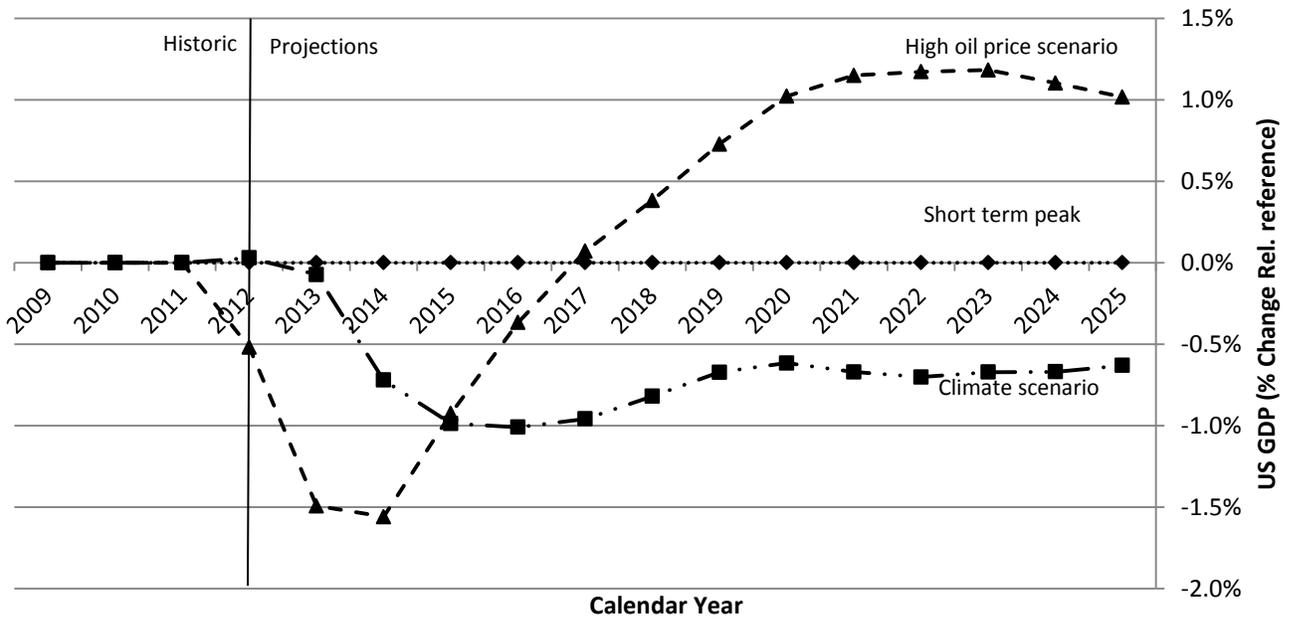


Figure 2-15 GDP projections, percentage change difference relative to the reference scenario (EIA, 2012).

The three scenarios were modeled in APMT-Economics. The following section summarizes the findings.

2.8.3 Modeling Results

Increased fuel price decreases airline traffic. Fuel price increased leads to increased unit operating cost. APMT-E is a long-term model, and it therefore is assumed that all costs are passed to passengers in the form of fare increases. The price-elasticity relationship determines the magnitude of traffic decrease

for a given fare increase. It is found that GDP activity in each scenario is a significant factor in determining increase or decrease in overall traffic. Impacts of each scenario are discussed below. Figure 2-16-Figure 2-18 shows scenario temporal trends.

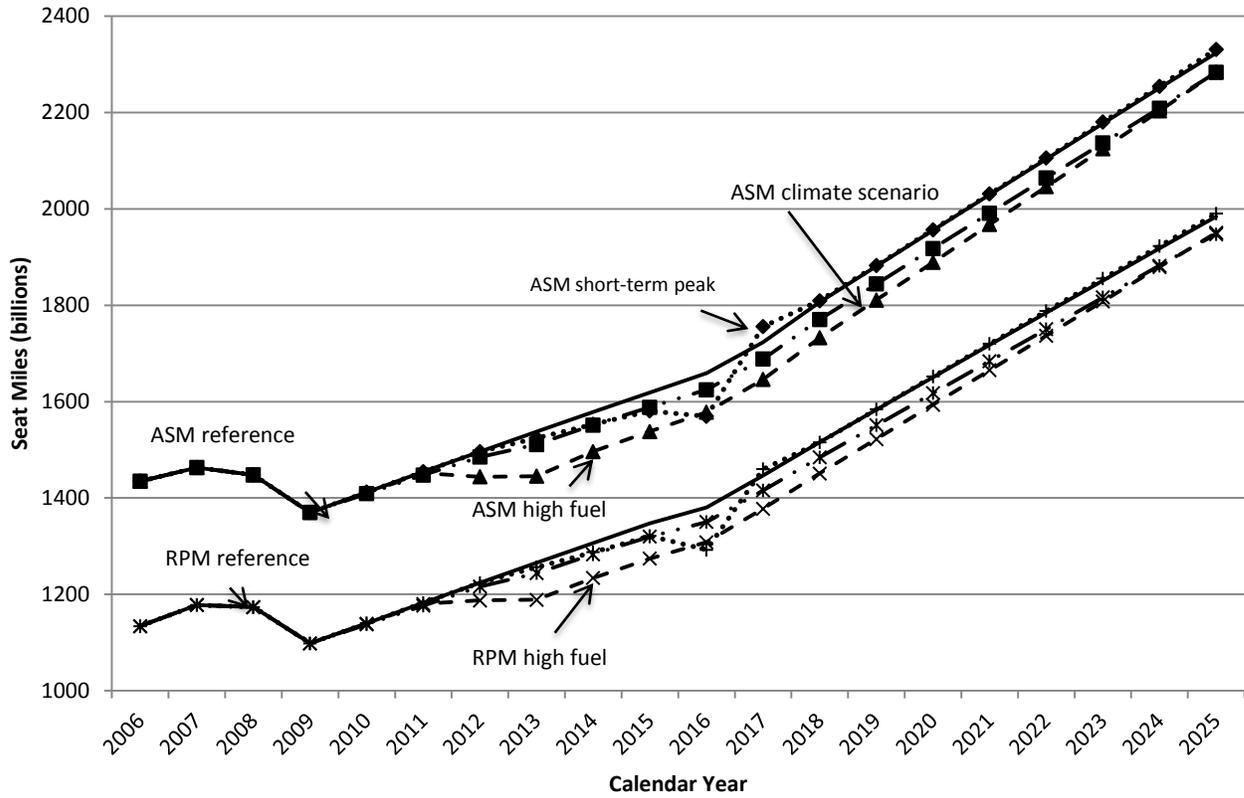


Figure 2-16 APMT-E ASM and RPM projections to 2025.

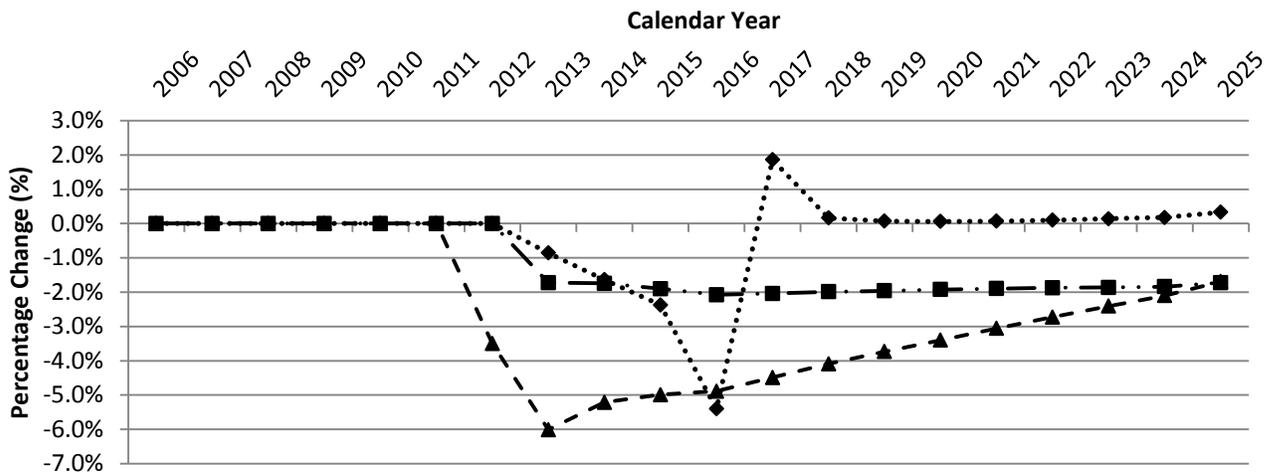


Figure 2-17 APMT-E ASM percentage change in fuel price scenarios relative to reference scenario.

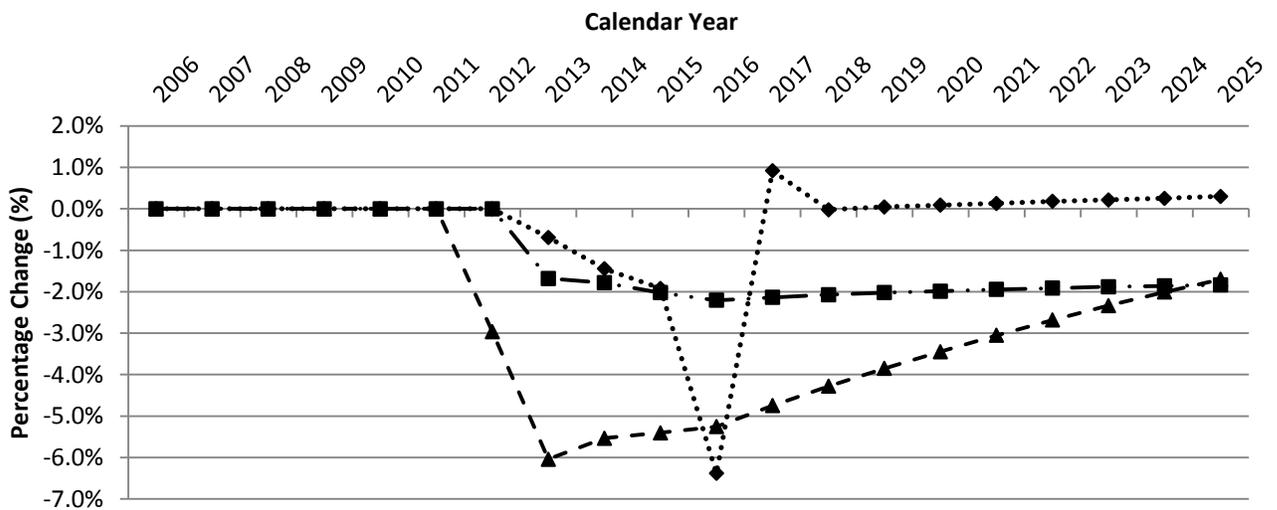


Figure 2-18 APMT-E RSM percentage change in fuel price scenarios relative to reference scenario.

2.8.3.1 High Oil Price Scenario

EIA (2012) forecasts that in a high jet fuel price scenario, jet fuel prices increase by 60% relative to the reference scenario in 2013, decreasing to about 40% in 2025. High oil prices are driven in part by increased economic activity in non-OECD countries, in particular China. US GDP decreases between 2012 and 2017 relative to the reference, and thereafter increases relative to the reference. Impacts relative to the reference scenario in absolute terms are shown in Figure 2-16, and in relative terms for ASMs in Figure 2.17 and RPMs and Figure 2.18. In summary, increased GDP activity after 2017 increases traffic relative to the reference; increased fuel price decreases traffic relative to the reference. Fuel price impact is larger than GDP impact, and traffic decreases. In detail:

- Increases in fuel price of 60% in 2013 increases airline operating cost by 4%.
- Airlines increase fares, and therefore revenue increases by close to 4%, to cover costs and maintain profit margins.
- Increase in fares leads to a decrease in RSMs and ASMs of about 4% relative to the reference.
- RSMs and ASMs continue to grow relative to 2012 levels.
- Operating results decrease driven by traffic decrease.

2.8.3.2 Climate Scenario

EIA (2012) forecasts that in a climate scenario with a \$25/tCO₂ emissions cost, jet fuel prices increase by 8% relative to the reference scenario in 2013. Jet fuel prices increase by 10% relative to the reference in 2025 because carbon dioxide prices increase. GDP activity decreases driven by the impact of a carbon dioxide price on the economy.

Absolute impacts on airline traffic are shown in Figure 2-17. Impacts relative to the reference scenario are shown in Figure 2-18. In summary, decreased GDP activity decreases traffic relative to the reference; increased fuel price further decreases traffic relative to the reference. Fuel price impact and GDP impact combine to decrease traffic. The impact to traffic is less than in the high-oil price scenario because of the lower magnitude of fuel price increase. Specifically:

- Decrease in GDP decreases airline operating cost between 0.5% and 1%, even though fuel price increases by 8%.
- Although airlines increase fares, revenue decreases because of a decrease in traffic, driven by decreased GDP.
- Increase in fares leads to a further decrease in RSMs and ASMs of about 2%.
- Operating results decrease driven by traffic decrease from GDP decrease.

2.8.3.3 Short Term Peak

In order to simulate the 2008 oil price peak, a hypothetical scenario was developed, which, mapped the run-up, peak and decrease after the 2008 peak, onto the period between 2013 and 2018. In this scenario, jet fuel prices increase by 70% relative to the reference scenario in 2016. GDP activity remains constant relative to the reference. Absolute impacts on airline traffic are shown in Figure 2.16. Impacts relative to the reference scenario are shown in Figures 2.17 and 2.18. In summary, GDP activity has no impact on traffic relative to the reference; increased fuel price decreases traffic relative to the reference. In detail:

- Increased fuel price of 70% in 2013 increase airline operating cost by 5%.
- Airlines increase fares, which increase revenue by close to 5% 2016.
- Increase in fares leads to a decrease in RSMs and ASMs of about 6% in 2016
- After the peak in oil prices, traffic returns to reference levels, growing relative to 2012 levels by 2025.

2.8.4 Summary

Three fuel price scenarios were developed: a high oil price scenario, a short-term peak scenario and a climate scenario using a \$25/tCO₂ emissions allowance price (EIA, 2012). Scenarios were forecast to 2025. It was found that an increase in oil price leads to a decrease in airline RPMs and ASMs. The

magnitude of the impact on airline traffic ranged between 0% and 6.5%. Model results show important couplings in GDP and fuel price in relation to traffic. For example GDP growth in the high oil price scenario leads to increased oil price (EIA, 2012), but also dampens the impact of fuel price increase, relative the reference scenario. In the climate scenario, GDP growth slows relative to the reference scenario, and fuel price increases. The net impact in this scenario is a greater decrease in airline traffic, relative to a scenario where GDP remained unchanged.

These findings suggest that the cause of fuel price increase is important in determining overall impact on airlines. If fuel increase is driven from the fuel demand side, it can mean that GDP activity has increased, meaning more demand for airline service. An example of such a scenario is the EIA high fuel price scenario, where economic activity on non-OECD countries, and in after 2017, from the US and EU drives fuel prices up, as well as airline traffic. This is relatively better than a scenario where fuel price increase is driven from the fuel supply side. In this scenario, such as the EIA climate scenario, or fuel crises such as a war, the fuel price increase is not dampened by GDP increase, and the net impact is therefore negative for airlines.

APMT-E is a long-term model and therefore does not capture the short term dynamics of airline response to fuel price increase. For this reason the results in this section are only indicative of actual airline response to fuel price increase. For example, APMT-E assumes that airlines pass through 100% of operating costs through to passengers, as well as a fixed margin for profit. While such an assumption may be true for the industry as a whole in the long term, it is not necessarily true in the short term, where airlines may not be able to pass all costs through to passengers, and may rather operate at a loss, or change operating behavior. For this reason, only general trends such as direction of impact, rough magnitude, and interactions of GDP and fuel price are analyzed and discussed.

2.9 Discussion and Conclusions for Section 2

Jet fuel price has significantly increased during the past decade, resulting in fuel becoming airline's primary operating cost. This report provides evidence that airlines reacted to increased fuel prices in a variety of ways. Three forms of investigation were used: analysis of operations data, industry interviews and modeling future impacts.

Airline mission fuel efficiency was found to be correlated to fuel price, providing evidence that airlines adopted new operational strategies to reduce total fuel burn for the same amount of traffic. However, investment in new aircraft appears to have slowed when fuel prices increased after 2004. This finding provides empirical evidence to the findings of Winchester et al. (2013) who argue that a climate policy could reduce investment in new aircraft.

It was found that mission fuel efficiency increases were driven, in part, by cruise speed reductions. This suggests that airlines adopted optimized cost index values given the dramatic changes in operating cost structure. Fuel cost as a percentage of total operating cost increased from around 15% to nearly 40% in 2011. A number of additional operational changes leading to increased fuel efficiency are identified through airline interviews. It was found that all airlines surveyed have some kind of fuel management program, or are developing such a program. Operational efficiency and finances are identified as the motivation of such programs.

In terms of network and schedule, it was found that increasing fuel price may have slowed US domestic capacity growth and reduced short stage length traffic between 2004 and 2007. However, there appears to have been little impact on network structure and airport connectivity. This was measured by calculating the Gini coefficient of the US domestic network, and the degree of connectivity of US domestic airports, classified by the FAA designators of airport type.

Three fuel prices scenarios were projected to 2025. Fuel price increase was found to decrease airline traffic. Model results show important links in GDP and fuel price in relation to traffic. GDP growth can increase oil prices, but also dampen the impact of fuel price increase

Policy implications were discussed. A key finding of this report is that increased fuel price appears to increase mission fuel efficiency, but slow investment in new aircraft. Therefore, during future fuel price increases, stakeholders could consider mechanisms to ensure airline investment in new aircraft.

3 Evaluating the Effects of Oil Price Change on the US Domestic Cargo Industry

The domestic air cargo industry in the US has experienced rapid growth in the past last two decades. In 1993, there were approximately 10.5 billion revenue ton-miles (RTM), of both freight and mail, flown domestically in the US. In 2010, RTMs had climbed to 12.5 billion, an increase of more than 19% (BTS, 2013). This increase in output occurred during a time when jet fuel prices rose from \$0.81 per gallon in January of 1993 (adjusted to 2010 dollars), to \$2.43 per gallon in December of 2010, a 200% increase (EIA, 2013). While fuel price increases do not create more demand for air cargo services, they clearly have not prevented growth in the industry either. This does not imply that the air cargo industry is immune to the effects and pressures of increasing fuel prices. It does however indicate that the air cargo industry has had to adjust to an environment of rapidly escalating fuel costs in order to continue its growth. Big air cargo logistics companies have made structural and operational changes to help lessen the impact of fuel price increases on their business operations. This is in contrast to their network structures, which have remained relatively static. Econometric forecasting, using 5 hypothetical scenarios, helped to clarify the how the effects of future GDP growth and future fuel price have on the expected levels of air cargo traffic projected decades into the future. These Traffic level projections depend mostly on GDP variability, and the inherent structure of the cargo carriers' service model.

3.1 Current US Domestic Air Cargo Structure

Domestic air cargo can be broken up into four different carrier group classifications;

- Transnational Logistics Companies
- Contract Carriers
- Niche Carriers
- Passenger Carriers

Clearly there are many ways of differentiating air cargo in the US. The above categories are by no means the only, or even necessarily the best way to breakdown the domestic air cargo industry. However, this breakdown limits the number of groups to a manageable level, but at the same time adequately differentiates cargo carriers by their specific type of operations.

3.1.1 Transnational Logistics Companies

There are three large transnational logistics companies as we define them; UPS, FedEx, and DHL. These are companies that have large, global operations; handling not only the air-bound portion of the cargo journey, but also the land based; first and last miles of pick-up and delivery. DHL's operations are almost exclusively international, having eliminated its US domestic air cargo program in 2008, and moving to a model of hiring independent contracting airlines for its domestic air cargo service (Ewing, 2008). DHL's purchase of Airborne Express in 2003, and subsequent expansion, indicated it was poised to become a true competitor to FedEx and UPS in the domestic air cargo market, but that never materialized. FedEx and UPS are the two dominant air cargo transporters and overall logistics companies in the US. They both have extensive international and US domestic operations, in both air cargo and land based package transport. In 2010 FedEx and UPS accounted for 76% of all domestic air cargo (freight and mail) (see Figure 3-1). This dominance of the market is further reinforced by the fact that the third largest carrier, on a RTM basis, was ABX air (formally Airborne Express), accounting for only 3.7% (1).

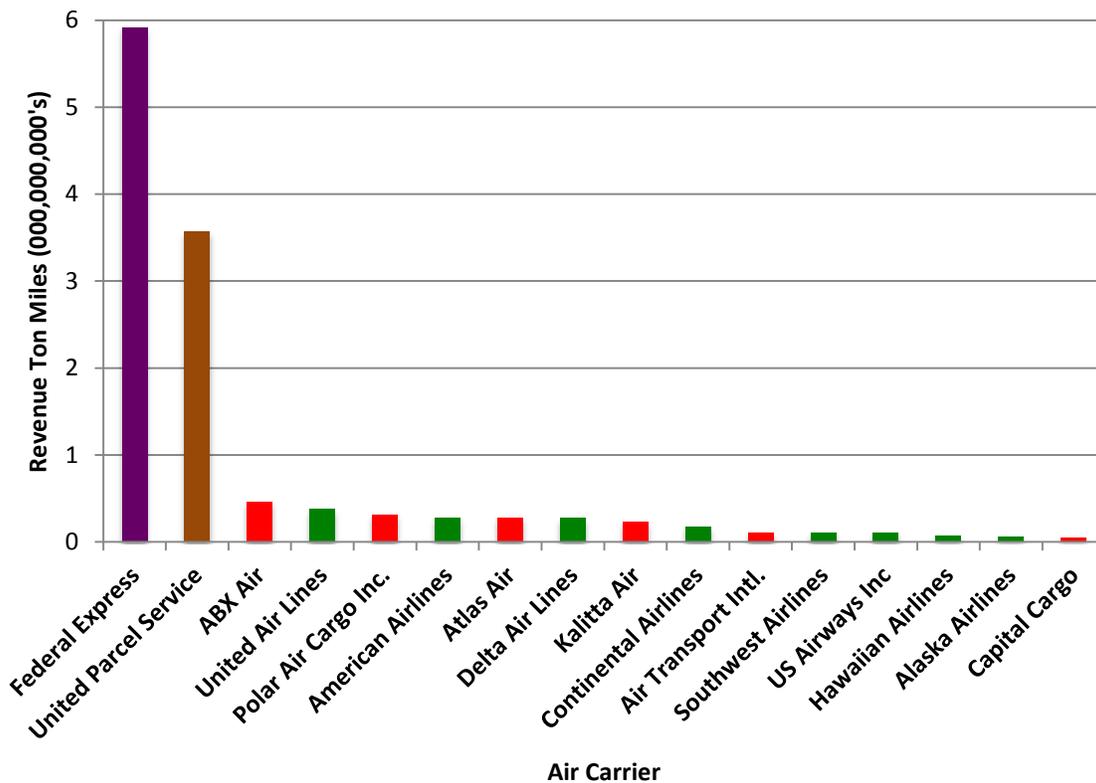


Figure 3-1 Breakdown of cargo (freight and mail) carried by individual airlines in 2010. Red color indicates a cargo carrier and green color represents a passenger carrier.

Even with the dominance of FedEx and UPS, the remaining 24% of air cargo carried by these other carriers, is significant. Large-jet operating contract carriers, account for roughly half of this 24% (11.9% of the total). Listed below are the eight major contract carriers:

- ABX Air (formerly Airborne Express)
- Capitol Cargo
- Air Transport International
- Atlas Air Inc.
- Polar Air Cargo
- Kalitta Air
- Amerijet
- ASTAR Air Cargo

ABX Air, Capitol Cargo, and Air Transport International are all owned by the parent company; Air Transport Services Group. Both Atlas Air Inc. and Polar Air Cargo are owned by Atlas Air Worldwide Holdings. The remaining three cargo carriers are independent.

Much of these contract carriers' operations are actually services carried out on behalf of DHL. Since DHL was forced to eliminate its domestic service back in 2008, and downsized out of its Cincinnati hub, it has had to rely on independent contractors to carry out the domestic portions of its international cargo

shipments. Another substantial component of these contract carriers' operations are freight forwarders, contracting out space in a plane, or even an entire chartered flight; as a means of transporting small volumes of cargo for their clients.

3.1.2 Niche Carriers

Niche carriers are cargo carriers that serve very specific market regions. Often these markets are too small for large air cargo companies or have conditions (weather; mountains; runway length) that limit the types of aircraft that can serve them. For example Asia Pacific Airlines has a fleet of three Boeing 727 narrow body aircraft, and operates charter flights to and from Guam, mostly to the west coast of the United States (APA, 2013). Everts Air Cargo operates scheduled and chartered air cargo service in Alaska and northwest Canada. In both these instances the markets were likely too small and too specialized to warrant the entrance and competition by large air cargo carriers. These small niche carriers account for an insignificant amount of RTMs, only 0.6% of the 2010 total (see Figure 3-2). However, the fact that these carriers are often the only carrier serving a particular market, one that often has a significant geographic footprint, means they should not be wholly discounted.

3.1.3 Passenger Carriers

The fourth and final market segment group is passenger carriers. Traditional passenger carrier airlines, such as United Airlines or American Airlines, transport a significant amount of air cargo (11.9% of the total in 2010). United Airlines itself was the fourth largest cargo carrier with 2.3% of the market (defined as freight + mail RTMs). It should be emphasized that we are only focusing on passenger airlines' cargo RTM levels. The RTMs attributable to passenger traffic are omitted in the analysis. If passenger miles were converted to RTMs they would dwarf cargo RTMs and skew the role played by cargo carriers.

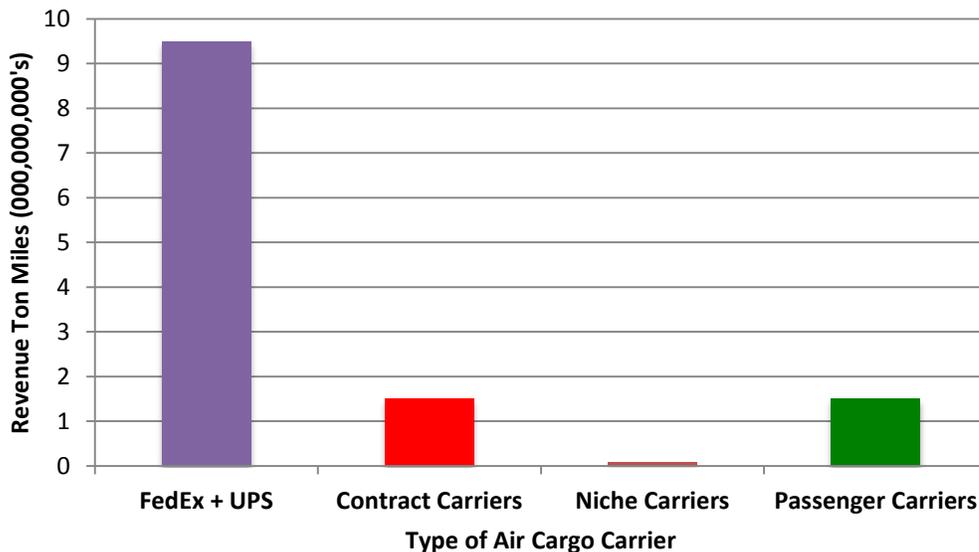


Figure 3-2 Breakdown of air cargo carried (freight + mail) by the main air cargo carrier groups in the US, for 2010. Passenger carriers, while not classified as "cargo carriers", do transport significant cargo as an ancillary part of their business operations.

3.2 Air Cargo Comparison to Passenger Traffic

It is interesting to contrast the domestic air cargo industry with the passenger carrier industry. Dedicated air cargo carriers (UPS + FedEx + contract carriers) accounted for approximately 88% of all domestic cargo RTMs in the US, for 2010 (see Figure 3-3). Traditional passenger carriers account for only around 12%. However of all RTMs (which include passenger RTMs) cargo carriers accounted for only about 16% of the industry total, with the remaining 84% provided by the passenger carriers (United, American, Delta, etc.). Furthermore cargo carriers only had 4.5% of the departures, and air hours, industry wide, in 2010. These numbers emphasize that while the air cargo industry is significant; its operations are dwarfed by the scope and scale of passenger carriers. This not meant to discount the significance of air cargo carriers' impact on the aviation industry. At certain times of the day and at certain airports, air cargo flights overwhelmingly dominate the air operations. However when viewed across the whole domestic commercial aviation industry, air cargo is approximately 20 times smaller (on a departures basis) than the commercial passenger portion. Given its size and scope, and the fact that it already carries a significant amount of air cargo, passenger carriers could have an even larger impact on air cargo in the future.

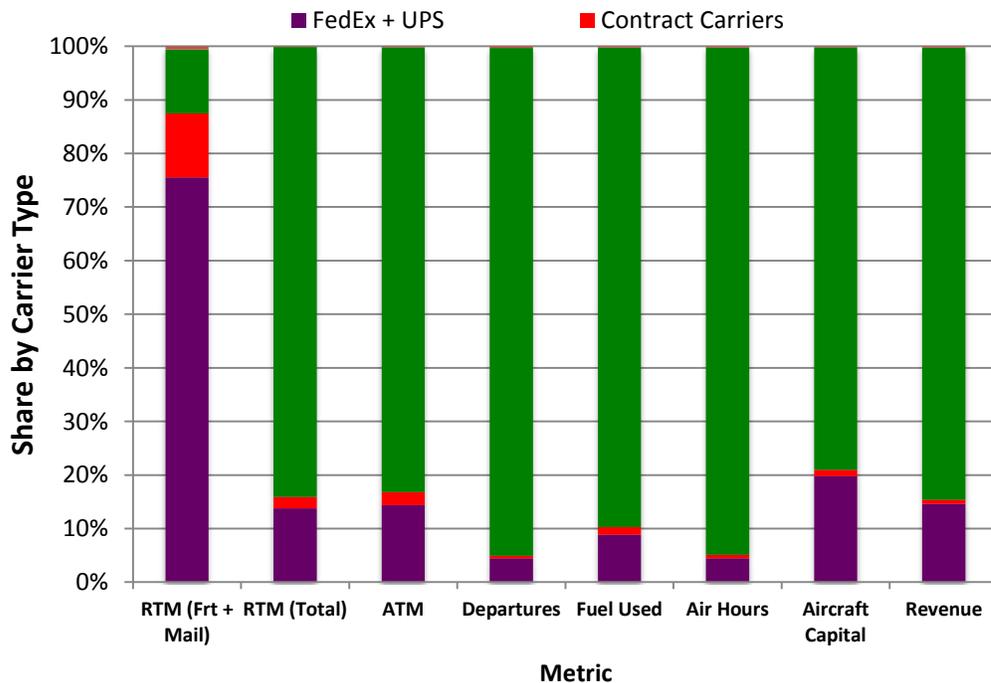


Figure 3-3 Contribution to different activity metrics, within the US domestic commercial aviation industry by carrier type, for 2010.

3.2.1 FedEx, UPS, and Contract Carrier Comparison

While FedEx, UPS, and large jet operating contract carriers do not encompass the entirety of the air cargo industry, they essentially represent the entirety of air cargo market, comprised of firms whose business operations are based on air cargo. As stated in the previous section, and shown in Figures 3.2 and Table 3.3 FedEx, UPS, and contract carriers make up close to 88% of all cargo carried. However, if you exclude the cargo carried by dedicated passenger carriers, whose cargo operations are but a minor part

of their overall business operations; operations that have little influence into their decision-making processes; then FedEx, UPS, and contract carriers make up of over 99% of air cargo transported on an RTM basis. Figure 3-4 emphasizes the comprehensive dominance of FedEx, UPS, and contract carriers in the air cargo industry. In terms of RTM, revenue, ATM, fuel used, and value of aircraft capital, the three aforementioned groups make up 98%+ of the air cargo industry total. In terms of departures and air hours, regional niche carriers comprise a bit more of the total, 5.3% and 4.1% respectively (see Figure 3-4). These numbers should not be surprising, as niche carriers tend to fly small planes with low cargo loads per departure, but often in markets not served by larger carriers. This structure results in disproportionately high departures and “time in the air”, versus the amount of cargo being carried. The reality is, the air cargo industry is made up of only a handful of firms and is dominated by just two big players.

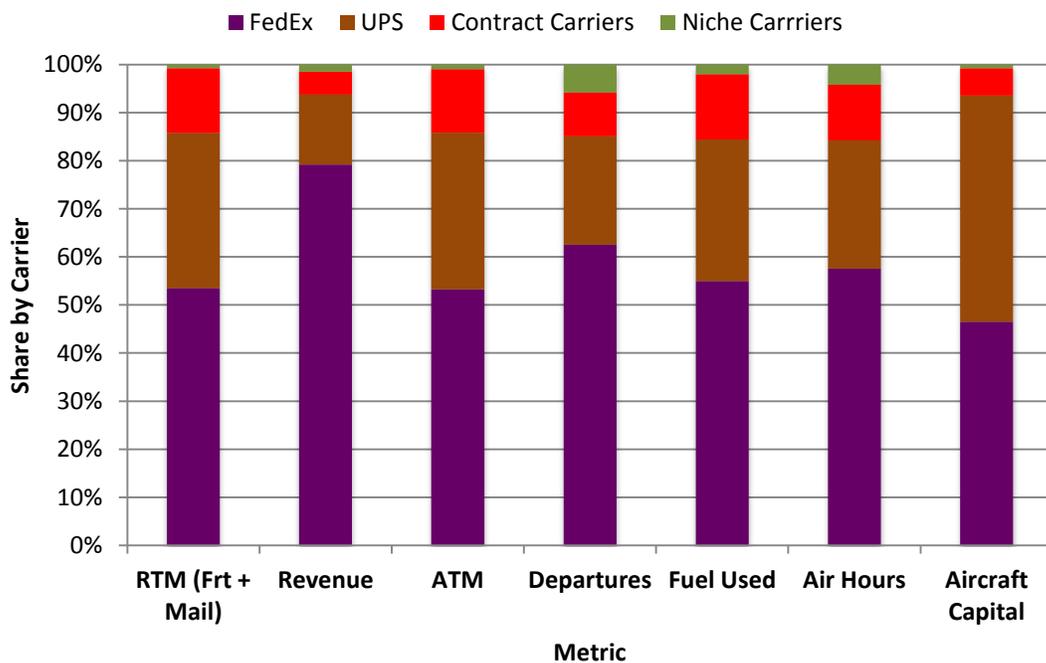


Figure 3-4 Comparison of air cargo carriers, over different activity metrics, within the US commercial aviation industry for 2010.

Up to this point only brief mention has been made of DHL, the worlds largest logistics company. In 2008 DHL ceased providing U.S. domestic express service. It still performs international shipments into the US. However a different carrier, providing contract services to DHL, performs any further domestic service. DHL therefore partners with these large contract carriers to provide the final domestic portion of its international express shipments. DHL is by far the biggest user of these contract carriers.

3.3 Actions Taken By the Cargo Carriers

Bureau of Transportation Statistics (BTS) data was analyzed over the time period 2000-2010, on a quarterly basis, to see how air cargo operations have changed over time. This operational, time series data, was then compared to changes in jet fuel price, over the same time period, to see if any trends could be determined as to how cargo carriers are responding to fuel price changes. Both operational changes and fleet changes by the major cargo carriers were analyzed.

Major cargo carrier network structure over the specified study period will be discussed in Section 3.4. The time series data is used to perform the Econometric analysis looking at the key drivers of the air cargo market and the impact of future fuel prices changes and future GDP growth has on air cargo carriers' operations. Based on different macroeconomic scenarios, we forecast the evolution of the air cargo market from 2010 to 2035, and find that the different hypothesis on the evolution of fuel prices do not impact it as much as the different economic hypothesis.

3.3.1 Fuel Price Change

From the first quarter of 2000 to fourth quarter of 2010 the price per gallon of jet fuel rose from \$0.99 to \$2.34 (adjusted to 2010 dollars), an increase of 136% (see Figure 3-5). Additionally, the highest price reached was \$3.71, a 274% increase from the initial price in 2000. It cannot be determined from the data if these fuel price changes were the direct cause of decisions made by air cargo carriers. However, fuel price fluctuations without a doubt were a consideration for air cargo carriers when making adjustments in operational structure and fleet composition. The high overall fuel costs felt by all carriers means that any changes in its price are significant to operations. While it is beyond the scope of this project to determine whether fuel price changes were the direct cause of the operational changes made by the airlines, it is constructive to look at what changes cargo carriers made while the price of jet fuel was fluctuating. Rational explanations can then be posed as to why these changes may have taken place due to, or in spite of, these fuel price fluctuations.

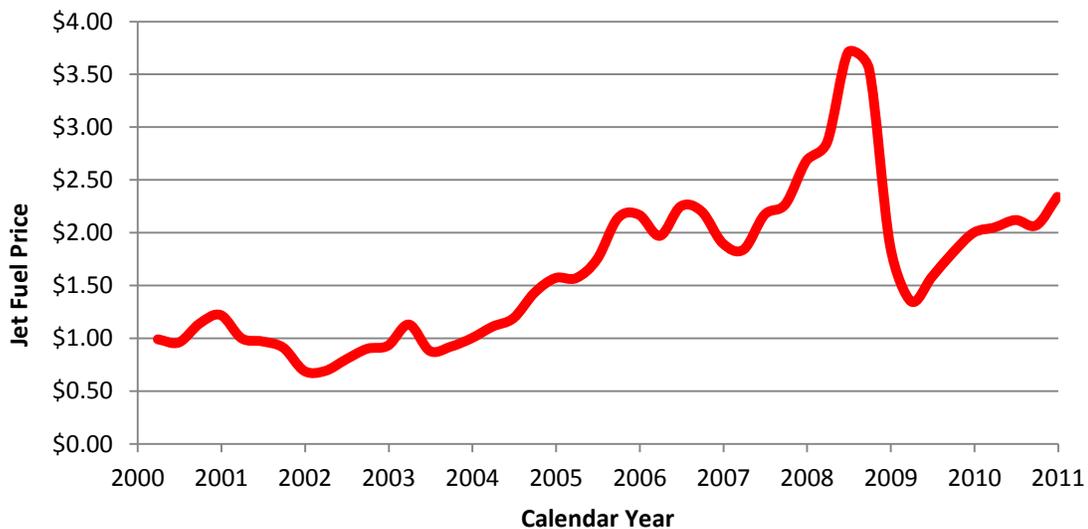


Figure 3-5 Changes in jet fuel price over the time period 2000-2010, reported quarterly.

3.3.2 Actions Taken By FedEx

From 2000 to 2010 FedEx made clear and pronounced fleet changes, as well as operational changes. Over this time period FedEx significantly changed its fleet mix and fleet utilization. In the beginning of 2001 the two aircraft types with the most departures were the Cessna-208 Caravan and the Boeing 727. Introduced in 1984, The Cessna 208 is a single engine turbo prop aircraft designed to carry light passenger or cargo loads, on short distance routes. The Boeing 727 is a narrow body jet aircraft, first introduced as a passenger aircraft in the 1960s, and became popular as a cargo aircraft in the 1970s. Its production ceased in 1984 (Boeing, 2013).

Over the eleven-year study period the share of departures made by FedEx using the Cessna 208 dropped from 36% at the beginning of 2000 (and a high of 40%) down to 30% by the end of 2010 (a 17% reduction). The share of departures performed by the Boeing 727 dropped even more, from over 26% to less than 12% over the same interval (a 56% reduction). Even with these drops the Cessna 208 remains the most commonly flown aircraft in FedEx's fleet. However, the 727 dropped from the second most flown aircraft type, down to fourth. The share of total departures for each aircraft type in FedEx's fleet, reported ~~quarterly, quarterly~~ can be seen in Figure 3-6. Two aircraft types that saw the biggest increase in their share of departures were the McDonnell Douglas DC-10 and the Airbus A300. The DC10's share increased by nearly 50% (from 12% of the total to 18%), while the A300's share of total departures increased by 83% (from 9% to 16.5%) over the 11 year period.

It cannot be determined from the data analysis if the fleet changes were in response to increased fuel prices. However the data does show, over this period of sustained fuel price increases, that FedEx decreased its use of its less fuel-efficient planes, and increased its use of its more fuel-efficient planes. Looking at the Cessna 208 and Boeing 727, their respective weighted average fuel efficiencies were 0.443 and 0.256 gallons of fuel (g_fuel) per RTM. This is in contrast to the efficiencies of the DC-10 and A300, which have weighted averages of 0.121 and 0.125 g_fuel/RTM, respectively. The DC-10 and A300 are more than twice as efficient as the 727 and more than three and a half times more efficient than the Cessna 208, on a g_fuel/RTM basis. The aggregate fleet wide fuel efficiency for FedEx improved from 0.135 fuel/RTM in Q1 2000, to 0.117 in Q1 2010, a 13% improvement.

Transitioning to a more fuel-efficient fleet went further than just the A300 and the DC-10. FedEx increased the departure share of the wide body McDonnell Douglas MD-11 by 163% (from less than 3% to more than 7% of the share). The MD-11 is the most fuel-efficient aircraft in FedEx's fleet on a ton-mile basis, averaging only 0.085 g_fuel/RTM, and also transports the most cargo per flight operation. Furthermore FedEx began making its first flights with the highly fuel-efficient 777 (0.104 g_fuel/RTM, in limited use) in the first quarter of 2009. This was a little more than a year after jet fuel prices reached their decade peak of \$3.71 per gallon.

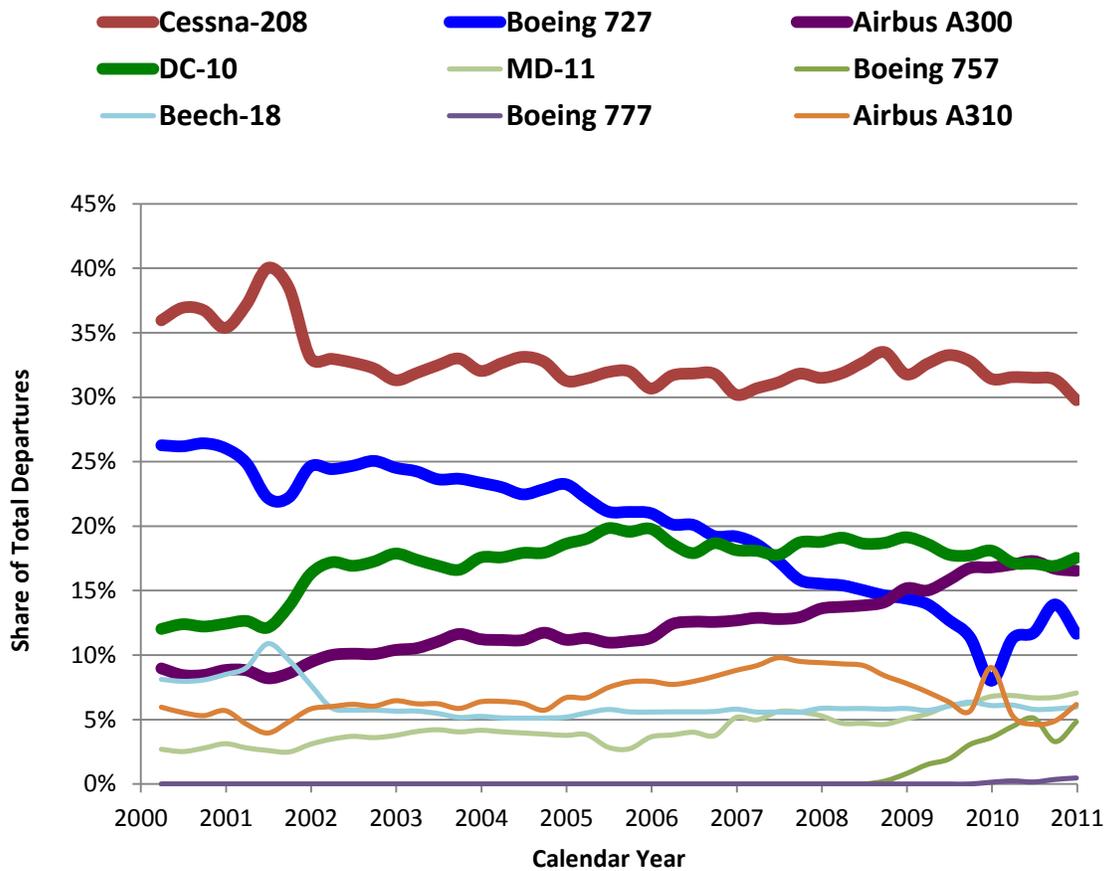


Figure 3-6 Percent share of FedEx's total departures for each aircraft type in its fleet, reported quarterly from 2000-2010.

Figure 3-7 shows the evolution of FedEx's total departures on a quarterly basis from 2000 to 2010. It should be noted that FedEx's overall number of departures differed by only 4% at the end of the decade from those at the beginning (281,451 departures in 2000 versus 270,046 in 2010). Furthermore, for most of the decade, increased fuel prices actually coincided with increased departures. There was a large, nearly 11%, decrease in departures from Q1 2008 to Q1 2009, which followed the US economic recession and crash in fuel prices. All three of these trends lend credence to the belief that airline operations, and in this specific case FedEx's, are relatively inelastic to fuel price changes.

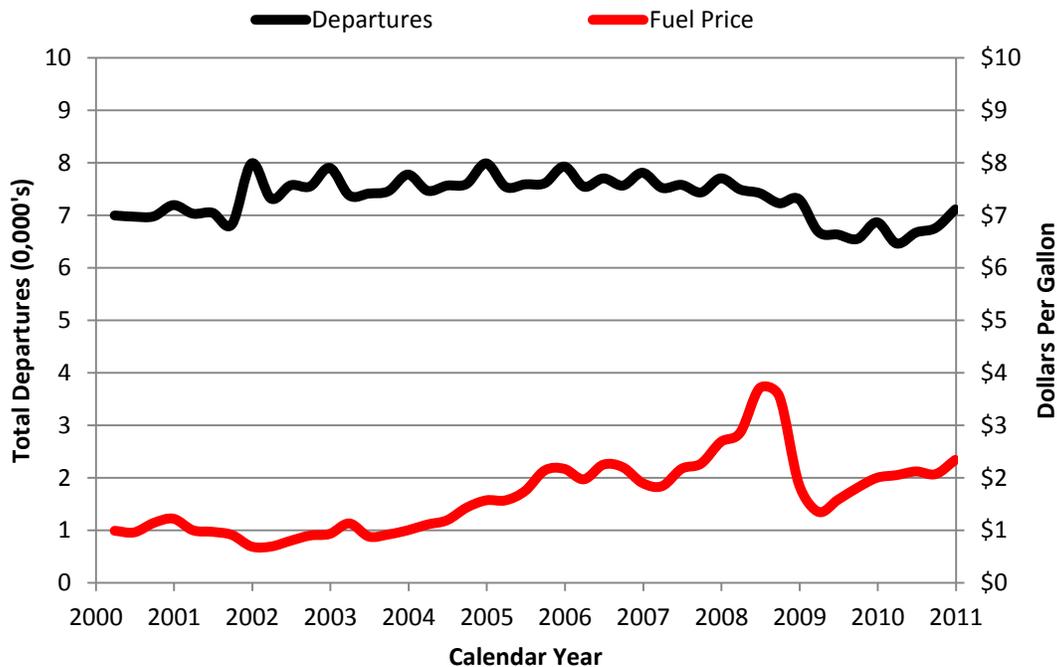


Figure 3-7 FedEx departures reported quarterly, from 2000 through 2010, compared to jet fuel price for the same time period, also reported quarterly.

The fleet changes made by FedEx logically led to operational changes by the airline as well. Figure 3-8 stacks the changes in four operational categories; Plane Miles; Air Hours; RTMs; Departures; with that of fuel price as seen in Figure 3-5. The two most telling metrics in Figure 3-8, and the two that relate most closely to the fleet changes, are Departures and RTMs. As discussed above, the number of departures from the beginning of the decade differs little from the number at the end. Furthermore from 2002 to 2007, the more-or-less sustained level of departures was only about 10% greater than what it was in 2000, and never peaked past 15%. By contrast, the level of RTMs was well over 140% of the initial 2000 value, and peaked at 150% in the fourth quarter of 2007, just before the great recession of 2008. By the final quarter of 2010 departures were less than 2% greater than they were at the beginning of 2000, while RTMs were 140% of their original value.

Overall the data does not reveal a cause and effect between fuel price increase and the operational changes observed, however it is clear that either as a result of, or independent from, fuel price changes, FedEx moved to an aircraft fleet, with increased numbers of wide body jets, which are more efficient on fuel/ton mile basis, and capable of carrying more cargo, more miles, per departure.

The regular fluctuations in the data points for Figure 3-8 reflect seasonal variations in cargo traffic. The holiday season of October-December, which makes up Q4, is consistently the highest trafficked quarter every year (the exception was the period of the great recession of 2008, where demand plummeted). Cargo traffic is consistently the lowest in the cold winter months of Q1, and steadily rises, through the spring and summer of Q2 and Q3, and finally peaking in the late fall and early winter of Q4.

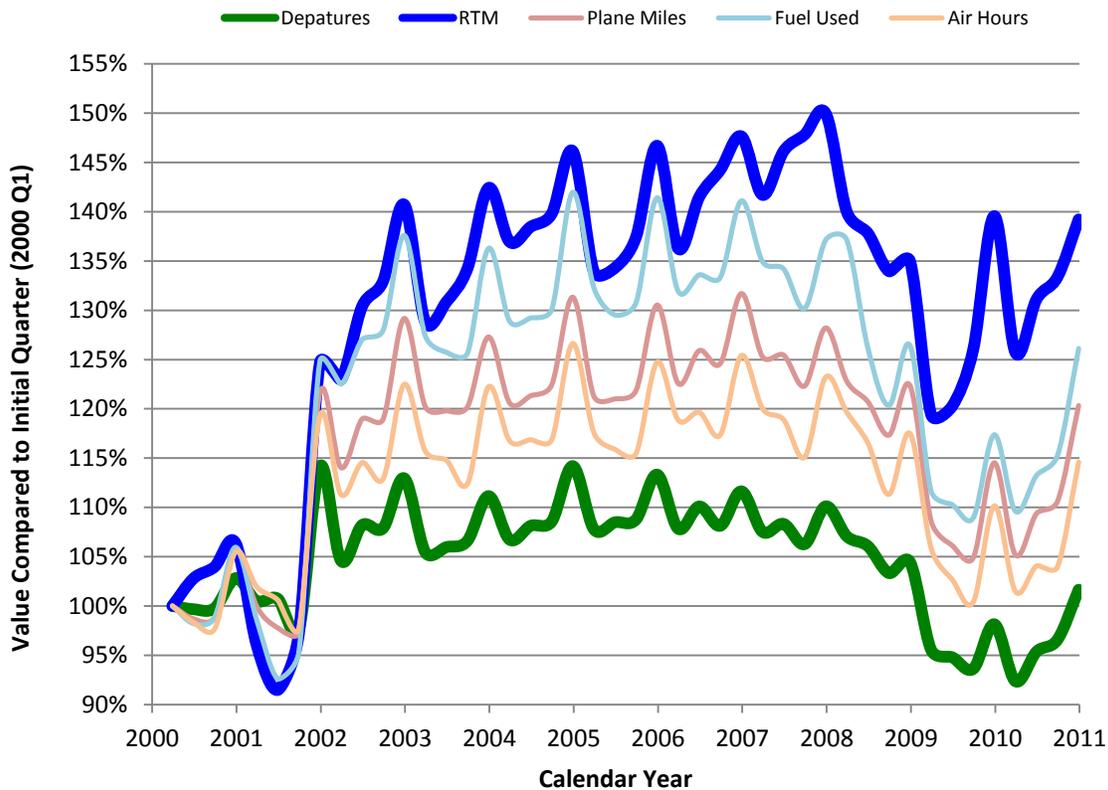


Figure 3-8 Comparison of the Change in air operations performed by FedEx from 2000-2010 using the initial 2000 Q1 value as the baseline; and juxtaposed next to changes in jet fuel price over the same time period.

3.3.3 Actions Taken By UPS

UPS did more than make a few fleet adjustments from 2000 to 2010, it completely overhauled its fleet. Looking at Figure 3-9, three of the five aircraft types used by UPS at the beginning of the decade were either phased out completely, or no longer played a significant role with the airline by the end of the decade. The McDonnell Douglas DC-8, the Boeing 727, and the Boeing 747 all show a gradual decline in usage throughout the decade. The 727 and the DC-8 are no longer in the fleet by the end of 2007 and 2009 respectively, and the 747 has had its departure share drop by 66% (from more than 4% to less than 1.5%). Furthermore UPS's most used aircraft type, the Boeing 757, saw its share drop from 44% of departures, to 34%.

Given that UPS's overall departure numbers have remained fairly static over the decade, total departures, and share, made by these aircraft types had to be replaced by others. As can be seen in Figure 3-9 the McDonnell Douglas MD-11 and the Airbus A300 are the two aircraft that were brought into UPS's fleet during the decade. The efficiency characteristics of UPS's aircraft changes are similar to those of the changes made by FedEx. The 727 and the DC-8 are both relatively fuel inefficient. The weighted average fuel efficiency (g_fuel/RTM) of UPS's 727 fleet was 0.309. This is even more inefficient than FedEx's 727 fleet. Furthermore, the fuel efficiency for the DC-8 of 0.180 g_fuel/RTM is the second lowest efficiency (trailed only by the 727). The two aircraft type replacements, by contrast,

are both substantially more fuel-efficient. The A300, which by the end of 2010 had the greatest departure share of any aircraft type in UPS's fleet, has an aggregate g_fuel/RTM ratio of 0.124. The MD-11 had a 0.095 g_fuel/RTM. The aggregate fleet wide fuel efficiency for UPS improved from 0.125 g_fuel/RTM in Q1 2000, to 0.105 g_fuel/RTM in Q1 2010, a 16% improvement. This trend of fleet replacement and renewal rather than expansion, is further supported by the fact that UPS's departures remained relatively consistent quarter by quarter throughout the decade.

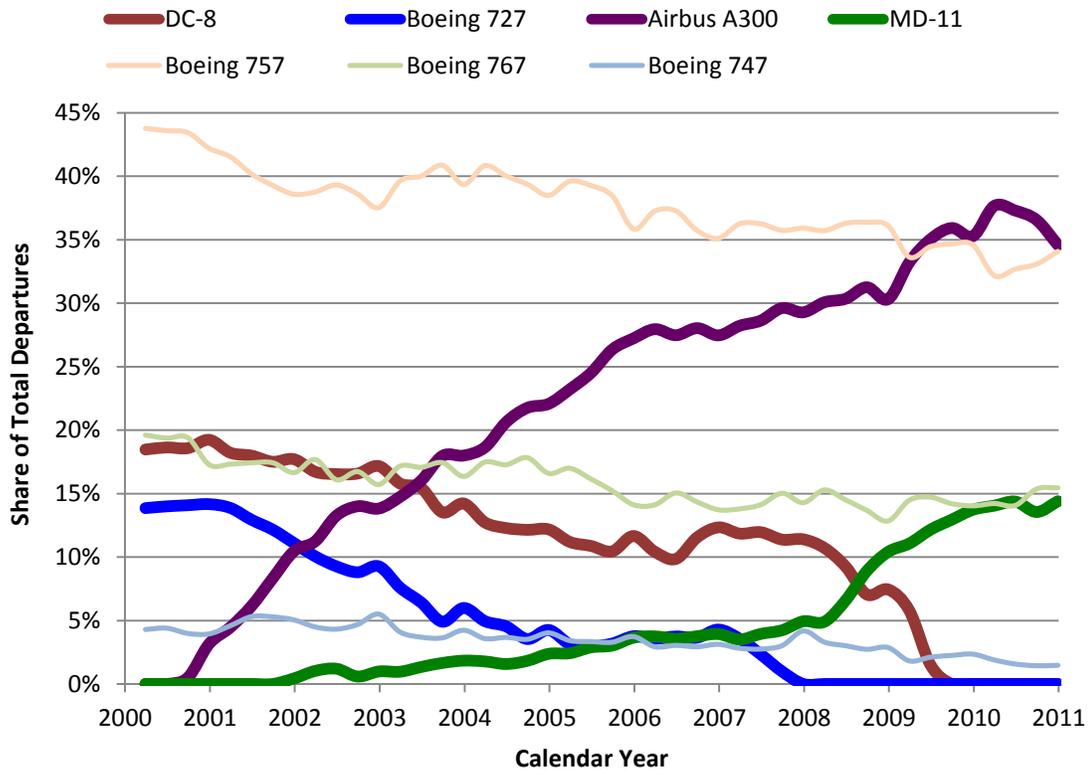


Figure 3-9 Percent Share of UPS's total departures for each aircraft type in its fleet; reported quarterly from 2000-2010.

Operational changes by UPS indicate a period of growth and expansion into the market for most of decade. Except for an initial decline in operational metrics during the year following the September 11th terrorist attacks of 2001, UPS exhibits gradual and consistent growth in RTMs flown. This is in contrast to FedEx, whose RTM output makes a big jump in 2002 and 2003, but then remains relatively constant for the rest of the decade (this excludes most of 2008 and 2009, as these quarters fall within the unique period of the great US recession and global financial crisis). Acknowledging the seasonal variation in air cargo, UPS's RTM output grows methodically from 2003 into the beginning of 2008, and then continues again in 2009, after the effects of the great recession have begun to be mitigated.

A further look at Figure 3-10 shows that by the end of the decade, UPS is performing only 93% of the departures that it did in 2000, and yet is flying 132% of the RTMs. While this cannot be solely

attributable to fleet changes, it is undeniable that UPS made a conscious decision to modify its fleet, emphasizing larger jets, which are able to carry more cargo, and fly greater distances per departure.

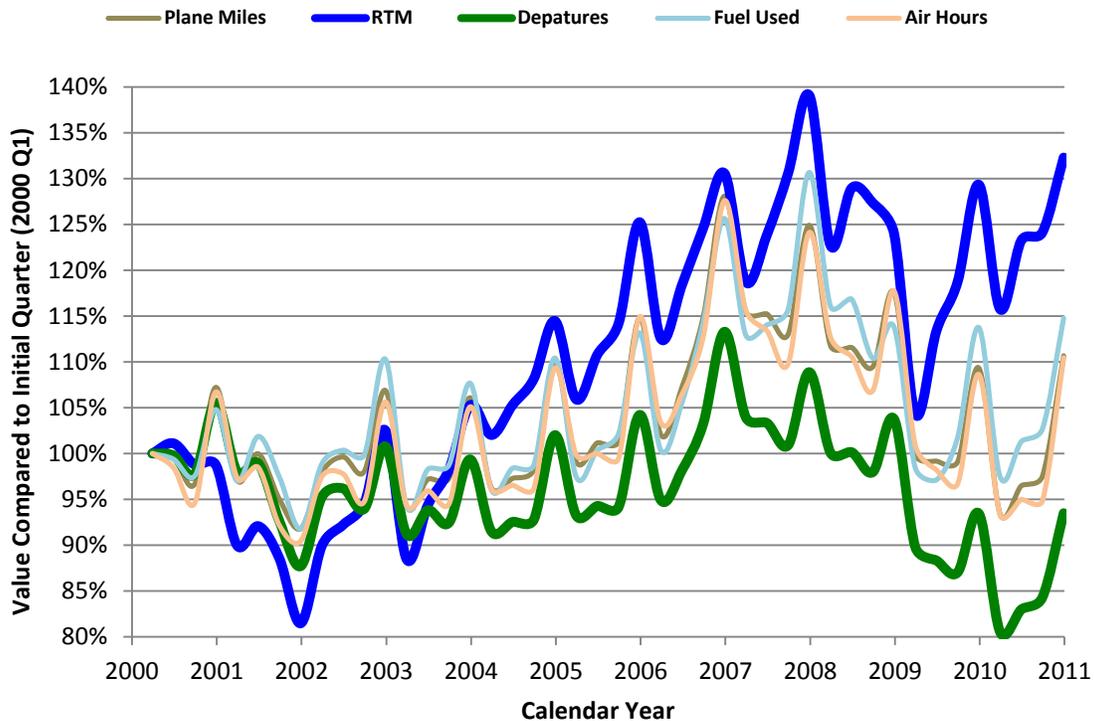


Figure 3-10 Comparison of the change in air operations performed by UPS from 2000-2010 using the initial 2000 quarter 1 value as the baseline; and juxtaposed next to changes in jet fuel price over the same time period.

3.3.4 Actions Taken By Contract Carriers

It is difficult to combine all contract carriers and come up with a generalized trend that describes the actions taken by the group as one entity. Figure 3-11 shows the magnitude of the difference in departures between FedEx, UPS, and the contract carriers. In some years the combined number of departures made by contract carriers is very close to the number made by UPS. However in other years they may be but a third. One interpretation of the data indicates that contract carriers are very susceptible to economic events domestically and are a volatile within market. This volatility in one sense can make it difficult to predict contract carrier operations levels in the future. However the clear effect economic conditions have had on contract carrier output (in this case departures) shows that their output follows the trends in the economy; far more than it does for UPS or FedEx.

Figure 3-12, as it relates to contract carriers, is similar to Figure 3-8 and Figure 3-10 for FedEx and UPS, respectively. Except for the great recession in 2008, there seems to be very little coloration between fuel price evolution and the evolution of RTMs and departures.

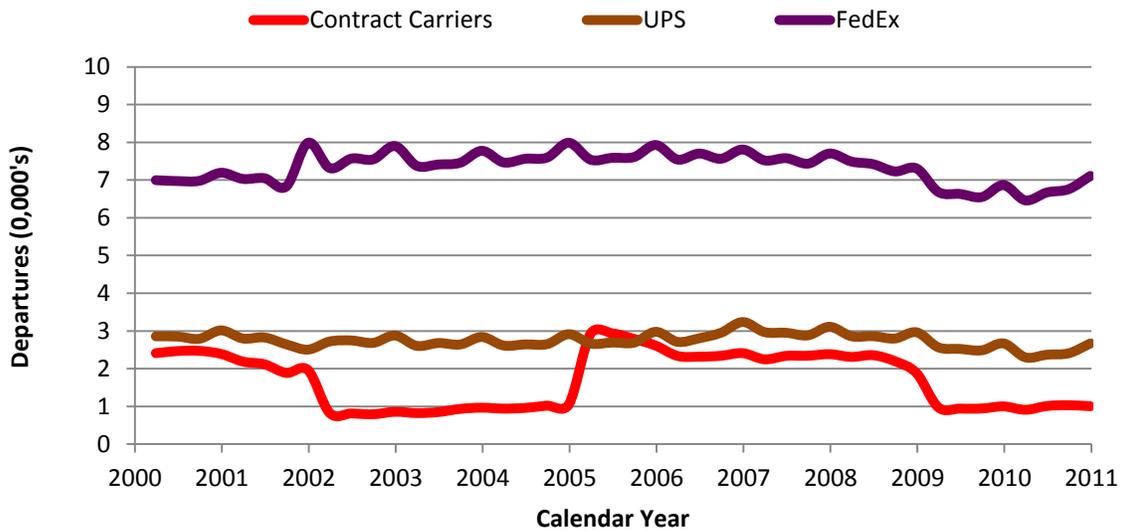


Figure 3-11 Comparison of departures between contract carriers, FedEx, and UPS reported quarterly from 2000-2010.

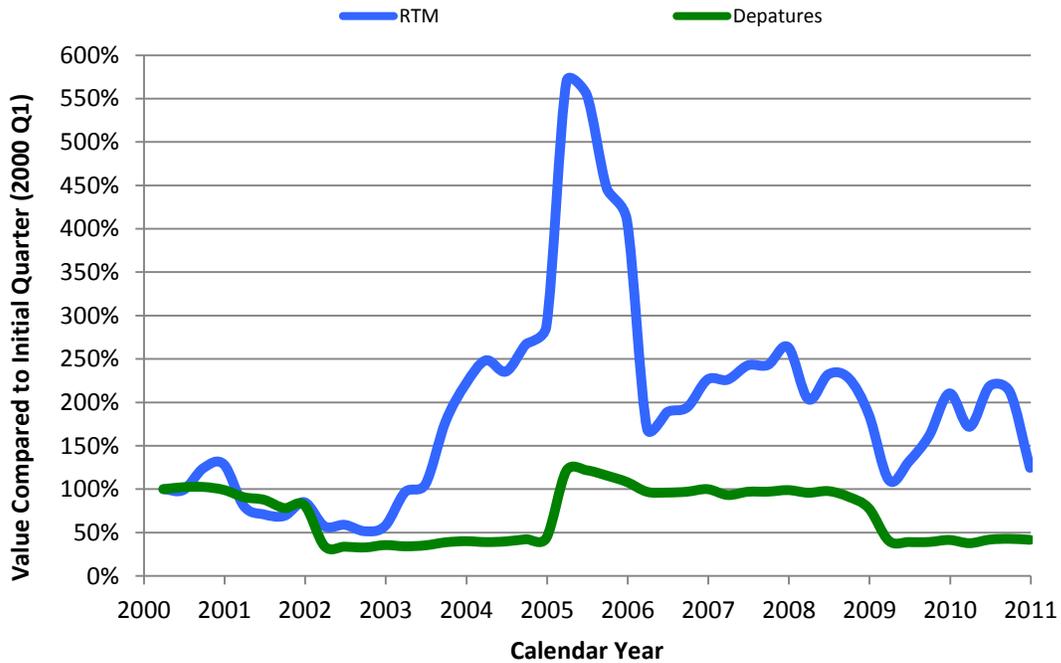


Figure 3-12 Comparison of changes in air operations performed by contract carriers from 2000-2010 using the initial 2000 quarter 1 value as the baseline; and juxtaposed next to changes in jet fuel price over the same time period.

Contract carrier RTMs show immense volatility. Even if the massive anomalous changes in RTMs in 2005 are excluded, quarter-on-quarter and year-on-year shifts of 20-30-40% are common. It is not clear from the data what causes these wild shifts, but clearly the general economic climate plays a role.

However, and perhaps not unexpectedly, fuel price in and of itself does not seem to directly effect contract carrier operations.

3.3.5 Actions Taken By Passenger Carriers

As mentioned in Section 3.2, passenger carriers accounted for nearly 12% of the cargo RTM traffic in 2010. In 2000, passenger carriers accounted for 15% of cargo RTM traffic. Since the primary business of these carriers is not cargo transport but passenger transport, it is hard to make any connection between the price of the fuel and the amount of cargo service they provide. The passenger market governs these carriers' internal economics and decisions; with the US domestic cargo market being just an ancillary side. This being said, passenger carriers still make up a significant portion of the cargo market, yet due to these passenger carriers sheer size of operations, the cargo transported is likely not a deciding factor in how they operate. Therefor 10%-15% of air cargo traffic is governed by outside forces in the commercial passenger market.

3.4 Cargo Network Analysis

Jet fuel price changes do not solely affect aircraft fleet composition and operational outputs. The network structure, and spatial footprint, may also be affected by fuel price changes; directly as a cargo carrier may adjust its business operations; or indirectly as a result of fleet changes necessitating flight operation adjustments at particular airports. This analysis focused on the airport networks of FedEx and UPS, as they are by far the two dominant air cargo carriers in the domestic US market. Eight years of data from the Bureau of Transportation Statistics (BTS) T-100 database provided the basis for the network analysis, allowing temporal comparisons to be made from year-to-year. Gini coefficients, and the Herfindahl–Hirschman Index, were used to quantify the network structure for these two carriers.

The Gini coefficients express the level of inequality that exists in FedEx’s and UPS’s cargo networks. The calculations of the Gini coefficients were done according to Equation 3.1; where X is the cumulative number of airports in the carrier’s network, up to k , and Y is the cumulative amount of cargo (in tons freight and mail), up to value k :

$$G_1 = 1 - \sum_{k=1}^n (X_k - X_{k-1})(Y_k + Y_{k-1}) \quad (3.1)$$

A Gini coefficient of 1.0 implies a completely unequal network, where all cargo traffic comes out of a single airport. Conversely, a Gini coefficient of 0 indicates an equally distributed network, where transported cargo is evenly distributed throughout all airports on the network. Gini coefficients above 0.7 indicate hub-and-spoke systems dominated by a few main hubs. Coefficients approaching 0.8 and 0.9 indicate very large and extensive networks, where traffic is dominated by as few as 3-5 hubs (Reynolds-Feighan, 2013)

The Herfindahl–Hirschman index (HHI) can be used to express how centralized, and hub focused, a carrier’s network is structured. It is typically used to measure the size of a firm (in this case; an airport) in relation to the industry (in this case; the individual carrier’s network). It is an indicator of the amount of competition among these airports. An HHI of 0 indicates the carrier employs a large number of airports, each with the same amount of cargo shipped, whereas an HHI of 1 represents a single large airport where all cargo originates. Generally speaking, HHI scores between 0.15 and 0.25 represent moderately concentrated “markets”, whereas scores above 0.25 are considered highly concentrated and lacking competition (9)

The HHI in this case is calculated by taking the respective share of cargo shipped for each individual airport in the carrier’s network, squaring the individual values, and summing all these values together. The equation for the HHI is as follows,

$$HHI = \sum_{i=1}^N S_i^2 \quad (3.2)$$

where N = the number of airports in the network, and S_i = the share of cargo for that particular airport.

3.4.1 FedEx Network Structure

FedEx has the largest cargo network in the US, with approximately 300 airports operating cargo shipments year-on-year. This is about three times the size of UPS's network, which year-on-year, sends cargo shipments in a domestic network of approximately 100 airports.

Table 3.1 FedEx main hub airports and their cargo traffic share from 2003-2010.

FedEx: Hubs (10)	2003	2004	2005	2006	2007	2008	2009	2010
'EWR'	4%	4%	4%	4%	4%	4%	3%	3%
'OAK'	5%	5%	5%	5%	5%	5%	4%	4%
'IND'	8%	8%	9%	9%	9%	9%	9%	9%
'MEM'	32%	32%	32%	32%	33%	33%	36%	35%
Total Cargo	50%	49%	50%	51%	50%	51%	52%	52%
Total Airports	316	313	313	294	303	314	303	298

FedEx's main network hub has always been Memphis International Airport (MEM). As shown in Table 3.1, MEM comprises roughly 33% of all cargo shipped, each year from 2003 – 2010, and Indianapolis (IND) handles just under 10% of cargo over the same eight-year span. Oakland (OAK) and Newark (EWR) are the third and fourth most trafficked hubs respectively, though with greatly reduced shares (in 2005 LAX was fourth and EWR was the fifth largest hub). Combined, these four hubs consistently have a greater than 50% share of FedEx's cargo shipped. This type of concentration is to be expected for a large cargo carrier with a consolidated hub and spoke system.

3.4.2 UPS Network Structure

While the UPS network consists of only of about 1/3 the number of airports as FedEx's, the structure of the two networks is very similar. Table 3-2 shows the four main UPS hubs, and the yearly share of total cargo transported by the four main hubs. Following very closely the trend observed for FedEx, UPS's main hub, Louisville International Airport (SDF), consistently accounts for roughly 33% of all cargo transported. Furthermore the combined total of all cargo transported, of the top four hubs is right around 50%. The structure of FedEx's and UPS's networks are strikingly similar, with the only major difference being the size of the respective networks.

Table 3.2 UPS main hub airports and their Cargo traffic share from 2003 – 2010.

UPS: Hubs (10)	2003	2004	2005	2006	2007	2008	2009	2010
'PHL'	5%	5%	5%	5%	5%	5%	4%	3%
'ONT'	5%	6%	6%	6%	6%	6%	6%	6%
'ANC'	7%	7%	7%	6%	6%	7%	6%	7%
'SDF'	32%	32%	32%	32%	33%	33%	35%	37%
Total Cargo	49%	50%	50%	50%	50%	50%	52%	54%
Total Airports	103	102	106	111	105	107	106	103

3.4.3 Carrier Network Comparison

Tables 3.3 and 3.4 compare respectively, the Gini coefficients, and the HHI indices for Fedex and UPS. The Gini coefficients for both Fedex and UPS are very high, indicating that both networks have a high degree of inequality in cargo transported. This inequality is also very consistent from year-to-year. The largest year-to-year change in the Gini coefficient was only 0.65% for Fedex and 1.75% for UPS.

Table 3.3 Gini coefficients for the Fedex and UPS networks; from 2003-2010.

Year	2003	2004	2005	2006	2007	2008	2009	2010
FedEx Gini	0.898	0.898	0.899	0.893	0.895	0.897	0.893	0.888
UPS Gini	0.731	0.729	0.732	0.735	0.723	0.734	0.731	0.731

While the Gini coefficients are consistent for both carriers, they do differ significantly in magnitude. Fedex’s Gini is at least 0.21 greater than the Gini for UPS every year. This is the result of Fedex having a much larger network, and one with many small airports with relatively little cargo being transported through them. This leads to a greater level inequality between FedEx’s main hubs and the small airports on the periphery of its network. It is this greater number of “thinner” spokes, in Fedex’s hub and spoke system that leads to the greater inequality.

Table 3.4 Herfindahl–Hirschman indices for the Fedex and UPS networks; from 2003 – 2010.

Year	2003	2004	2005	2006	2007	2008	2009	2010
FedEx HHI	0.735	0.736	0.717	0.716	0.720	0.717	0.726	0.721
UPS HHI	0.803	0.783	0.795	0.803	0.814	0.800	0.807	0.779

The HHI indices for both carriers follow a similar trend to that of the Gini coefficient. The values for both carriers are very high each year, indicating highly consolidated networks with low levels of competition between airports. Furthermore, the values are consistent temporally, with the year-on-year changes in the HHI value never more than 3.5% for either carrier. In half the years the change is only around 1% or less. Both FedEx and UPS focus their cargo operations around only a few main hub airports despite the large size of their networks (see Tables 3.1 and 3.2). This is the cause for these extremely high HHI indices. The higher values for UPS are the result of a smaller overall network size. Both FedEx and UPS have similar 3-5 hub centered networks, but FedEx has more airports, spreading competition out to more entities, disaggregating the network more, and thereby producing lower HHI values.

The main conclusion of this network analysis is that while there are big differences in size and scale of the FedEx’s and UPS’s respective networks, the way those two networks are structured, and the constancy of that structure over time, is strikingly similar. The time period 2003 – 2010 saw huge changes in jet fuel price, and yet the structure of these two carriers’ networks remained virtually static. It appears the significant fleet composition, and operational changes, were made in a way that could be accommodated by a network structure subject to minimal modifications.

3.5 Econometric Analysis and Forecast

We estimated econometric models in order to investigate the historical evolution of US domestic air cargo traffic and yields, and to predict future traffic and yields under different forecast scenarios for oil price and economic growth.

We initially attempted to estimate an aggregate model that incorporated all domestic air cargo traffic carried by air cargo airlines. This proved unsuccessful, probably because of the substantial heterogeneity across the industry, as well as different conventions used by various air cargo airlines in reporting their financial and traffic data to the US DOT. We therefore shifted to a disaggregate approach. We modeled yields and traffic for FedEx and UPS individually, and also attempted an aggregate model for the other air cargo operators. While we obtained reasonable results for FedEx and UPS, the aggregate model again proved unsuccessful. We therefore focus on the individual FedEx and UPS results here.

While FedEx and UPS compete, we did not attempt to capture the competitive behavior in our econometric models. Firstly, the industry is oligopolistic, which makes modeling competition difficult. Second, different product mixes and reporting conventions make it impossible to accurately compare prices for comparable services. Finally, the focus of the study is on the effect of oil price, not competition, and we do not consider complex modeling of competitive dynamics necessary to gauge the impact of oil price.

We employed a cascade regression model that included a price (yield) equation and a demand equation. The basic model formulation is as follows:

$$yield = f(\text{fuel price, other variables})$$

$$traffic = g(\text{yield, GDP, other variables})$$

To forecast with the model, the forecast fuel price is used to estimate yield based on the first equation, and the estimated yield is used, along with forecast GDP, in the second equation.

Table 3-5 summarizes the variables used in the models. In addition to the economic variables, several time-related variables are included. These include a secular trend variable that increases by 1 with each quarter beginning in 1990. Additionally there are seasonal dummy variables defined in terms of quarter (Winter, Spring, Summer, and Fall) and dummy variables for the quarters near the time of the 9/11 terrorist attacks, during which air transport was significantly disrupted.

Both the yield equation and the demand equation were estimated on Form 41 data downloaded from the BTS website. The estimation data sets consisted of quarterly data from 1993 to the first quarter of 2013. Cargo revenue ton-miles was calculated as the difference between total ton-miles and passenger ton-miles. Cargo revenue was calculated as the difference between total operating revenue and the sum of charter passenger revenue, revenue from the transportation of passengers, revenue from cancellation fees, and public service revenue. Yield was calculated as the ratio of cargo revenue and cargo revenue ton-miles. It was converted to 2010 (3rd Quarter) dollars using the CPI obtained from the Bureau of Labor Statistics.

The fuel prices we used are the “U.S. Gulf Coast Kerosene-Type Jet Fuel Spot Prices”, given in dollars per gallon, and converted to 2010 dollars using the CPI. The monthly data was obtained from the US Energy Information Administration (EIA, 2013), calculated by EIA from daily data by taking an average of the daily closing spot prices for U.S. Gulf Coast Kerosene-Type Jet Fuel over the month. As

the other data we had was quarterly data, we calculated quarterly jet fuel prices by taking an unweighted average of the monthly closing spot prices over the quarter.

The real Gross Domestic Product (GDP) is the “output of goods and services produced by labor and property located in the United States”, according to the Bureau of Economic Analysis (BEA, 2013). We used it as the indicator of the state of the economy in the United States. Originally provided in constant 2009 dollars, it was also converted to 2010 dollars.

3.5.1 Yield Model

Specification of the yield model was log-linear. After some experiments, the fuel price term is specified as $FP \cdot \ln(FP)$. If, as in a standard log-linear model, the fuel price term were $\ln(FP)$ then this would imply that the elasticity of yield with respect to fuel price is constant, which is not plausible: as fuel price increases, it accounts for a larger portion of total cost, in which case a fractional increase in fuel price should lead to a larger fractional increase in yield—i.e. the elasticity should increase. The $FP \cdot \ln(FP)$ term has this property.

Initial estimation on the quarterly data set reveals significant autocorrelation in the residuals. When OLS is used for such data the resulting estimates, while unbiased, are inefficient. Moreover, the standard error estimates are biased. We therefore estimated the model using the Yule-Walker method. The estimation results appear in Table 3-6. Estimates on the fuel price ($FP \cdot \ln(FP)$) and *TIME* terms are significant at the .05 level and of comparable magnitude for FedEx and UPS. This establishes the link between yield and fuel price and, since the estimates derive from two different data sets, provides some cross-validation. However, the sensitivity of yield to fuel price implied by these results is quite low. The elasticity of yield to fuel price is the product of the coefficient on the fuel price term and the fuel price. At a fuel price of \$3, this elasticity is less than 0.1 for both models.

The *TIME* terms also tell somewhat similar stories for the two carriers. In the early 1990s, the negative first order effect dominates, reducing yields for both FedEx and UPS. As time progresses, the influence of the positive second order effect grows, shifting the sign of the secular trend from negative to positive in 2010 and 2004 for FedEx and UPS, respectively. One might suspect that the early trend reflects the influence of price competition in the years after UPS' entry into the market, evolving into a less competitive, duopolistic, behavior as the market matures. In any case, the projection of these trends into the future suggests substantial yield growth over the next two decades, irrespective of any change in fuel price. (On the other hand, when we estimate models that exclude the *TIME* variables, the parameter on fuel price becomes small and insignificant, and the overall R^2 substantially diminishes.)

Two coefficients of determination (R^2) values are presented for the models. The regression R^2 reflects the explanatory power of the independent variables alone, while the total R^2 also accounts for the contribution of the autocorrelation in the residual. In both models the total R^2 is much higher than the regression R^2 , reflecting the presence of strong autocorrelation. Moreover, the regression R^2 is rather low, particularly in the case of UPS. Clearly, more research is required to gain a better understanding of the factors influencing yield in this sector.

3.5.2 Traffic Model

The traffic model specification is also log-linear, and estimated separately for FedEx and UPS. As in the yield model, OLS reveals substantial autocorrelation, and as a result the Yule-Walker estimation method is employed. Estimation results are shown in Table 3-7. The estimates on GDP and YIELD have

the expected signs and are statistically significant in both the FedEx and the UPS models, but vary considerably in magnitude. FedEx traffic is more price-sensitive and very highly sensitive to GDP, with a 1% increase in GDP resulting in a traffic increase of over 2%, all else equal. Both models suggest that air cargo is price inelastic (i.e. the price elasticity is less than 1). This is especially true for UPS, for whom a 1% increase in yield results in a traffic reduction of about 0.1%. For FedEx the price elasticity of -0.54 is more typical. In both cases, price elasticities must be interpreted with care since the services offered by each company are highly heterogeneous. There could thus be a substantial change in yield simply as a result of a change in the mix of services provided, without any change in the prices for specific services.

Regarding time effects, both carriers have higher traffic in the fourth quarter, reflecting holiday gift-giving. FedEx traffic also exhibits a negative secular trend of about 2% annually. This may reflect the erosion of its market share as a result of the growth of UPS over this period. On the other hand, economic growth favors FedEx because of the higher GDP elasticity. If GDP grew 2%, the effect of FedEx's higher GDP elasticity would just about offset its secular traffic decline, leaving its traffic growth on a par with that of UPS at about 2%.

These models exhibit considerably greater explanatory power than the yield models, with regression R^2 's of 0.8 or higher and total R^2 's over 0.9. This, in combination with the price inelasticity and higher GDP sensitivity found in both models, allows us to conclude with some confidence that in the future, economic growth will have a larger effect on air cargo traffic levels, than will oil price escalation.

3.5.3 Sensitivity of Future Cargo Traffic to Oil Price and Economic Growth

Now that we have modeled the evolution of the air cargo market based on time series data, we can forecast its future evolution. Our forecasts are based on quarterly data found in *Annual Energy Outlook 2012* (DOE/EIA, 2012), prepared by the U.S. Energy Information Administration (USEIA). Their horizon extends to 2035. There are five main different scenarios for the GDP and fuel prices.

The reference case is defined as a "business-as-usual trend estimate, given known technology and technological and demographic trends", and assumes an annual average growth rate of 2.50% for GDP and 2.40% for jet fuel prices. It assumes the laws and regulations remain unchanged throughout the projections. The average annual growth rate of the U.S. energy consumption is 0.3 percent, lower than the levels of growth experienced in the 20 years prior to the 2008-2009 recession. The reasons of this smaller growth are the "more moderate projected economic growth and population growth, coupled with increasing levels of energy efficiency".

The low economic growth scenario assumes an average growth rate of 2.00% for GDP and 2.30% for kerosene prices. The lower economic growth relative to the reference case is due to lower growth rates for industrial outputs, population and labor productivity as well as higher interest rates.

The high economic growth scenario assumes an average growth rate of 3.00% for GDP and 2.50% for kerosene prices. This case assumes higher growth rates for population, labor productivity, employment while inflation and interest rates are lower than those the reference case.

The low oil price scenario assumes an average growth rate of 2.60% for GDP and an average growth rate of -0.60% for kerosene prices. Here, non-OECD economic growth is assumed to be lower than that in the reference case (3.5 percent per year instead of 5 percent per year from 2010 to 2035). This leads to a slower growth in energy demand. This scenario focuses on non-OECD countries, where there is a higher level of uncertainty about future growth than in mature countries.

The high oil price scenario assumes an average growth rate of 2.60% for GDP and an average growth rate of 3.30% for kerosene prices. In this case, non-OECD countries are assumed to have a higher demand for energy than in other scenarios, leading to higher prices. Higher demand for energy is due to higher economic growth. This scenario also assumes that OPEC countries are reducing their market share and that petroleum liquid resources outside OPEC countries and the United States are less accessible and more expensive to produce than in the reference case, increasing the prices.

To generate an RTM forecast for a particular scenario, we first used the fuel price forecast combined with the yield model to predict future yields. Then, combining the future yield estimate and the scenario-specific GDP forecast, we estimated RTM. The RTM model yields a prediction of the natural log of quarterly RTM. We converted this to annual RTM in conventional units by first converting the quarterly values, using the formula for the expected value of a log-linearly distributed variable:

$$E(\text{RTM}) = \exp[(\ln(\widehat{\text{RTM}}) + 0.5 \cdot \sigma_{\text{RTM}}^2)]$$

where $\ln(\widehat{\text{RTM}})$ is the predicted value of the natural log of RTM, and σ_{RTM} is the standard error of the regression.

Figure 3-13 through 3-15 summarize the results for FedEx and UPS, and for the sum of the two. In all cases, RTM is much more sensitive to the economic growth scenarios than to the fuel price ones. This is hardly surprising in light of the high GDP elasticities in the traffic models, and the comparatively modest fuel price elasticities combined with the low sensitivity of yield to fuel price. All together, the high-growth 2035 RTM level is about 50% greater than the low-growth one, while the high and low oil price scenarios differ by less than 10%.

The FedEx forecast shows increasing traffic through the early to mid-2020s, followed by a decline. This reflects the positive quadratic time coefficient in the FedEx yield model, which eventually overcomes the strong GDP-induced growth for this carrier. UPS, with far lower price elasticity and a smaller quadratic yield effect, exhibits steady RTM growth throughout the forecast period. When the traffic is summed, we find that traffic growth levels off in the mid 2020s, and even begins to decline after 2030 in some scenarios. The reliability of these time projections, based as they are on extrapolations of secular effects estimated on 1993-2013 data, is not great, and almost certainly far less than our estimates of the sensitivity of traffic to economic growth and oil price.

3.5.4 Forecast Uncertainty

In Section 3.5 we used the econometric models and USEIA scenarios to assess the sensitivity of future RTM growth to a plausible range of economic growth and oil price scenarios. It is important to understand that these scenarios do not fully reflect the uncertainties in future RTM growth. One quantifiable uncertainty derives from errors in the regression coefficient estimates, while another comes from the error term in the regression. To assess the magnitudes of the uncertainties arising from these sources, we performed a standard prediction error calculation using the FedEx reference scenario. A full assessment of the prediction error must take uncertainties associated with both the yield equation and the traffic equation into account, and we do not attempt that here. Instead, we assumed full information about future yield as well as GDP, and calculated 95% confidence bounds for future traffic. The results are shown (in a quarterly time series) in Figure 3-16. As is common with econometric forecasts, the confidence intervals widen over time. By 2035, the upper bound is about 70% greater than the lower

bound. Thus the uncertainty deriving from the econometric model, even assuming perfect yield information, is greater than that resulting from uncertainty about future economic output and oil prices.

Table 3.5 Variables used in econometric models.

Variable	Definition
RTM	Cargo Revenue Ton-Miles
GDP	Real Gross Domestic Product (2010 \$)
FP	Jet Fuel Price in (2010 \$)
YIELD	Cargo Revenue per Cargo Revenue Ton-mile
TIME	Time Variable (=1 for first quarter of 1990, 2 for second quarter of 1990, etc.)
TIME2	Time ²
Q_i i=1,2,3,4	Quarter dummy variable (=1 if quarter is i; 0 otherwise)
Q301	Dummy for 3 rd quarter of 2001 (the time of the 9/11 attacks)
Q401	Dummy for 4 th quarter of 2001
Q102	Dummy for 1 st quarter of 2002

Table 3.6 Estimation results, yield regression models.

Variable		FedEx	UPS
Intercept	Estimate	-5.2884	-7.0542
	Std. Error	0.1158	0.0577
FP*LN(FP)	Estimate	0.0226	0.0374
	Std. Error	0.008905	0.0187
TIME	Estimate	-0.0174	-0.007673
	Std. Error	0.004925	0.003567
TIME2	Estimate	0.000112	0.0000775
	Std. Error	0.0000458	0.000036
Q1	Estimate	0.0324	0.04
	Std. Error	0.009168	0.0244
Q2	Estimate	0.0193	-0.0136
	Std. Error	0.007716	0.0217
Q4	Estimate	-0.0122	0.004013
	Std. Error	0.008008	0.0219
Q301	Estimate	--	0.1541
	Std. Error	--	0.0782
Q401	Estimate	-0.0703	--
	Std. Error	0.0332	--
Q102	Estimate	-0.0599	--
	Std. Error	0.0332	--
Reg. R²		0.5121	0.3432
Total R²		0.9567	0.6087

Table 3.7 Estimation results, cargo RTM models.

Variable		FedEx	UPS
Intercept	Estimate	-47.683	-12.05
	Std. Error	6.9384	3.0503
LN(YIELD)	Estimate	-0.5392	-0.1131
	Std. Error	0.0631	0.0495
LN(GDP)	Estimate	2.1785	1.0495
	Std. Error	0.2356	0.0988
TIME	Estimate	-0.00527	--
	Std. Error	0.001438	--
Q1	Estimate	--	-0.0408
	Std. Error	--	0.008258
Q2	Estimate	--	--
	Std. Error	--	--
Q4	Estimate	0.0491	0.0612
	Std. Error	0.005166	0.008007
Q301	Estimate	-0.0541	--
	Std. Error	0.0212	--
Reg. R²		0.9366	0.7983
Total R²		0.9924	0.9472

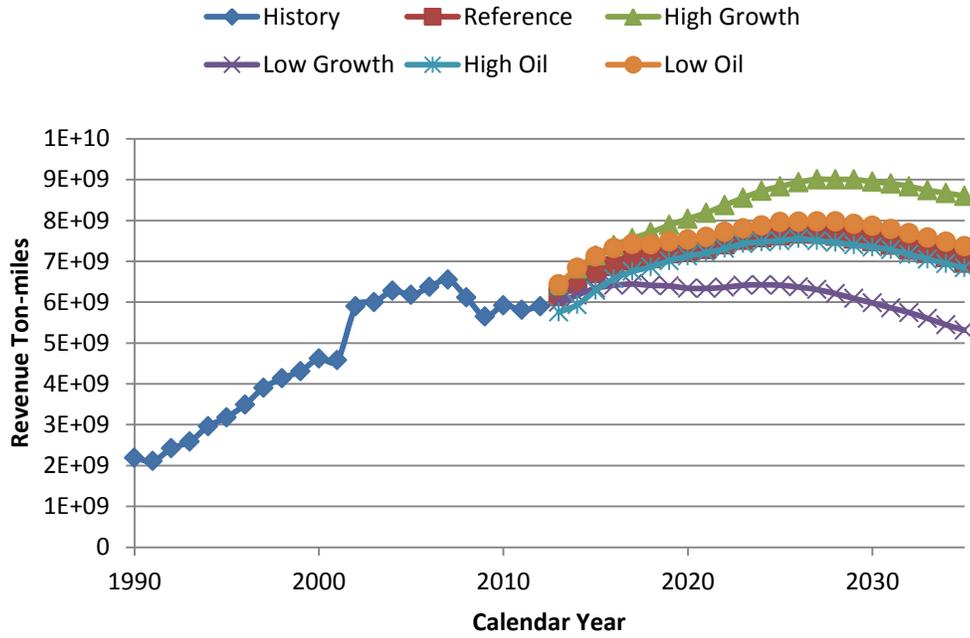


Figure 3-13 FedEx RTM projection under alternative scenarios.

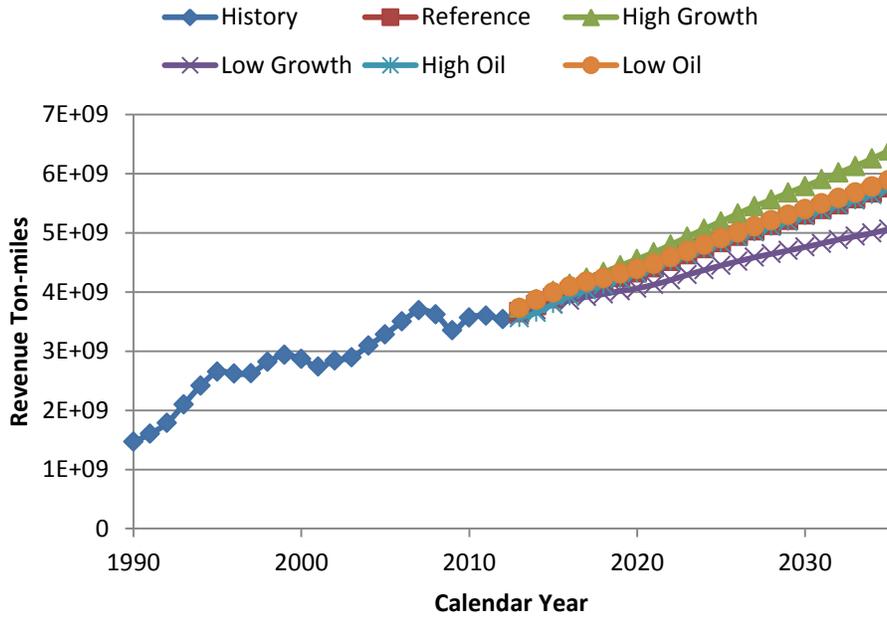


Figure 3-14 UPS RTM projections under alternative scenarios.

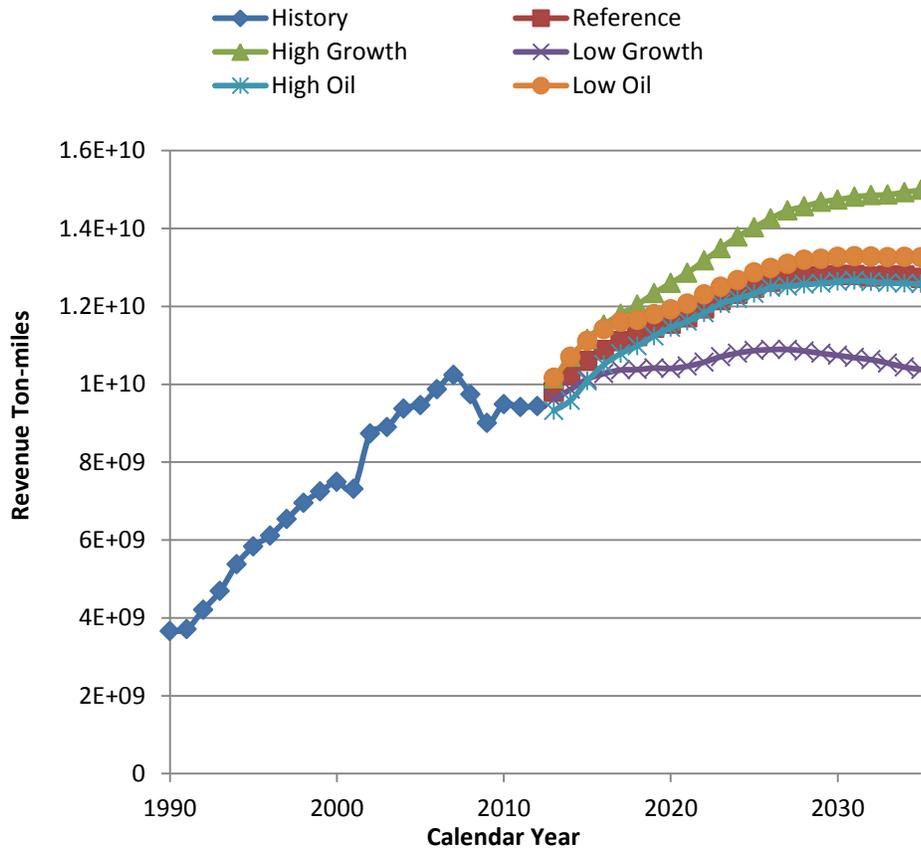


Figure 3-15 FedEx plus UPS RTM projections under alternative scenarios.

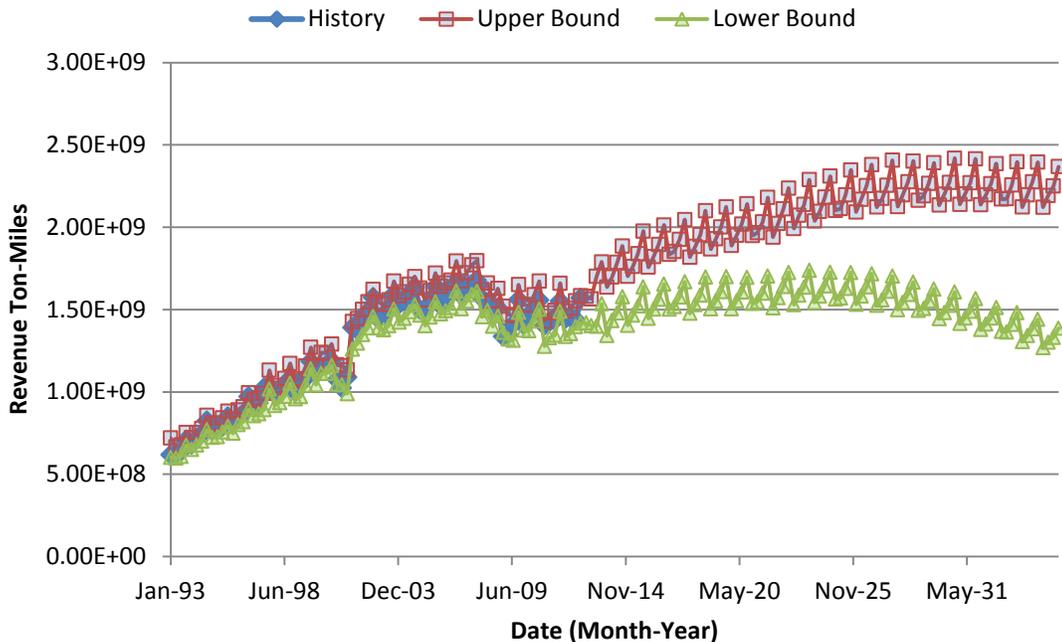


Figure 3-16 Confidence intervals for FedEx RTM, reference scenario, assuming perfect yield information.

3.6 Forecasting Results

From the forecasting statistical analysis it is very likely that GDP growth will have a much greater effect on future cargo traffic than will increases in fuel price (see Figure 3-15). This should not be surprising given the high GDP elasticities for both UPS and FedEx. For FedEx specifically, the high GDP growth rate scenario results in a 65% more RTMs than the low GDP growth scenario. The same trend holds for UPS where the high GDP scenario results in 30% more RTMs flown than in the low GDP scenario. The differences in RTMs flown between the high and low fuel price scenario are only about 5% for FedEx and 1% for UPS.

Independent of scenario type, UPS exhibited an almost linear increase in its RTM traffic over the forecast time period. One explanation for this may be the type of service UPS provides, a very consistent relatively economical, “basic” type shipping service. Regardless of fuel price changes or levels of GDP growth; short of an economic collapse or a population growth eliminating disaster; there will be a gradually increasing demand for UPS’s basic shipping services. FedEx on the other hand had a more volatility and variation in its RTM growth patterns over the forecast period. This may be a result of FedEx’s services geared toward faster, “luxury” options, for air transport. This type of service has greater appeal during times of high economic growth, where additional capital is available to promote faster goods transport in a likely more competitive market.

3.7 Summary for Section 3

In the past decade, air cargo carriers operating jet aircraft made a clear decision to modernize and increase the size of the aircraft in their fleets. This is clearly reflected in the traffic data for United Parcel

Service (UPS) and Federal Express (FedEx). It cannot be shown with the data available or via statistical analysis, if these changes were in direct response to an increase in fuel price. However, given that the cost of jet fuel can easily exceed 25% of operating costs of an air cargo carrier, it is safe to assume that increases in fuel price were a major consideration by cargo carriers when making fleet renewal changes.

Fleet composition changes did not lead to major changes in the network structure for either UPS or FedEx. The minor spatial traffic level changes across each carrier's network segments, over time; indicates that both FedEx and UPS were able to make substantial fleet overhauls without having to adjust their network structures. Large air cargo carriers were able to integrate these larger aircraft, carrying more cargo, into their existing network structures.

The forecast produced in our analysis, shows that air cargo RTMs will increase substantially in the next decades, regardless of differences in GDP growth or fuel price changes. The salient issue is how much these traffic levels could change, given a particular GDP and or fuel price conditions. Furthermore, given the entrenched consistency of FedEx and UPS network structures, it is likely that the air cargo traffic growth will take place as an expansion of traffic along existing segment pairs, rather than a major reworking, and redirecting, of the cargo carriers' network structure.

4 Oil Price Impacts in General Aviation

General Aviation (GA) is the operation of civilian aircraft for purposes other than commercial passenger or cargo transport (U.S. Department of Transportation & Federal Aviation Administration, 2012). Compared with scheduled commercial air services (e.g., passengers and cargo), GA presents modeling challenges due to its flexibility of operation (in term of schedules), larger coverage (in term of destinations), and less restrictions (in terms of operating rules). General aviation is important to the U.S. economy. For example, in 2009, GA contributed \$38.8 billion in economic output. Factoring in manufacturing and visitor expenditures, general aviation accounted for an economic contribution of \$76.5 billion (U.S. Department of Transportation & Federal Aviation Administration, 2012).

The U.S. has the largest and most diverse system of general aviation airports in the world. In the National Plan for Integrated Airport Systems (NPIAS), more than 80% of the airports primarily serve GA operations. According to Terminal Area Forecast (TAF)⁶, the number of GA operations is almost three times the number of commercial air services. In 2009, non-airline operators at the general aviation airports alone spent over \$12 billion, flying an estimated 27 million flights. For many airports, GA operations is their major revenue source and justification to receive Federal funding (Federal Aviation Administration and U.S. Department of Transportation, 2010).

From the viewpoint of air service users, GA provides access to air transportation in rural and remote communities where limited commercial air services are offered. Besides transport, GA is also the primary means of delivering many other purposes such as aerial applications, instructional, law enforcement and disaster relief. However, as an essential part of the air transportation system, GA activities have been declining significantly in the past decade. Statistics from the TAF shows that from 1999 to 2010, the itinerant operations at the TAF airports decreased by about 12% while the local operation decreased by about 20.5% (see Figure 4-1). At the same time, the General Aviation and Air Taxi Survey (GAATA) survey also reports a 22% decline in the total number of hours flown by the GA, and a 30% drop in the utilization rate (average hours flown by an aircraft) of fixed aircraft.

It is believed that the decline in the GA activities is partially due to the high fuel prices (Federal Aviation Administration and U.S. Department of Transportation, 2010). Figure 4-1 shows the price of two typical GA fuels from 1999 to 2012. It can be observed that the price of Avgas and Jet-A increased by 92% and 120%, respectively in that period. In 2000, the cost of purchasing 1000 gallons of jet-A fuel accounted for about 8.5% of the U.S. personal income per capita. However, this number increased to about 13.7% in 2011. Little research has been done to specifically evaluate the impact of fuel price on General Aviation demand. However, it is clear that fuel prices affect the activity of all modes of transportation. The study by (Maghelal, 2011) shows that fuel price could significantly impact the U.S. transit ridership. The statistical model suggests that an additional one-dollar increase to the average fuel cost could result in an increase in transit trips by 484%. (Macharis et al., 2010) developed a GIS-based model to investigate the impact of fuel price on the competition between the intermodal transport (e.g., rail and barge) and unimodal transport (e.g., road). They found that demand shifts to intermodal transport

⁶ Statistics is obtained from TAF 2010. Operations reported as air carrier and air taxi/commuter is counted as commercial air services. Operations reported as itinerant and local GA is counted as GA.

if the fuel price increases. Gallo et al., (2011) concluded that a 22% increase in fuel price translates to a 2.56% decrease in demand for car use in Italy.

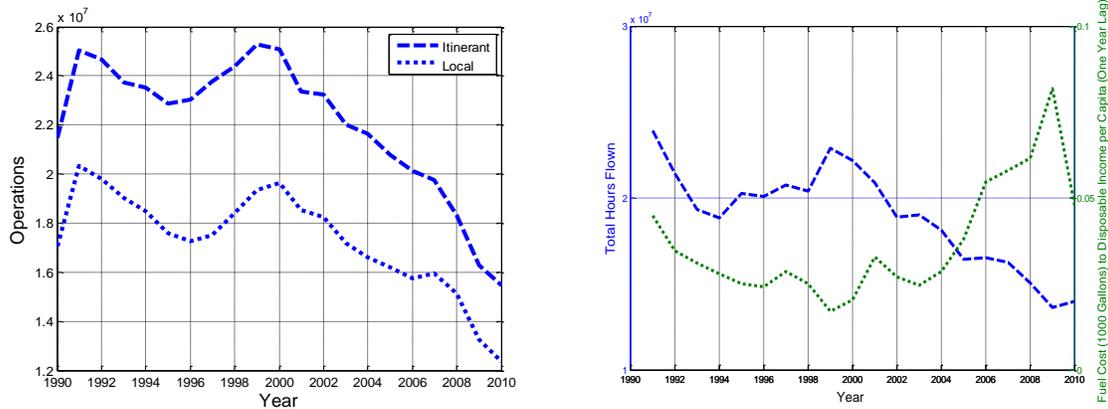


Figure 4-1 Historical trends of local and itinerant GA operations. Source: FAA.

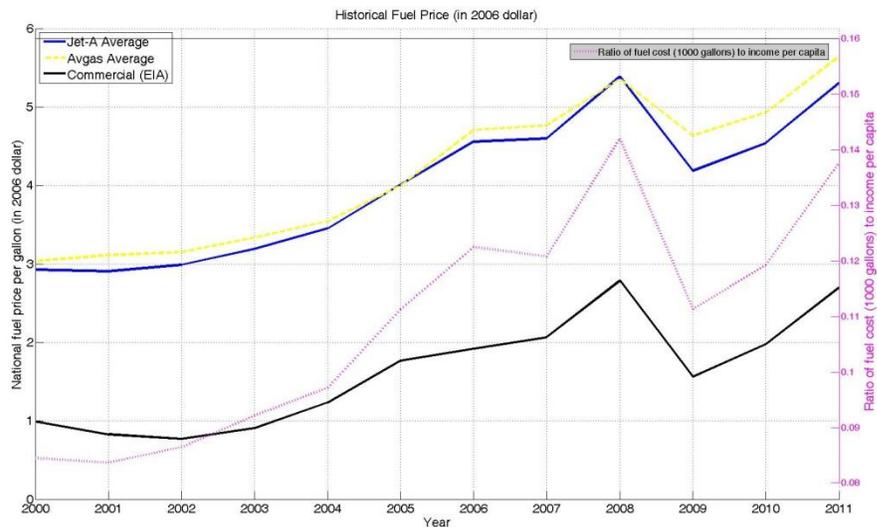


Figure 4-2 Historical trends of jet-a and avgas prices. Source: Business and Commercial Aviation.

4.1 Objectives

The objective of this section is to model the impact of fuel price on the GA demand at the airport level. To avoid confusion, GA demand refers to the number of GA operations (including both takeoff and landings) in the National Airspace System (NAS). Our analysis focuses on the itinerant and local GA operations reported in TAF. Local operations refer to aircraft operating in the traffic pattern or within sight of the tower, or aircraft known to be departing or arriving to and from local practice areas, or aircraft executing practice instrument approaches at the airport. Itinerant operations refer to operations of aircraft flying from one airport to another one. FAA reports all aircraft operations other than local operations as

itinerant. The analysis does not include air taxi operations because in TAF GA air taxi operations and commercial commuter operations are reported in the same category, and a separation of the two is not available. In the 2010 GAATA survey, the number of hours flown by air taxi⁷ accounted for 13% of the total number of hours flown by GA. Therefore, we believe our analysis covers the majority of the GA operations and is representative.

The models presented in this section could be used to forecast GA activities and evaluate the impact of fuel prices on GA demand. They could help the FAA to better allocate funding amongst GA airports, and airport planners to make appropriate plans to serve the local GA demand.

4.2 Review of Previous Research

In commercial air transportation, historical data is relatively well documented. A significant body of research has been published. By model outputs, they can be classified into two major categories: a) models to estimate demand, and b) models to estimate the distribution of the travel demand function. Models in the first category generate travel demand by using techniques such as statistical and gravity-based models (See, for example, (Abed et al., 2001; Grosche et al., 2007; Hsu & Wen, 2003; Kopsch, 2012; Marazzo et al., 2010; Pitfield et al., 2010; Ryerson & Hansen, 2010, 2011; Shen, 2004; Wei & Hansen, 2003, 2005, 2006)). Models in the second category estimate the distribution (i.e., market share) of travel demand mainly by using discrete choice models (See, for example, (Coldren & Koppelman, 2005; Coldren et al., 2003; Georg et al., 2006; Hess et al., 2007; K. Proussaloglou & Koppelman, 1995; Kimon Proussaloglou & Koppelman, 1999; Teichert et al., 2008; Warburg et al., 2006; Wen & Lai, 2010; Yoo & Ashford, 1996)).

Unlike commercial air transportation, historical data of GA operations is more limited. Demand modeling is more subjected to data availability, and hence relatively less research has been done. (Baik et al., 2006; D. Long et al., 2001) developed gravity models to distribute GA demand amongst destination airports by considering the number of based aircraft, number itinerant operations, and distance between airports. (Baxter & Philip Howrey, 1968; Ghobrial, 1997; Ghobrial & Ramdass, 1993; D. Long et al., 2001; Dou Long et al., 2001; Ratchford, 1974; Vahovich, 1978) used regression models to generate GA demand at different levels (e.g., national level or airport level) with explanatory variables such as socioeconomic factors and infrastructure supply factors (e.g., number of airports, runway length, and presence of control tower).

Nationwide GA demand modeling studies the GA demand from the point of view of economics. In order to estimate the GA demand, (Ratchford, 1974) developed a theoretical model for measuring the quantity and price of a service flow obtained from a durable good. The model can be applied in cases where aircraft utilization rate varies over time, and operating costs are independent of the purchase prices.

Further, using linear and translog models, (Ratchford, 1974) studied the impact of disposable income and GA price (which is determined by operating cost and fixed cost) on the GA service quantity (which is a function of aircraft stock and utilization rate). The study concluded that the GA service quantity is sensitive to income and GA prices changes.

⁷ It includes hours flown reported in category air taxi, air tour and air med in 2010 GAATA survey.

(Vahovich, 1978) adopted semi-translog and double translog functions to study the impact of aircraft operating cost and income on the number of hours flown by individual owners (versus companies). Some of the conclusions are: 1) for itinerant demand (hours flown), the elasticity of income is less (about 0.1) than for local operations. For local demand, the coefficient suggests that income has a negative effect on the local demand; however, it is not significant at a 5% significance level. 2) Variable cost is a significant determinant of hours flown. For local demand (hours flown), the elasticity is about -0.4, which indicates that a 10% increase in the cost would result in about 4% decrease in the local hours flown. For itinerant demand, it increases as cost increases until the costs reaches a critical point, beyond which demand begins to decrease.

Airport-level GA demand modeling often analyzes the demand from the engineering perspective. In many cases, they are also used as forecasting tools. (Ghobrial & Ramdass, 1993) developed an econometric model to forecast demand at GA airports. Their model is calibrated using data collected from 20 airports in Florida. Further, (Ghobrial, 1997) extended the model by enhancing model structure and using a larger sample of GA airports (82 GA airports) in Georgia for model calibration. In the extended model, the dependent variable is number of operations at a GA airport. The explanatory variables considered can be classified into three categories: 1) social-economic and demographic factors (e.g., employment and population) around the airport, 2) supply factors (e.g., airport tower and aircraft rental services) at or around the airport, and 3) location factor (e.g., whether an airport is close to tourist/recreational area or urban area). By using different combination of explanatory variables, four models are calibrated. The R-square of the four models is around 0.65.

(Dou Long et al., 2001) developed a linear model to forecast GA demand. The explanatory variables are population, household income within certain radius of the airport. The model is calibrated using the operations data of TAF airports and the Airport Demographic and Economic Database. The R-square of the model developed is about 0.3 for the nationwide model. The R-squares range from 0.3 to 0.6 if a separate model is calibrated for each of the nine FAA regions.

(Hoekstra, 2000) employed a linear regression model to forecast GA operations at small towered and non-towered airports. The explanatory variables include: number of based aircraft, income per capita and non-agricultural employment at the airport's county, dummy variables indicating the airport's FAA region, and dummy variable indicating whether the airport is certificated for commercial services. Further, (GRA, 2001) refined his model by considering more "local" explanatory variables such as presence of a flight school around the airport, population within certain radius of the airport, percentage of the airport's based aircraft among the total based aircraft within certain radius of the airport. Both of the models are calibrated using similar set of airports (127 small towered airports), and have an R-square of about 0.7.

Besides fuel cost, an aircraft's operating cost usually includes: oil cost, airframe, avionics, engine overhaul, maintenance cost and etc. However, compared with other costs, fuel cost is more correlated with aircraft usage. In addition, it is less predictable and could fluctuate significantly within short time periods. These indicate that its impact on the GA demand could be stronger than other operating costs. Thus, a separate study of its impact on the GA demand is necessary.

4.3 Data Sets Employed in the Study

As stated before, GA operations have less data compared to commercial operations. IN the next paragraphs we described some of the relevant data sources used to develop GA aviation activity models.

4.3.1 Terminal Area Forecast

The TAF contains historical and forecast information for enplanements, airport operations, TRACON operations, and based aircraft. The data covers 264 FAA towered airports, 248 Federal contract tower airports, 31 terminal radar approach control facilities, and 2,824 non-FAA airports. In the TAF, historical data at the towered airports are collected by air traffic controllers. Data for the non-towered airports represent “best estimates” and thus are less reliable. Based aircraft reported in TAF are aircraft (mostly general aviation aircraft) that are permanently based at the airport.

Table 4.1 presents the information about based aircraft at three TAF airports. There are five aircraft categories in TAF: single engine, multiple engine, jet engine, helicopters and others. Table 4.2 presents the operation at the three airports. There are seven operational categories.

- 1) Itinerant air carriers: represent the operations of commercial aircraft with seating capacity greater than 60.
- 2) Itinerant air taxi and commuter: represent the operations of aircraft with 60 or fewer seats and commuters with seating capacity with 60 or less that transport regional passengers on scheduled commercial flights.
- 3) Itinerant and local GA: represent all the operations of all the civil aircraft not classified as commercial.
- 4) Itinerant and local military: represent all the operations of all the military aircraft.
- 5) Overflights: represent the operations of aircraft in transit through the approach control facility airspace.

Table 4.1 Based aircraft in TAF.

Based aircraft	Single Engine	Jet Engine	Multiple Engine	Helicopters	Other
MEM	13	37	14	0	0
BCB	29	1	4	1	0
ATL	0	0	0	3	0

Table 4.2 Operations in TAF.

Operations	Itinerant Air Carrier	Itinerant Air Taxi and Commuter	Itinerant GA	Itinerant Military	Local GA	Local Military	Overflights
MEM	192,273	124,268	18,364	1,423	0	0	6,661
BCB	0	344	11,741	286	5,454	0	0
ATL	721,063	226,981	7,472	1,030	0	0	1,903

The TAF is prepared to assist the FAA in meeting its planning, budgeting and staffing requirements. Many state airport authorities and other aviation planners also use it as the basis or benchmark for airport planning and improvements. Therefore, we decided to use the operations information in the TAF for model calibration. This will guarantee that our models are consistent with the industry practice, and hence the model outputs can be used by the FAA.

It is necessary to point out that in our model calibration we also include the operations at the non-towered TAF airports. First, they account for about 60% of the GA operations in TAF. Excluding them could lead to parameter estimation bias to the towered airports. Second, the information about GA operations at those airports is less reliable and thus they represent our best estimates.

4.3.2 National Plan of Integrated Airport Systems (NPIAS)

In NPIAS, airports are classified into four major categories depending on factors such as passengers boarding and number of based aircraft. Figure 4-3 illustrates the airport classification in NPIAS.

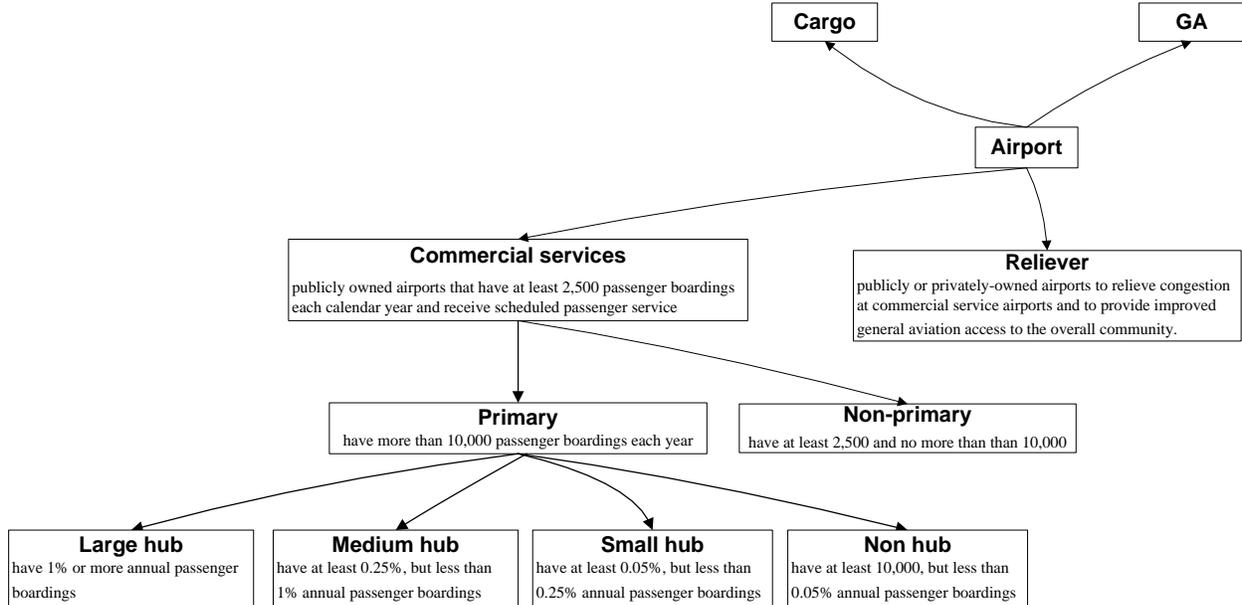


Figure 4-3 Classification of airports according to NPIAS.

The FAA airport database employed in this study is the FAA Landing Facilities database. It contains information about all landing facilities in the U.S. or its territories. Facilities information contains a facility *ID*, runway information and the general description of aviation maintenance services at the airport. Because our models require socio-economic based information around airports, we employed the Woods and Poole Economics database for years 2005-2009 (Woods and Poole Economics, 2009)

4.4 Econometric Model to Predict General Aviation Operations

We adopted the econometric model similar to the one used by (Ghobrial, 1997). The advantage of the model is that it provides a straightforward insight about the elasticity of fuel price. The econometric model has the form shown in Equation 4.1:

$$Opers = \left(\prod F_i^{\alpha_i} \right) \times e^{\beta_0 + \sum \beta_j F_j} \quad (4.1)$$

In economics, one important measurement of the quantitative responsiveness of a variable *D* (e.g., demand) to a change in another variable *P* (e.g., price) is the elasticity. More precisely, elasticity is defined as the percentage change in quantity of a variable *D* due to a percentage change in another variable *P* (the other variables are assumed to be constant). Elasticity is calculated by:

$$elasticity = \frac{\frac{\partial D}{D}}{\frac{\partial P}{P}} = \frac{P \partial D}{D \partial P} \quad (4.2)$$

The elasticity of GA operations with respect to a variable is associated with the variable's corresponding coefficient (i.e., α_i or β_j) in the model.

Applying the logarithmic function on both sides of the equation, we have

$$\log(Opers) = \sum \alpha_i \log(F_i) + \sum \beta_j F_j \quad (4.3)$$

Taking the derive with respect to F_i on both sides of the equation, we have,

$$\frac{1}{Opers} \frac{\partial Opers}{\partial F_i} = \alpha_i \frac{1}{F_i} \quad (4.4)$$

Rearranging the terms, we have,

$$\frac{F_i}{Opers} \frac{\partial Opers}{\partial F_i} = \alpha_i \quad (4.5)$$

The left-hand-side of the equation is elasticity of *Opers* with respect to variable F_i , it equals to the coefficient of variable F_i in the economic model (i.e., α_i).

4.4.1 Explanatory Variables Investigated

4.4.1.1 Socio-economic factors:

In commercial aviation, many carriers have adopted a hub-and-spoke network in which OD pairs are usually connected through one connection at a hub. In this case, local factors may not always be able to adequately explain carrier operations especially when the airport is a hub. Different from commercial aviation, GA operations are usually point-to-point. In this case, the “local” social-economic factors play a more significant role in generating and attracting GA operations. As shown in (Ghobrial, 1997; D. Long et al., 2001), the number of people around the airport has a positive impact on the GA operations. That is, more population around the airport tends to generate or attract more GA operations. Previous research on airport-level GA operations focused on the socio-economic and demographic factors around the airport. Similarly, the following local factors are considered in this study. (Ghobrial, 1997) considered the population in the county where the airport is located. (GRA, 2001; Dou Long et al., 2001) considered the population within certain radius (e.g., 50 or 100 miles) of the airport.

Following previous studies, the local socio-economic and demographic factors are also considered in our study. In the National Plan of Integrated Airport System (NPIAS), an airport is considered to be particularly important to communities that have limited or access to scheduled commercial services, and included in the NPIAS if it is at least 20 miles from the nearest NPIAS airport. In other words, in NPIAS, an airport is considered to primarily serve the GA demand within 20 miles around the airport. Following this, we considered the socio-economic and demographic factors of all the counties whose centers are within the 20 miles radius of the airport. This is slightly different from the previous studies in which the total social-economic and demographic factors (e.g., population) within a certain radius are considered. This is because the socio-economic and demographic data available to this study is reported at the county level (i.e., Wood and Poole). The following are the local socio-economic and demographic factors that were investigated.

Table 4.3 Local factor variables used in GA demand models.

Local factors	Expected impact on GA activities	Data Sources	Variable type
The weighted average (by population) income per capita of all the counties whose centers are within 20 miles of the airport	In general, the personal income is positively correlated with the consumption of general aviation services (Ratchford, 1974). This means its coefficient is expected to be positive	Woods & Poole Data	
Fuel price	As stated earlier, high fuel price tends to discourage GA demand. So, its coefficient is expected to be negative.	Business Aviation	
The weighted average (by population) of the ratio of the cost of purchasing 1000 gallons of fuel to the income per capita of the counties whose centers are within 20 miles of the airport	This factor can be considered as the relative fuel price. In (Vahovich, 1978), the ratio of cost to income is also found to have negative impact on the hours flown, which indicate that, as cost takes larger portion of an individual's income, hours flown decreases. In other words, if the relative fuel price goes up, then the GA demand tends to decline. Therefore, its coefficient is expected to be negative	Woods & Poole Data and Business Aviation	
The number of farm industry employment of all the counties whose centers are within 20 miles of the airport	Farm and forestry industry may have significant demand on aerial applications and observations. Thus, these two factors may have significant impact on the number of local operations	Woods & Poole Data	
The number of forestry employment of all the counties whose centers are within 20 miles of the airport			
Whether there is a flight school based at the airport	Since most of the instructional flights are local, this factor is expected to have significant influence on the number of local operations at an airport. More specifically, an airport tends to have more local operations if there is a flight school based at it.		dummy variable, it is 1 if there is one based at the airport; 0 otherwise.

In many cases, aviation is used as a medium and long-distance travel tool. This means the demand at an airport may be subjected to its “external environment” (e.g. economy condition). In order to capture the role of the “external environment”, we considered the factors reported in Table 4.4. We investigated two types of GA fuels: Avgas and Jet-A. Avgas is used by piston engine aircraft; Jet-A fuel is used by turboprop and turbofan (or turbojet) engine aircraft. However, as shown in Table 4.5, their historical prices are highly correlated. As a result, considering both of them in the model may introduce multicollinearity. To avoid this and to maintain consistency, we only considered the jet-A fuel price in the GA models.

Table 4.4 External variables used in GA demand models.

External Factors	Expected impact on GA activities	Data Sources
The total gross state product (GSP) of the counties whose centers are less than 500 miles but greater than 100 miles from the airport	These factors are expected to be positively related to GA activities. Their coefficients are expected to be positive	Woods & Poole Data
The total population of the counties whose centers are less than 500 miles but greater than 100 miles from the airport		
The total employment of the counties whose centers are less than 500 miles but greater than 100 miles from the airport		
The gross state product (GSP) of the state where the airport is located		
The total population of the state where the airport is located		
The total employment of the state where the airport is located		

Table 4.5 Regional correlation of GA fuel prices.

Fuel types	Statistics	FAA Region								Nation-wide
		Eastern	New England	Great Lakes	Central	Southern	Southwest	NW Mountain	Western Pacific	
Avgas and Jet-A (GA)	Coefficient of correlation	0.99	0.98	0.98	0.98	0.98	0.99	0.98	0.98	0.99
	P-value	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Avgas and commercial Jet-A	Coefficient of correlation	0.95	0.97	0.95	0.96	0.97	0.95	0.96	0.95	0.96
	P-value	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Jet-A (GA) and commercial Jet-A	Coefficient of correlation	0.98	0.99	0.99	0.99	0.99	0.98	0.99	0.99	0.99
	P-value	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Commercial Jet-A fuel price includes Federal and State taxes while excluding county and local taxes. Data is obtained from Energy Information Administration (EIA). Avgas and Jet-A fuel prices for GA are full retail and include all taxes and fees. The prices are results from a fuel price survey conducted by Aviation Research Group/US (ARG/US).

4.4.1.2 Airport Level-of-service Factors

An airport's level-of-service factor refers to facilities (e.g., control tower and ILS), infrastructure (e.g., runways), and services (e.g., engine and body repair stations) provided at the airport. These factors are crucial for the aviation activities. For example, the operations of large aircraft usually require long runways and good runway pavements. (Ghobrial, 1997) found that the presence of a control tower could increase the GA operations by about 253%, and presence of a runway with runway length greater than 4000 feet would increase the GA operations by 52%. We investigated various level-of-service factors at an airport shown in Table 4.6.

Table 4.6 Airport level of services factors considered in the development of GA demand models.

Level-of-Service factors	Expected impact on GA activities	Data Sources	Variable type
Total number of runways at the airport	In most of cases, availability of a service factor is expected to have positive impact on GA activities. Their coefficients are expected to be positive. For example, at many airports, runways are shared by both GA and scheduled commercial services. Hence, more runways means higher capacity and less congestion.	FAA airport data base	dummy variable, it is 1 if there is one based at the airport; 0 otherwise.
Presence of an airport control tower			
Availability of a concrete or asphalt runway at the airport			
Availability of a runway with runway length greater than 4000 ft. at the airport			
Availability of a runway with runway length greater than 1000 ft. at the airport			
Availability of an ILS at an airport			
Unavailability of an engine repair station at the airport			dummy variable, it is 1 if there is none at the airport; 0 otherwise.
Unavailability of a fuselage repair station at the airport			

4.4.1.3 Number of Based Aircraft at an Airport

Based aircraft at an airport are the operational and airworthy general aviation aircraft with hangar and tie-down space at the airport for at least a year. Thus, the number of based aircraft at an airport is expected to have a significant influence on the number GA operations at the airport. Under similar conditions, airports with more aircraft based at the airport tend to generate and attract more GA activities. For example, in 2010, the correlation coefficient between the number of itinerant operations and the total number of based aircraft at TAF airports is about 0.75. According to 2010 GAATA survey, 65% of the hours flown by local operations are performed by single engine piston aircraft and none of them are performed by turbofan aircraft. We investigated aircraft of the following five categories shown in Table 4.7.

Table 4.7 Number of based aircraft considered in the development of GA demand models.

Number of based aircraft at an airport	Expected impact on GA activities	Data Sources
Number of single engine aircraft based at the airport	These two factors are expected to have positive impact on GA activities. Since most of local hours flown is performed by single engine aircraft, their impact on local operation may be more significant.	TAF
Number of all the aircraft other than the three aircraft types given above (e.g., rotorcrafts and gliders)		
Number of multiple engine aircraft based at the airport	These two factors are expected to have positive impact on GA activities. Since most of hours flown by these two aircraft type are itinerant in nature, their impact on itinerant operation may be more significant.	
Number of turbojet or turbofan aircraft based at the airport		
Number of total based aircraft at the airport	This factor is expected to have positive impact on GA activities.	

4.4.1.4 Airport Categories

In NPIAS, airports in different categories play different roles in the general aviation. For example, large hubs primarily serve commercial aviation (e.g., scheduled commercial services) and thus only allow for limited general aviation activities. Instructional training usually concentrates on GA airports such that the capacity at the commercial service airport can be preserved. The following dummy variables are introduced to represent an airport category (see Table 4.8).

Table 4.8 Other factors considered in the development of GA demand models.

Number of based aircraft at an airport	Expected impact on GA activities	Data Sources	Variable type
Whether the airport is a primary commercial service airport	Since scheduled commercial services usually compete with GA for resources (e.g., runway and air space) at an airport, this factor is expected to have negative impact on the GA demand. Its coefficient is expected to be negative	NPIAS	dummy variable. It is 1 if the airport is; 0, otherwise.
Whether the airport is a reliever	Since reliever is to provide GA access to overall community, an airport tends to have more GA operations if it is a reliever. Its coefficient is expected to be positive.		

4.4.2 Selection of Explanatory Variables

The explanatory variables were selected based on the following major criteria:

Data availability: the historical data should be available for parameter calibration. Since airport-level demand models are usually used for forecasting, we also require that the forecast of an explanatory variable is available or easy to establish.

Causal relationship: the explanatory variables included in the model should have “direct” influence on the dependent variable. For example, the runway length is considered to have a causal relationship with the GA activities because airports with only short runways may not be able to support the operations of large aircraft.

Independence with other explanatory variables: the explanatory variables included in the model should not be highly correlated with each other. A high correlation between explanatory variables (i.e., multicollinearity) may result in inaccurate coefficient estimations. For example, we found that whether an airport has a runway with ILS is positively correlated with whether the airport has a control tower (the correlation coefficient is about 0.6). As a result, at most one of those two explanatory variables is considered and included in the final model.

R-square and adjusted R-square: R-square is introduced to measure how good the model fit the historical data. In general, it is believed that a higher R-square indicates a better fit. However, R-square tends to increase as more explanatory variables are included even though adding those variables will not significantly improve the explanatory ability of the model. To address this issue, adjusted R-square is also considered. It is introduced to correct the increase in R-Square due to the introduction of more

explanatory variables. Explanatory variables that could significantly increase the R-Square and adjusted R-Square are preferred. For example, we found that considering the availability of a concrete or asphalt paved runway could increase the R-Square and adjusted R-Square by 50%, and hence this factor is included in the models.

Statistical significance: it is introduced to measure whether adding a variable could significantly increase the model's explanatory ability. In the linear regression, a t-test is performed to test an explanatory variable's significance based on the given significance level. In this report, we require that a variable included in the final model has to be statistically significant at a 5% significance level.

Consistency with common belief: the coefficients of explanatory variables should be consistent with common belief. For example, the coefficient of personal income is expected to be positive in the model since it is believed that higher personal income will encourage more GA activities; however, we found that its coefficient is negative in our calibrated model. In this case, this variable may not be considered to be included in the model.

Forecasting ability: the last criterion we used to select the explanatory variables is whether it could improve the model's forecasting ability. R-square, adjusted R-square, and statistical significance only indicate how well the model fits the historical data that is used for model calibration. Since airport-level GA demand models are usually used for demand forecast, it is important to consider an explanatory variable's contribution to models' forecasting ability. In order to do so, we reserved two years TAF data (2010 and 2011) as the "unknown future data". An explanatory variable's contribution to models' forecasting ability is evaluated by comparing the model forecast with the future data (using paired dependent t-test at a 5% significance level). Variables with higher contribution are preferred to those with contributions. For example, we found that the total population in the state where an airport is in has higher contribution to total population within 500-mile radius of an airport. More specifically, the latter one tends to overestimate the GA demand. Therefore, the latter one is not included in the models.

4.5 Model Calibration

White's test suggests that the errors are heteroscedastic for both models with a 5% significance level. Standard estimation methods are inefficient when the errors are heteroscedastic. Since the form of the heteroscedasticity is unknown, we adopted the generalized method of moments (Hansen, 1982) to calibrate the model.

Static models assume that GA makes immediate and complete adjustment to changes in factors such as fuel prices and income. However, this assumption is not always valid. In other words, there might be a lag effect in GA aviation demand. Many studies (see for example, (Romero-Jordán et al., 2010)) introduce a lag term to capture this effect. Similarly, we also considered the Fuel-to-Income (F2I) ratio in previous year (i.e., one year lag) in the models. However, in both models, the estimated coefficient for the F2I ratio lag is positive, which is counter-intuitive. A possible explanation is that the time period (one year) is long enough for the GA to sufficiently adjust. All the tests and parameter calibrations are performed using the commercial software SAS 9.3.

4.5.1 Calibration Results and Analysis

Table 4.9 presents the calibration results to predict GA itinerant operations. The F2I ratio is significant at the 5% significant level but not at 1% significant level. Its coefficient is negative which indicates that there will be less itinerant operations if fuel price takes a larger portion of income. Given

other factors fixed (including income), a 10% increase in fuel price would result in a 4.3% decrease in the number of itinerant operations. Given other factors fixed (including fuel price), a 10% decrease in the income would result in an 11.1% increase in the F2I ratio and hence in a 4.8% decrease in the number of itinerant operations. Since the number of population around the airport has been considered in several studies, we also present its coefficient in Table 4-9. Its coefficient is positive, and its elasticity is about 0.53. However, this factor is not included in the final model because its coefficient is not significant at the required significance level. An airport with a runway with runway length greater than 4000 ft. is expected to have 40% more itinerant operations than an airport without one. An airport with a control tower is expected to have about 170% more itinerant operations than an airport without one. A reliever is expected to have 40% more itinerant operations than non-relievers.

Table 4.9 Calibration results for a model to predict itinerant operations.

Nonlinear GMM Summary of Residual Errors							
Equation	DF Model	DF Error	SSE	MSE	Root MSE	R-Square	Adj R-Sq
Itinerant operations	10	16201	223193	13.7765	3.7117	0.4121	0.4118

Nonlinear GMM Parameter Estimates				
Parameter	Estimate	Approx Std Err	t Value	Approx Pr > t
Intercept	-7.414	2.397	-3.09	0.002
State gross product of the state where the airport is located	0.338	0.027	12.64	<.0001
Total population of the counties whose centers are within 20 miles of the airport	0.531	0.290	1.83	0.067
Availability of a concrete or asphalt runway at the airport	8.168	0.314	26.02	<.0001
Availability of a runway with runway length greater than 4000 ft at the airport	0.334	0.078	4.28	<.0001
Total number of based aircraft at the airport	0.156	0.018	8.93	<.0001
The ratio of the cost of purchasing 1000 gallons of jet fuel to the income per capita (in 2006 year value)	-0.425	0.178	-2.39	0.0167
Availability of a control tower	1.013	0.067	15.22	<.0001
Unavailability of an engine repair plant at the airport	-1.243	0.067	-18.60	<.0001
Whether the airport is a reliever	0.336	0.107	3.14	0.0017

Table 4.10 presents the calibration results for the estimation of local operations. The F2I ratio for local operation is significant at the 5% significant level but not at 1% significant level. Its coefficient is negative which means that less local operations will be performed if fuel price takes a larger portion of income. Given other factors fixed (including income), a 10% increase in fuel price would result in a 5.2% decrease in the number of local operations. Given other factors fixed (including fuel price), a 10% decrease in the income would lead to a 11.1% increase in the F2I ratio and hence cause a 5.8% decrease in the number of local operations. According to our estimation, local operations are elastic to the farm industry employment. A 10% increase in the farm industry employment will lead to about 12.3% increase in local operation. In addition, an airport with a runway with runway length greater than 1000 ft. is expected to have 71% more local operations than an airport without one. An airport without commercial services is expected to have about 80% more local operations than an airport with the services. A flight school would increase the local operation at an airport by about 84%.

Compared with itinerant operations, local operations are more sensitive to the F2I ratio (higher elasticity). A possible explanation is that a fraction of the local operations are for conducted for pleasure (e.g., sightseeing and air tour) and flight experience (e.g., practice). They are not as necessary as itinerant operations that are responding to business needs. Pavement condition plays a fundamental role in both itinerant and local operations. In addition, presence of an engine plant at an airport will also significantly increase the number of itinerant and local operations. Both itinerant and local operations are inelastic to the number of based aircraft. A 10% increase in the number of based aircraft will result in about 1.6% increase in the itinerant operations while a 10% increase in the number of based single engine aircraft will lead to a 4.9% increase in local operations. The inelasticity may be because of the increasing traffic congestion on the runway and in the local airspace.

Table 4.10 Calibration results for a model to predict local operations.

Nonlinear GMM Summary of Residual Errors							
Equation	DF Model	DF Error	SSE	MSE	Root MSE	R-Square	Adj R-Sq
Local operations	10	16201	339652	20.9649	4.5787	0.5309	0.5306

Nonlinear GMM Parameter Estimates				
Parameter	Estimate	Approx Std Err	t Value	Approx Pr > t
Intercept	-11.143	1.516	-7.35	<.0001
State gross product of the state where the airport is located	0.330	0.036	9.26	<.0001
Total farm industry employment of the counties whose centers are within 20 miles of the airport	1.234	0.429	2.87	0.0041
Availability of a concrete or asphalt runway at the airport	11.346	0.344	32.98	<.0001
Availability of a runway with runway length greater than 1000 ft at the airport	0.538	0.073	7.38	<.0001
Total number of based single engine piston and turboprop aircraft at the airport	0.485	0.020	23.76	<.0001
The ratio of the cost of purchasing 1000 gallons of jet fuel to the income per capita (in 2006 year value)	-0.515	0.242	-2.13	0.0335
Unavailability of a engine repair plant at the airport	-1.778	0.090	-19.78	<.0001
Whether the airport is a primary commercial service airport	-1.241	0.127	-9.74	<.0001
Whether there is a flight school based at the airport	0.610	0.064	9.53	<.0001

4.6 Impact of Fuel Price on Airport-Level Market Share for Itinerant Operations

In the previous section, the operation at an airport is classified into two types: itinerant and local. This section is devoted to develop a procedure to evaluate the impact of fuel price on the airport-level market share of itinerant operations considering individual aircraft engine types.

As the first step to develop the procedure, we classify the aircraft into the following four categories: 1) Piston, 2) Turboprop, 3) Turbofan, and 4) others (e.g., rotorcraft and light-sport). Further, we assume that a flight (itinerant or local) can be performed under the following three different flight rules:

- 1) Instrumental Flight Rules (IFR): the flight plan is filed and the flight is flown according to rules and regulations established by the FAA to govern flight under conditions in which flight by outside visual reference is not safe. IFR flight depends upon flying by reference to instruments in the flight deck, and navigation is accomplished by reference to electronic signals.
- 2) Visual Flight Rules (VFR): the flight plan is filed; however, the flight is flown solely by reference to outside visual cues (horizon, buildings, flora, etc.) which permit navigation, orientation, and separation from terrain and other traffic.
- 3) None of the above (i.e., no-flight-plan rules) (NFR). That is no flight plan is filed and the flight is flown under VFR.

The classifications of aircraft types and flight rules are made to maintain consistency with those given in the GAATA survey since the survey data is a major data set used in the later part of the study. The procedure is designed by considering the objective of this project (i.e., evaluate the impact of oil price) and data availability.

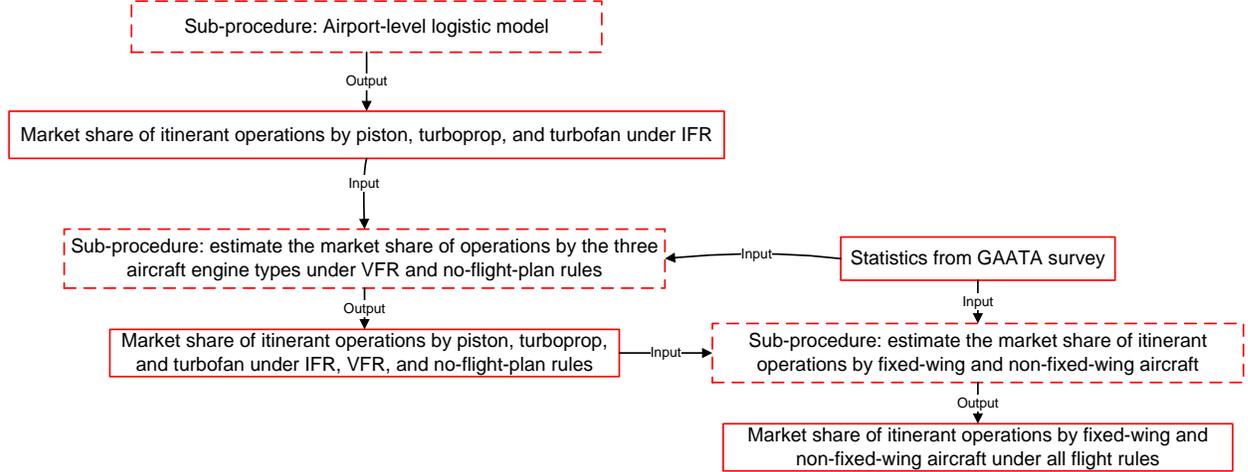


Figure 4-4 Flowchart of the procedure.

As shown in Figure 4-4, the algorithm developed contains three steps. The first step is to estimate the airport-level market share of itinerant operation of all three aircraft types under IFR conditions. The second step is to estimate the market share of itinerant operations of the three aircraft types under all flight rules. The third step is to estimate the market share of the four aircraft types (i.e., piston, turboprop, turbofan, and others) under all flight rules.

4.6.1 Impact of Fuel Price on the Airport-level Market Share of Itinerant Operation of Piston, Turboprop, and Turbojet under IFR

Similar to the airport-level demand modeling, we considered local socio-economic, demographic factors and level-of-service factors at an airport. Besides the factors introduced in the previous section, two new factors are considered in the model. The first one is the airport elevation. This factor is introduced to account for the impact of elevation on piston aircraft performance. More specifically, elevation is expected to have more negative impact on piston engine aircraft than the other two aircraft types. In other words, given other factors the same, airports with higher elevation tend to have less piston operations (in terms of market share) than those located at lower elevations. To account for this effect, we introduce a dummy variable and tentatively assign it to be 1 if the airport elevation is higher than 3000 ft.; 0, otherwise. The second new factor is the distance between the airport and central business district (CBD). This factor is introduced to account for the usage of turbojet. In the 2010 GAATA survey, about 54.4% of hours flown by turbojet are used by corporate jets operations that are more time-sensitive. This statistic is only about 18.4% and 2% for turboprop and piston. Shorter distances between the airport and CBD means less commuting time, and hence airports closer to CBD are expected to have more market share of turbojet operations provided they have the runway length to support such operations.

A logistic model is used to estimate airport-level market share of itinerant operation of piston, turboprop, and turbofan under IFR conditions. The market share is calculated against that of turbojet with the following closed form:

$$MS_{Pis-jet} = \frac{\exp(\sum c_j^{Pis-jet} X_j)}{\exp(\sum c_j^{Pis-jet} X_j) + \exp(\sum c_j^{Prop-jet} X_j) + 1} \quad (4.6)$$

$$MS_{Prop-jet} = \frac{\exp(\sum c_j^{Prop-jet} X_j)}{\exp(\sum c_j^{Pis-jet} X_j) + \exp(\sum c_j^{Prop-jet} X_j) + 1} \quad (4.7)$$

$$MS_{jet-jet} = \frac{1}{\exp(\sum C_j^{Pis-jet} X_j) + \exp(\sum C_j^{Prop-jet} X_j) + 1} \quad (4.8)$$

where X_j s are explanatory variables, and $C_j^{Pis-jet}$ s and $C_j^{Prop-jet}$ s are coefficients to be estimated. The model is calibrated using ETMS 2005-2010 data in SAS 9.3. The estimated coefficients are presented in Table 4.11. All coefficients are significant at the 5% significance level.

Table 4.11 Logistic regression calibration results.

Explanatory variables	Piston-Turbofan	P-value	Turboprop-Turbofan	P-value
Intercept	5.1360	<.0001	3.6729	<.0001
Total number of runways at the airport	-0.0474	<.0001	-0.0063	0.0207
Availability of a runway with runway length greater than 4000 ft. at the airport	-2.1843	<.0001	-1.6414	<.0001
Availability of a concrete or asphalt runway at the airport	-1.2090	0.005	-1.4506	0.001
Airport elevation greater than 3000 ft	-0.8481	<.0001	0.0634	<.0001
Number of single and multiple engine aircraft based at the airport	0.0018	<.0001	0.0007	<.0001
Number of turbojet or turbofan aircraft based at the airport	-0.0056	<.0001	-0.0015	<.0001
The ratio of the cost of purchasing 1000 gallons of jet fuel to the income per capita (in 2006 year value)	-1.6305	<.0001	-1.2649	<.0001
Presence of an airport control tower	-0.7221	<.0001	-0.5171	<.0001
Unavailability of an engine repair station at the airport	0.0710	<.0001	0.1901	<.0001
The total population of the counties whose centers are less than 20 miles from the airport	-0.0001	<.0001	-0.0001	<.0001
Distance between the airport and CBD (in miles)	-0.0168	<.0001	-0.0156	<.0001
Whether the airport is a large or medium hub	-1.1039	<.0001	-0.5346	<.0001

4.6.2 Analysis

Let odds be $\frac{MS}{1-MS}$. For the odds $\frac{MS_1}{1-MS_1}$ and $\frac{MS_2}{1-MS_2}$, the odds ratio is defined as $OR_{12} = \frac{\frac{MS_1}{1-MS_1}}{\frac{MS_2}{1-MS_2}}$. The

logistic model assumes that the log-odds is a linear function of the following form:

$$\log\left(\frac{MS_{Pis}}{1-MS_{Pis}}\right) = \sum C_j^{Pis} X_j \quad (4.9)$$

$$\log\left(\frac{MS_{Prop}}{1-MS_{Prop}}\right) = \sum C_j^{Prop} X_j \quad (4.10)$$

$$\log\left(\frac{MS_{jet}}{1-MS_{jet}}\right) = \sum C_j^{jet} X_j \quad (4.11)$$

That is

$$\log\left(\frac{MS_{Pis}}{1-MS_{Pis}}\right) - \log\left(\frac{MS_{jet}}{1-MS_{jet}}\right) = \sum C_j^{Pis-jet} X_j \quad (4.12)$$

$$\log\left(\frac{MS_{Prop}}{1-MS_{Prop}}\right) - \log\left(\frac{MS_{jet}}{1-MS_{jet}}\right) = \sum C_j^{Prop-jet} X_j \quad (4.13)$$

That is

$$OR_{Pis,jet} = \exp(\sum C_j^{Pis-jet} X_j) \quad (4.14)$$

$$OR_{Prop,jet} = \exp(\sum C_j^{Prop-jet} X_j) \quad (4.15)$$

Therefore, the j th model coefficient can be interpreted as the change in the log of odds ratio due to one unit change in the j th explanatory variable.

Table 4.12 Change in odds ratio due to one unit change in explanatory variable.

Explanatory variables	Unit change	Change in Odds Ratio (in terms of percentage)		
		Piston-Turbofan	Turboprop-Turbofan	Piston-Turboprop
Total number of runways at the airport	1	-4.63%	-0.63%	-4.03%
Availability of a runway with runway length greater than 4000 ft. at the airport	1	-88.74%	-80.63%	-41.89%
Availability of a concrete or asphalt runway at the airport	1	-70.15%	-76.56%	27.33%
Airport elevation greater than 3000 ft	1	-57.18%	6.55%	-59.81%
Number of single and multiple engine aircraft based at the airport	1	0.18%	0.07%	0.11%
Number of turbojet or turbofan aircraft based at the airport	1	-0.56%	-0.15%	-0.41%
The ratio of the cost of purchasing 1000 gallons of jet fuel to the income per capita (in 2006 year value)	10%	-15.05%	-11.88%	-3.59%
Presence of an airport control tower	1	-51.43%	-40.38%	-18.54%
Unavailability of an engine repair station at the airport	1	7.36%	20.94%	-11.23%
The total population of the counties whose centers are less than 20 miles from the airport	1000	-0.01%	-0.01%	0.00%
Distance between the airport and CBD (in miles)	1	-1.67%	-1.55%	-0.12%
Whether the airport is a large or medium hub	1	-66.84%	-41.41%	-43.41%

It can be observed that a 10% increase in the F2I ratio would decrease the $OR_{Pis,jet}$ and $OR_{prop,jet}$ by about 15% and 12%, respectively. This means that: 1) the market share of itinerant operation by turbofan would increase while those by the other two aircraft engine types will decrease. This indicates that piston and turboprop operations are more sensitive to fuel cost than those conducted by turbofan aircraft. In addition, a 10% increase in the F2I ratio would decrease the $OR_{Pis,prop}$ by about 4%. The result indicates that piston aircraft operations are more sensitive to fuel cost than those of turboprop aircraft.

One additional runway would decrease $OR_{Pis,jet}$, $OR_{prop,jet}$, and $OR_{piston,prop}$ by about 4.6%, 0.63%, and 4%, respectively. This indicates that the market share of itinerant operations by turboprop and turbofan would increase compared with that of piston aircraft. The availability of a runway with runway length greater than 4000 ft. would decrease $OR_{Pis,jet}$, $OR_{prop,jet}$, and $OR_{piston,prop}$ by about 89%, 81%, and 42%, respectively. This indicates that turbofan operations are more sensitive to runway length than the other two aircraft engine types; and turboprop is more sensitive than piston. The availability of a concrete or asphalt paved runway would decrease $OR_{Pis,jet}$ and $OR_{prop,jet}$ by about 70% and 77%, respectively. This indicates that turbofan is more sensitive to the runway pavement than the other two aircraft engine types. The impact of other factors on the market share of the three aircraft engine types can be interpreted in the similar way. Since the objective of the project is to evaluate the impact of fuel cost on GA activities, for simplicity we decide not to give a detailed analysis.

However, it is necessary to point out that it is usually believed that the performance of turboprop is higher than piston while lower than turbofan. From this point of view, some of the calibration results for the turboprop seem to be counterintuitive. For example, piston operations seem to be more sensitive to the runway pavement and availability of an engine repair station than for turboprop aircraft. Turbofan is slightly more sensitive to elevation than the turboprop. We noticed that in our calibration the number of records for turboprop is only about half of that for piston and turbofan. In other words, the sample size for the turboprop is significantly smaller than the other two groups. Based on the data available to us, we cannot rule out if the counterintuitive results for turboprop are because of the small sample size or the result of some of the turboprop aircraft unique characteristics. We believe that further investigation is needed when more data is available in the future.

4.6.3 Model Validation

We applied the airport-level logistic model to “forecast” the market share of itinerant operations for TAF airports in 2011. We validate our model by comparing our forecast with the real ones. The real market share is estimated by using ETMS 2011. It is reasonable to believe that the sample size should be sufficiently large in order to have a relatively reliable estimation. However, the ETMS data currently

available to our study only provides a sparse sample of GA activities (10-20 days out of 365 days). Moreover, the utilization rate for GA aircraft is usually low, which means that a 10-20 day sample of GA activities might still be sparse. We tentatively only consider the airports with at least 1000 operations in the comparison analysis. There are 22 airports that meet the criterion. The comparison between the observed market share and the projected one by aircraft engine type is presented in Figure 4-5. It can be observed that the two statistics are close for the three aircraft engine types. Further, the paired dependent t-test also fails to detect any difference between the two at the 5% significance level.

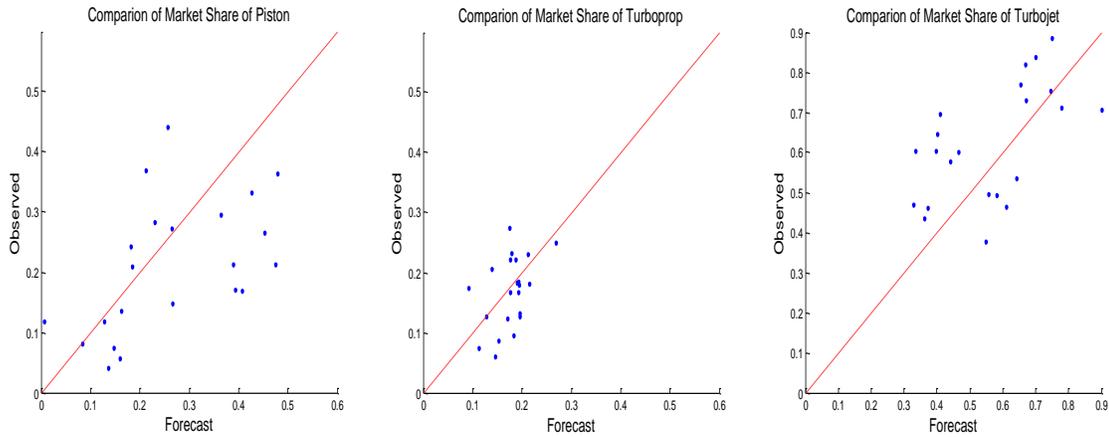


Figure 4-5 Comparison of market share of itinerant operations under IFR by aircraft engine type.

4.6.4 Airport-level Market Share of Itinerant Operation of Piston, Turboprop, and Turbojet under All Flight Rules

The previous part focused on the market share of itinerant operations for piston, turboprop and turboprop under IFR flight rules. However, for an airport, there could be operations of all the four aircraft types under all flight rules. This is especially true for GA airports. Unfortunately, data about airport-level operations under VFR and no-flight-plan rules is rarely available. The major data set containing nationwide information about the operations (hours flown) under the IFR, VFR and no-flight-plan flight rules is the GAATA survey. With the data currently available to this study, we develop the following three sub-procedures to estimate the airport-level market share of itinerant operation of all aircraft type under all flight rules. The sub-procedures are presented in Figure 4-6.

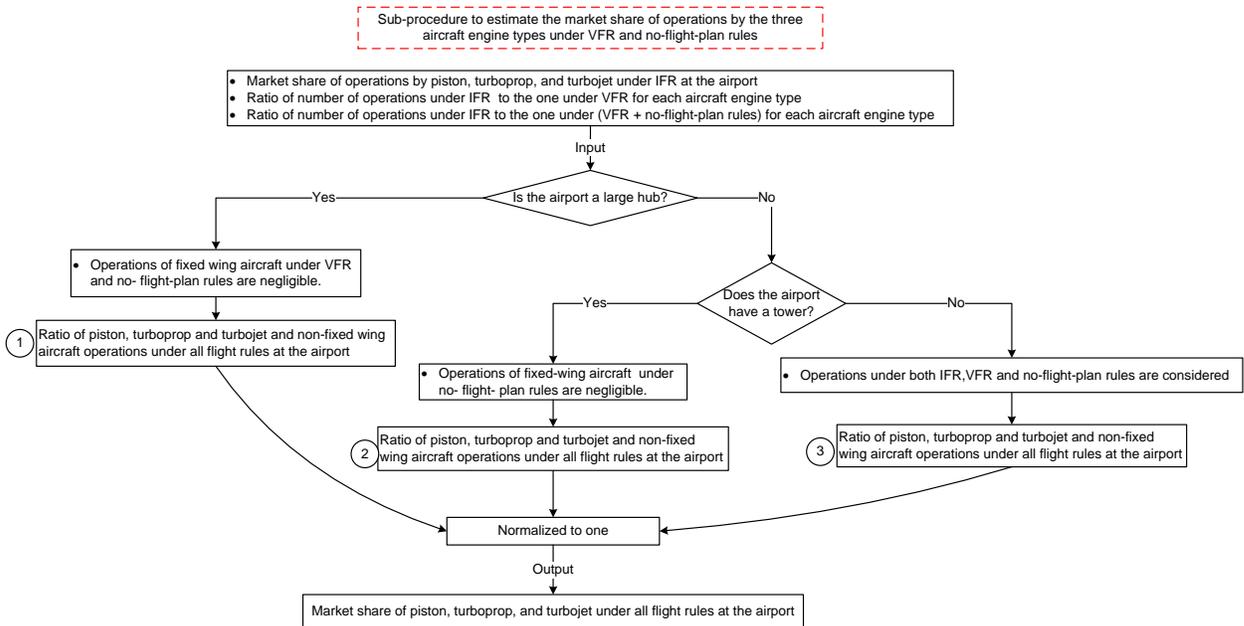


Figure 4-6 Flowchart of the sub-procedure to estimate the market share of itinerant operations under VFR and no-flight-plan rules.

To have a comprehensive and representative estimation, we consider the survey data from year 2000-2010 in the GAATA survey. Survey data for those years are currently available to the general public at FAA’s website. Tables 4-13 and 4-14 present the total number of hour flown by the three aircraft types for the three flight rules from the year 2000 to 2010. It is necessary to point out that the hours flown reported in the survey correspond to both itinerant and local operations. Since only the hours flown by itinerant operations are of interest, we exclude hours flown by local and air taxi operations.

Table 4.13 Hours flown under IFR, VFR, and no-flight-plan rules by aircraft engine type (GAATA survey 2000-2010).

Hours flown under VFR			Hours flown under IFR			Hours flown under no flight plan		
VFR	Total	Market Share	IFR	Total	Market Share	No flight plan	Total	Market Share
Piston	60,378,081	73.37%	Piston	44,977,369	45.52%	Piston	85,671,023	39.69%
Turboprop	3,258,598	3.96%	Turboprop	16,298,816	16.49%	Turboprop	4,245,650	1.97%
Turbofan	751,211	0.91%	Turbofan	35,201,699	35.63%	Turbofan	549,236	0.25%
Non-fixed wing	17,905,193	21.76%	Non-fixed wing	2,333,442	2.36%	Non-fixed wing	125,407,963	58.09%

Table 4.14 Market share of hours flown under IFR, VFR, and no-flight-plan rules by aircraft engine type.

	Market share of flight rules by aircraft type		
	VFR	IFR	No flight plan
Piston	31.61%	23.55%	44.85%
Turboprop	13.69%	68.47%	17.84%
Turbofan	2.06%	96.44%	1.50%
Non-fixed wing	12.29%	1.60%	86.10%

We assume that in the GAATA survey hours flown generated by local operations includes the hours flown in categories: instructional, aerial applications, sightseeing and air tour (air taxi). All the others hours flown in the survey are included in the itinerant operations category.

Table 4.15 Estimation of hours flown by local operations.

Hours flown for local operation		
Local	Total	Market Share
Piston	57,573,609	70.65%
Turboprop	5,305,329	6.51%
Turbofan	389,077	0.48%
Non-fixed wing	18,222,505	22.36%

Table 4.15 summarizes the total number of hours flown by local operation for the three aircraft types from year 2000 to 2010. Most of the hours flown are performed by piston (about 70%) and non-fixed wing aircraft (about 22%). We assume that the hours flown by the air taxi and air medical categories are itinerant operations. Table 4.16 summarizes the total number of hours flown by air taxi and air medical for the three aircraft engine types from year 2000 to 2010.

Table 4.16 Estimation of hours flown by air taxi.

Hours flown for air taxi		
Air Taxi	Total	Market Share
Piston	8,552,041	31.09%
Turboprop	5,219,193	18.97%
Turbofan	6,986,890	25.40%
Non-fixed wing	6,750,075	24.54%

Further, we assume that the number of local operation under IFR is negligible. In other words, hours flown by local operations are assumed to be flown under VFR and no-flight-plan rules. Therefore, they are subtracted from the total hours flown under VFR and no-flight plans by the three aircraft engine types. For air taxi, we assume air taxi operations by the three aircraft types are mainly under IFR. That is, hours flown by air taxi are assumed to be flown under IFR rules. They are subtracted from the total hours flown under IFR by the three aircraft engine types. Table 4.17 summarizes our estimates of total number of hours flown generated by itinerant operations by aircraft engine type. It can be observed that for piston aircraft the major of hours flown by itinerant operations are under VFR flight rules and no-flight-plan rules. However, for turboprop and turbofan aircraft, the major of hours flown are under IFR.

Table 4.17 Estimation of hours flown under IFR and VFR plus no-flight-plan rules by aircraft engine type.

Estimation of hours flown by itinerant operations under VFR+No-flight-plan and IFR by aircraft type				
	VFR+No-flight-plan	IFR	VFR+No-flight-plan	IFR
Piston	88,475,495	36,425,328	70.84%	29.16%
Turboprop	2,198,919	11,079,623	16.56%	83.44%
Turbofan	911,370	28,214,809	3.13%	96.87%

To account for the variations in flight operations among airports, we developed the following scheme to estimate the market share of itinerant operation for piston, turboprop and turbojet under all flight rules at different airports.

- 1) For large and medium hubs, we assume that itinerant operations under VFR and no-flight-plan rules are negligible. In other words, the market share of itinerant operation for piston, turboprop and turbojet under the two flight rules is assumed to be zero. For those airports, the market share of operations for piston, turboprop and turbofan under IFR flight (from the airport-level market share of operations model) is directly used.
- 2) For airports not classified as large or medium hubs but having a control tower, we assume that itinerant operations under no-flight-plan rules are negligible. In other words, the market share of itinerant operation for piston, turboprop and turbojet under the no-flight-plan rules is assumed to be zero. This requires a separation between hours flown under VFR and no-flight-plan rules. To do so, we used the share of hours flown under VFR in the total hours flown those under VFR and no-flight-plan rules for the three aircraft engine types. The hours flown under VFR for three aircraft engine types are estimated by multiplying the total hours flown by both VFR and no-

flight-plan rules (given in Table) by its percentage. The estimation of hours flown under VFR by aircraft engine type is presented in Table 4.18.

Table 4.18 Estimation of hours flown under VFR and IFR by aircraft engine type.

Estimation of hours flown by itinerant operations under VFR and IFR by aircraft type				
	VFR	IFR	VFR	IFR
Piston	36,576,606	36,425,328	50.10%	49.90%
Turboprop	954,845	11,079,623	7.93%	92.07%
Turbofan	526,458	28,214,809	1.83%	98.17%

We assume that the market share of itinerant operations under IFR by piston is MS_{piston} . Note that this market share is obtained from the airport-level market share of operations model. Then, the “market share” of itinerant operation under VFR by piston is estimated to be,

$$\left(0.501/0.499\right) * MS_{piston}.$$

The “market share” of itinerant operations under IFR by turboprop and turbofan aircraft are estimated by the same way. The market share of itinerant operations of the three aircraft engine types (under IFR and VFR) is estimated by normalizing the “market share” to one.

- 3) For the other airports (mainly GA airports), the ratios of IFR to VFR plus no-flight-plan rules for the three aircraft engine types are given in Table 4.17. The market share of itinerant operations of the three aircraft engine types (under all flight rules) is estimated using the same method presented in the previous section.

4.6.5 Market Share of Operation of Non-fixed-wing Aircraft

In this part, we developed a procedure to estimate the market share of itinerant operations by the non-fixed-wing aircraft.

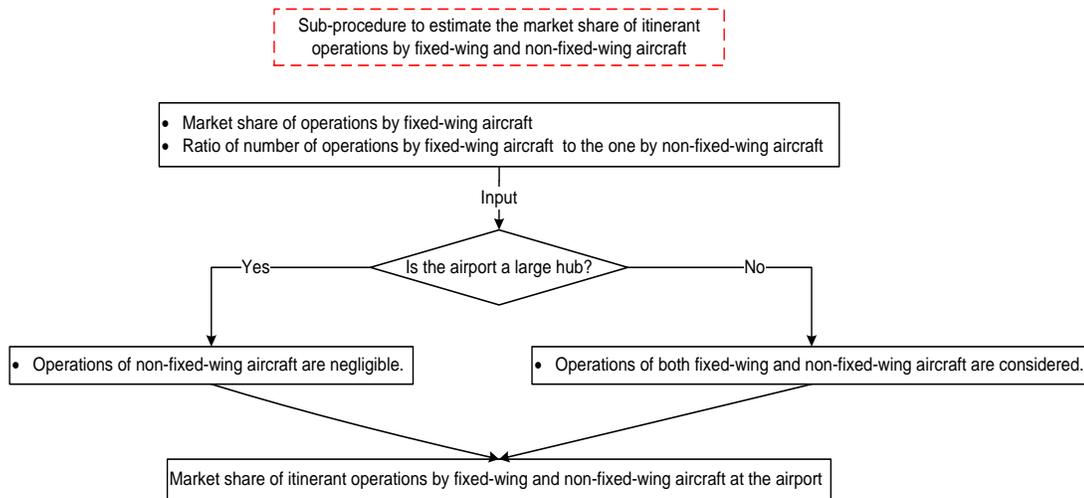


Figure 4-7 Flowchart of the sub-procedure to estimate market share of itinerant operations by fixed-wing and non-fixed-wing aircraft.

The same procedure applies to the estimation of fixed-wing aircraft, the total hours flown by non-fixed wing aircraft reported in the GAATA survey are also generated by itinerant, local, and air taxi operations. Similarly, we estimated the hours flown by itinerant operations by excluding the hours flown generated by local and air taxi operations.

It is necessary to point out the market share of hours flown by itinerant operations by non-fixed wing (with respect to fixed-wing) are not necessarily the same as the market share of itinerant operation by non-fixed wing aircraft. This is because the hours flown by itinerant operations may be different for non-fixed wing and fixed-wing aircraft. To convert the hours flown to itinerant operations, we estimated the average hours flown per itinerant operation for the three fixed-wing aircraft engine type using ETMS data (2006-2010). However, most of the hours flown by the non-fixed-wing aircraft are under VFR and no-flight-plan rules (as shown in Table 4.19), and information about their operations is not available to this study. Therefore, we used the single engine piston aircraft as a surrogate to non-fixed-wing aircraft in this study. Among the aircraft engine types with operation information available (e.g., the ETMS data) to this study, the performance of single engine piston is the closest to the non-fixed wing aircraft in general.

Table 4.19 Average hours flown by aircraft engine type.

Aircraft Type	Average hours flown per itinerant operation
Piston	1.57
Turboprop	1.35
Turbojet	1.50
Non-fixed wing (Single engine piston)	1.61

Table 4-19 presents the average hours flown per itinerant operation of the four aircraft engine types. The number of operations by the four aircraft engine types is estimated by dividing the hours flown by the average hours flown per operation.

Table 4.20 Market share of itinerant operations by fixed-wing and non-fixed wing aircraft.

Hours flown	Piston	Turboprop	Turbojet	Non-fixed wing	Operations	Piston	Turboprop	Turbojet	Non-fixed wing	Market share of fixed-wing aircraft	Market share of Non-fixed-wing aircraft
2000	14,172,620	1,966,106	2,350,406	3,716,512	2000	9,021,975	1,015,126	1,562,536	1,454,798	88.86%	11.14%
2001	13,804,781	1,204,354	2,300,459	3,504,813	2001	8,787,817	894,931	1,529,332	1,275,626	89.78%	10.22%
2002	12,602,598	1,243,400	2,475,965	3,719,365	2002	8,022,534	923,946	1,646,007	1,351,351	88.69%	11.31%
2003	12,870,076	1,337,448	2,469,324	3,806,772	2003	8,192,804	993,831	1,641,592	1,380,648	88.69%	11.31%
2004	11,745,641	1,310,177	2,845,987	4,156,164	2004	7,477,014	973,566	1,891,996	1,246,779	89.24%	10.76%
2005	10,837,425	1,183,880	2,785,062	3,968,942	2005	6,898,864	879,718	1,851,493	1,300,868	88.10%	11.90%
2006	10,829,871	1,178,568	3,120,038	4,298,606	2006	6,894,055	875,770	2,074,183	1,218,570	88.98%	11.02%
2007	10,376,429	1,265,758	2,830,338	4,096,096	2007	6,605,404	940,560	1,881,592	1,389,058	87.16%	12.84%
2008	9,605,118	1,074,926	2,853,925	3,928,851	2008	6,114,404	798,756	1,897,273	1,290,802	87.22%	12.78%
2009	9,222,239	1,077,843	2,457,713	3,535,556	2009	5,870,672	800,924	1,633,873	1,376,313	85.78%	14.22%
2010	8,838,308	1,036,560	2,637,610	3,674,170	2010	5,626,589	770,247	1,733,468	1,276,700	86.46%	13.54%

Table 4.20 summarizes the market share of itinerant operation by fixed-wing and non-fixed-wing aircraft from year 2000-2010. Let Ms_F be the market share of operations of fixed-wing aircraft and Ms_{NF} be the market share of operations of non-fixed-wing aircraft. Further defined,

$$P_{F-NF} = \ln\left(\frac{Ms_F}{Ms_{NF}}\right) \quad (4.16)$$

We found that P_{F-NF} and $F2I$ ratio are highly correlated with a correlation coefficient of about -0.84. The coefficient is significant at 5% significance level. Therefore, it is reasonable to assume the following linear relationship exist between the two:

$$P_{F-NF} = a * F2I + c \quad (4.17)$$

where a and c are coefficients to be estimated. By using the relationship $Ms_F + Ms_{NF} = 1$, we have:

$$Ms_F = \frac{\exp(a * F2I + c)}{1 + \exp(a * F2I + c)} \quad (4.18)$$

The coefficients are estimated using linear regression with the historical operation data presented in Table 4.20 including the historical $F2I$ ratio data.

The statistics are summarized in Table 4.21. The estimated value of coefficient a is significant at the 1% significance level. It is negative which indicates that the market share of fixed-wing aircraft operations decreases as the $F2I$ ratio increases.

For the hours flown by itinerant operations, the hours flown for personal purpose account for about 56%. About 37% of the hours flown for personal purpose are performed by fixed-wing aircraft while the statistics is about 29.6% for non-fixed-wing aircraft.

Table 4.21 Regression results.

	Coefficient	R-square
a	-5.22	0.7
b	2.55	

The R-square in the model is 0.7. Further, the calibrated model is applied to estimate the market of fixed-wing aircraft operations from year 2001-2010. The results are compared with the historical data using a Kolmogorov–Smirnov test. The test fails to detect any difference between the two at the 5% significance level.

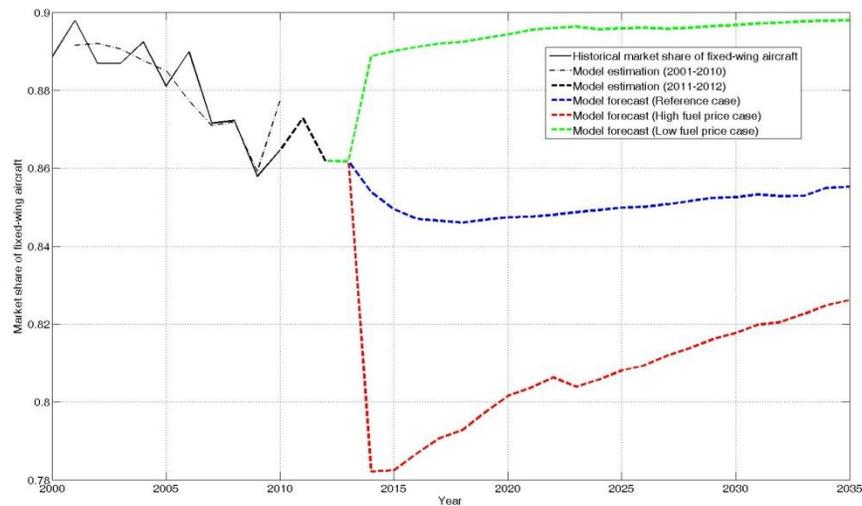


Figure 4-8 Market share of fixed-wing aircraft.

The market share of fixed-wing aircraft operations from year 2013 to 2035 are forecasted for each fuel scenario using our model (shown in Figure 4-8). These forecasts are used in the sub-procedure to estimate the market share of operations by non-fixed-wing aircraft.

4.7 Impact of Fuel Price in the Spatial Distribution of General Aviation Operations

In this section we evaluate the impact of fuel price on the spatial distribution of GA operations. The distribution of GA operations refers to the airport-to-airport operations under all flight rules (see Figure 4-9). The major data set containing information about the airport-to-airport operations is the ETMS data. However, as mentioned earlier, this data set only provides information for flights operated under IFR rules. Therefore, following (Dou Long et al., 2001), we assume that the distribution of operations under IFR, VFR and NFR are similar. In other words, the distribution of IFR operation can be used to represent

flight operations under other flight rules. As explained in the previous section, we still use the single engine piston as surrogate to non-fixed-wing aircraft.

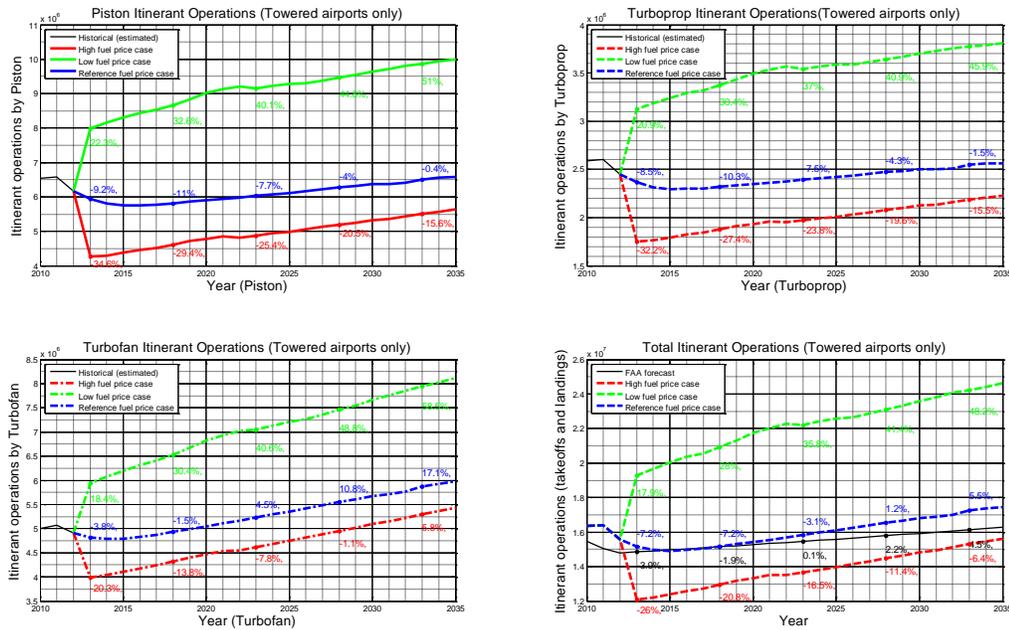


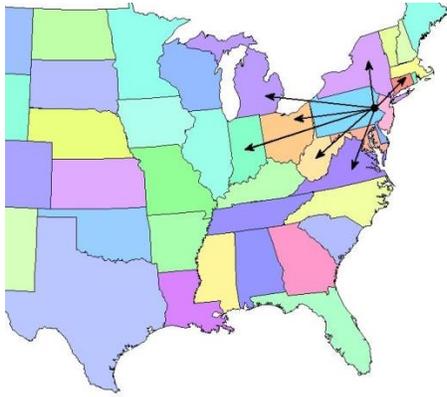
Figure 4-9 Itinerant operations by aircraft type (towered airports).

The second procedure uses a gravity model (Baik. et al., 2006; D. Long et al., 2001) to distribute trips spatially. This was a requirement by the FAA sponsor of the study. Though gravity models could estimate the distribution of GA demand amongst destination airports, previously developed models only consider number of based aircraft, number itinerant operations, and distance between airports. Therefore, they provide relatively less insight about the factors that influence the GA airport choice.

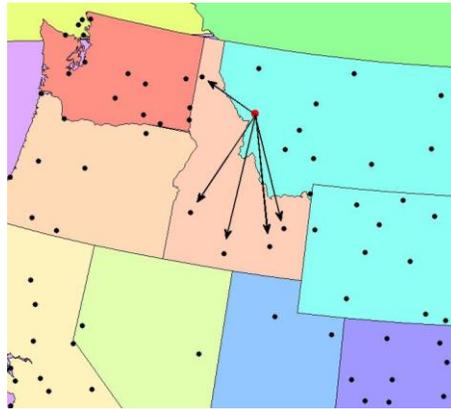
4.7.1 Two-level Model

As mentioned in an earlier section, ETMS contains a sparse sample of GA activities. Using discrete choice models to directly model the airport choice behaviors (i.e., origin airport to destination airport) may not be practical. Many origin airports could have hundreds or even thousands of possible airport destinations, however, there may be only a few operations at those airports in the ETMS data. As a result, the available historical data might not be sufficient for the model calibration.

To address these issues, we proposed a two-level model to describe the airport choice behaviors. In the first-level, a logit model is used to model the state-choice behaviors, that is, how the GA demand at an origin airport is likely to distribute spatially to neighboring states and airports (see Figure 4-10). We considered the state-level variables such as Gross State Product (GSP) growth rate, population density, and distance in the utility function. In addition, the future forecasting of the state-level variables we considered are relatively easy to obtain. Using discrete choice model at this level is reasonable because the number of choices (i.e., destinations state) is relatively small (compared to destination airports) and stable so that the available historical data (i.e., ETMS) is sufficient for the model calibration.



First-level model: state-choice model



Second-level: airport-choice in a chosen state

Figure 4-10 Two-level model to distribute GA demand.

For an origin airport, the output of the first-level model is the market share of flying to each of the 50 states in the US. To further assign the projected operations (in terms of market share) to a state amongst the airports in the state, we designed a gravity-based model. In the model, each airport in a state is given an attractiveness value based on its number of based aircraft and distance to the origin airports. The market share of flying to an airport is proportional to its attractiveness value. The major advantage of the gravity-based model is: it is consistent with the idea of gravity model while does not rely on historical data for model calibration. Next, we present the details of the two-level choice model.

4.7.2 First level model: Logit-Based State Choice Model

In this level, we use a logit model to model the state choice behaviors. Logit models have been widely used to model choice behaviors in air transportation (see, for example, (Peeta et al., 2008)). In the logit model, the probability of choosing choice k is given as:

$$P_k = \frac{e^{U_k}}{\sum_j e^{U_j}} \quad (4.19)$$

where U_k is the utility of the k th choice (i.e., state). In most cases, it is a linear function of variables related to the characteristics of the k th choice. GA activities are influenced by variables such as social-economic factors, infrastructures, and weather condition. Next, we discuss the variables that are considered in the state choice model.

Distance: The influence of travel distance to the GA activities has been considered in several studies (D. Long et al., 2001). In general, very long travel distance is believed to have negative influence. In other words, very long travel distance may discourage some GA activities. This is reasonable because pilots usually have to consider the aircraft conditions as well as their physical or psychological limitations when choosing the destination state. Therefore, its coefficient in the model is expected to be negative for all aircraft types. This factor is calculated by measuring the great circle distance between the origin airport and the center of destination state.

Population density: On one hand, states with lower population density usually have relatively less access to public ground transportation infrastructure systems and commercial air services. In these states,

GA is an important means of personal long distance travel. In other words, people in these states may rely more on GA operations. On the other hand, states with higher population density tend to generate more business opportunities and hence attract more GA activities for business purpose. This factor is calculated by dividing the state population by the state area.

GSP growth rate: It is generally believed that transportation activities are positively correlated with economic conditions. GSP (gross state product) growth rate is an important indicator of a state's economic condition. Therefore, it is reasonable to include this variable in the choice model. A high growth rate usually indicates a good economic condition and hence is expected to attract more GA activities. A very low or negative growth rate implies a poor economic situation and hence is expected to attract less GA operations. Therefore, its coefficient is expected to be positive in the choice model for all aircraft types.

Number of non-primary commercial service and reliever airport: Airports are important infrastructure providing landing facilities to aircraft. Therefore, the number of airports in each state is expected to have significant influence in GA activities. We considered the two types of airports in the model: 1). non-primary commercial service airports and 2) reliever airports.

Non-primary commercial service airport is a commercial service airport that has between 2,500 and 10,000 annual passenger enplanements. Currently, there are about 121 of these airports in the NPIAS. In general, they are used mainly by GA and have an average of 30 aircraft based at the airport. The total number of based aircraft at these airports accounts for about 1.6% of the nation's GA fleet.

Reliever airports are high-capacity GA airports built to provide alternatives to using congested commercial service airports and GA access to the surrounding area. Usually, they have 100 or more based aircraft, or have 25,000 annual itinerant operations. Currently, there are about 269 of these airports with an average of 186 aircraft based at the airport. The total number of based aircraft accounts for about 22% of the nation's GA fleet.

It is necessary to point out that we also investigated other types of airports in the nation. In most cases, the large hubs tend to concentrate on the operations of commercial and freight carriers and they have limited GA activities. Thus, we did not consider them in the model. In addition, we found that the number of medium, small, non-hubs and GA airports in each state is correlated with the number of reliever airports in the state. Though those airports play important roles in the GA activities, including them would introduce multicollinearity into the model, which will make the coefficient estimation unreliable. For the airports that are not in NPIAS, we found no statistical justification (5% significance level) to include them in the model (2006 ETMS data). This may be because they usually have relatively low general aviation activities. Therefore, we only considered the above two airports types in our model. Their coefficients in the model are expected to be positive. These two variables are obtained from the NPIAS airport information.

Weather conditions: Weather condition has significant impact on the GA activities. For example, extremely cold weather will discourage GA activities because aircraft are designed to operate within certain temperature ranges. However, this factor is difficult to quantify because it includes too many variables that could influence the GA activities such as temperature, and number of sunny and cloudy days. To address this issue, we use the latitude of the center of each state to represent the weather condition. It is believed that latitude is one of the fundamental factors that influence the weather condition. For example, states with high latitude tend to have lower temperature, more snow, and less

intensity of sunlight. Even though the weather condition may vary significantly within a state, it is relatively stable from year to year. Therefore, using a constant value (i.e., the latitude) to represent a state’s weather condition is realistic while reducing the complexity of data collecting efforts.

Other factors considered but not included in the model: We also considered some other state-level factors such as population, GSP, GSP per capita, fuel price (Avgas and Jet A) and number of business establishment in a state. However, they are either highly correlated with at least one of the above factors or statistically not justified to be included in the model (2006 ETMS data).

4.7.3 Parameter Calibration

The model is calibrated for each aircraft type by using the 2006 ETMS data. The computation is performed in the commercial software SAS 9.3. The summary of the parameter estimation is presented in Table 4.22. All the parameter estimations are significant at the 5% significance level.

Table 4.22 Regression parameter estimation results.

Explanatory variables	Single Engine Piston	Piston	Turboprop	Turbojet
Distance between airport and destination state (center)	-8.153	-7.925	-5.891	-2.356
Population of destination state	0.084	0.081	0.065	0.073
GDP growth rate of destination state	0.029	0.014	0.060	0.037
Population density in destination state	-0.440	-0.404	-0.174	0.035
Latitude of destination state (center)	-0.047	-0.044	-0.041	-0.042
The average of F2I ratio of the origin and destination state	-0.028	-0.027	-0.021	-0.004

The parameter estimation for the variable distance is negative for all the three aircraft types. The operations of piston aircraft are the most impacted by distance while that of jet aircraft are the least impacted. This is reasonable because jet aircraft generally have the best performance while piston aircraft have the lowest one among the three aircraft types.

The parameter estimation for population density is negative for piston and turboprop aircraft. As mentioned earlier, long distance travel to remote or small communities with low population densities tend to rely more on GA operations. In the GAATA 2006 survey, about 41% of the total hours flown by those two aircraft are for personal use. Therefore, it is reasonable to believe that the negative coefficient estimation is because those two types of aircraft are used more to access places with low population density. The coefficient for the jet aircraft is positive, which indicates that jet aircraft tend to fly more to states with high population density. This may be because that places with high population density usually have more business opportunities, and a large portion of jet aircraft are mainly used for business purposes. For example, in the GAATA 2006, about 58% of the hours flown by jet aircraft are for business or corporate use (only about 7% for personal travel).

The coefficient for the GSP growth rate is positive for all the three aircraft types. This indicates the states with higher GSP growth rate tend to attract more GA activities. This result is consistent with the common belief that transportation activities are positively related with economic conditions. In addition, our estimation shows that jet aircraft are more influenced by this factor. This result is consistent with the earlier analysis, that is, a large portion of jet aircraft are used for business purpose and hence their activities are more sensitive to economic conditions.

The coefficients for the number of non-primary commercial service and reliever airport are positive for all the three aircraft types. This indicates that these two types of airports help attract GA activities. The coefficient for the latitude is negative for all the three aircraft types, which indicates that they prefer to fly to states with low altitude. One possible explanation is that states with high latitude usually have low temperature that discourages GA activities. Small GA aircraft are very sensitive to icing conditions.

A study done by Virginia Tech shows that in the winter months up to 30% of the flights would have to be cancelled in selected cities of Northeast corridor due to icing conditions.

4.7.4 Second level model: gravity-based airport choice model

For an origin airport, we have used the first level model to estimate the market share of operations to each state. In this part, we proposed a gravity-based model to further assign the projected operations to each state amongst the airports in the state. Using discrete models at this level is not practical either because of the two issues mentioned in the earlier part of this report. Therefore, we adopted the idea of the gravity model in this level.

In the gravity models proposed by (Baik. et al., 2006; D. Long et al., 2001), the operations to a destination airport are determined by its attractiveness which is assumed to be a function of its “mass” and impedance. The “mass” of an airport is usually determined by the number of itinerant operations or the number of based aircraft. The information about the number of itinerant operations and number of based aircraft for each airport is available in the TAF. The impedance of a destination airport is a function of its distance to the origin airport.

To assign the projected market share of operations to a state amongst the airports in the state, we use the same idea to design a gravity-based airport choice model. In the model, each of the destination airports in the state is also assigned an attractiveness value based on its “mass” and distance to the origin airport. It is necessary to point out that TAF does not provide information about the number of itinerant operations performed by each of the aircraft types discussed in the report. Therefore, we used the number of based aircraft at the destination airport as its mass.

Following the basic idea of the gravity model, for a destination airport, we used the probability of flying the distance between it and the origin airport as its impedance. We calculate this probability by using a Weibull distribution which is fitted using the travel distance information in the ETMS data.

Let o be the origin airport, j be the airport in a state, and $D_{o \rightarrow j}$ be the greater circle distance between the two airports, then the attractiveness of airport j respect to airport o is defined as:

$$A_{origin \rightarrow j} = Opers_{ij} \times P(D_{origin \rightarrow state \rightarrow j}) \quad (4.20)$$

For each aircraft type, $Opers_j$ is the number of based piston aircraft (single plus multiple engine aircraft) at airport j . Note that TAF only provides the information about the number of based jet (the combination of turboprop and jet aircraft defined in this report) at each airport. Therefore, for both turboprop and jet aircraft, we take N_{based} as the number of based jet at airport j in TAF.

As mentioned earlier, one of the issues of using gravity models to model GA airport choice is the lack of reliable historical data for the model calibration. To avoid this, we used the following equation to assign the projected operations to a state amongst the airports in the state:

$$P_{state \rightarrow j} = \frac{A_{origin \rightarrow j}}{\sum_k A_{origin \rightarrow k}} \quad (4.21)$$

The market share of operations to an airport is essentially the market share of its attractiveness in the total attractiveness of all the airports in the same state. It can be considered as the conditional probability of choosing airport j given that the state where airport j is located is chosen. Using this way to assign the projected operations is consistent with the idea of gravity model while does not require historical data for model parameter calibration.

Then, the probability of flying to airport j from origin airport o is calculated as follows:

$$P_{o \rightarrow state \rightarrow j} = P_{o \rightarrow state} \times P_{state \rightarrow j} \quad (4.22)$$

The first term on the right hand side of the equation is the probability of choosing the state where airport j is located. This is calculated by the first-level model. The second term is the conditional probability of choosing airport j amongst all the airports in the same state. This is calculated by the second-level model.

4.8 Model Application

In this section, we applied our two-level model which is calibrated by using the 2006 ETMS data to project the airport choice behaviors in 2008. For each aircraft type, our results are compared with the observations in 2008 ETMS data in the state level and airport level, respectively.

4.8.1 State level comparison

For the state level comparison, our comparison are focused on the airports with at least 50 unique observed destinations in the 2008 ETMS data (i.e., ideally, at least one destination in each state). 57 airports for piston aircraft, 15 airports for turboprop aircraft, and 135 airports for jet aircraft are considered in the comparison.

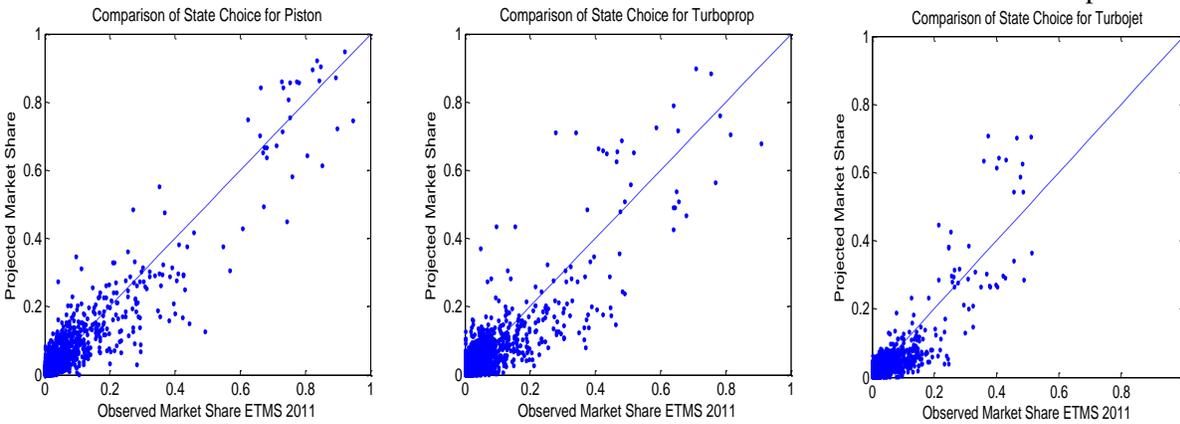


Figure 4-11 Comparison of state choice by aircraft type.

The scatter plots of the comparison are shown in Figure 4-11. With a 5% significance level, the dependent t-test detects no significant difference between the observed state choice behaviors and the projected ones for piston and turboprop aircraft. This indicates that the state choice model could capture the state-level choice behaviors for piston and turboprop aircraft.

However, for the jet aircraft, the test shows that significant difference may exist between the observed state choice behaviors and the projected ones. If only the airports with at least 150 observed destinations in the 2008 ETMS data are considered in the comparison, then no significant difference can be detected by the test (the p-value is about 0.3). Therefore, we believe this is partially because jet aircraft potentially having more choices to fly to because of their better performance and range characteristics.

4.8.2 Airport Choice Comparison

In this section, we compare the observed airport choice behaviors in the 2008 ETMS with the projected ones. For the aircraft at an origin airport, they could have hundreds or thousands of possible

destinations. To have a reliable observation of airport choice behaviors, it requires a large sample of the operations of each aircraft type at each origin airport. However, in the 2008 ETMS data, for an origin airport, the average number of unique destination airports is 8 for piston, 5 for turboprop, and 9 for jet aircraft. Those statistics are significantly smaller than the number of potential choices. Therefore, it may be unreasonable to evaluate our model by directly comparing the observed market share of flying to each destination airport with our projected one.

Table 4.23 Comparison between the PPDS and the OPDS

Percentage range	Piston			Turboprop			Jet					
	2490 origin airports	Number of destination airports		1706 origin airports	Number of destination airports		1441 origin airports	Number of destination airports				
	Percentage of airport in the range	Mini	Mean	Max	Percentage of airport in the range	Mini	Mean	Max	Percentage of airport in the range	Mini	Mean	Max
0%-10%	12.29%	1	1.42	6	15.53%	1	1.33	6	7.77%	1	1.21	3
10%-20%	0.20%	6	7.40	9	0.12%	6	6.00	6	0.21%	6	12.00	24
20%-30%	2.37%	4	6.59	29	1.35%	4	5.74	15	0.69%	4	5.90	11
30%-40%	4.58%	3	8.75	70	4.04%	3	7.68	39	1.80%	3	3.69	13
40%-50%	4.98%	5	20.32	74	5.33%	5	15.78	93	0.76%	5	8.45	27
50%-60%	17.95%	2	13.08	133	17.17%	2	10.62	70	9.09%	2	15.09	304
60%-70%	12.45%	3	14.15	97	13.42%	3	11.61	56	15.06%	3	34.85	188
70%-80%	7.27%	4	13.36	57	8.79%	4	11.89	44	17.42%	4	32.99	126
89%-90%	6.79%	5	15.31	53	5.51%	5	11.94	56	10.83%	5	19.53	99
90%-100%	31.12%	1	2.80	42	28.72%	1	2.19	30	36.36%	1	3.50	43

To address this issue, we proposed the following way for comparison. For an origin airport, we applied the two-level model to project the market share of flying to each destination airport. Then, we create a projected preferred destination set (PPDS) by selecting the top 5% of its destinations by their projected market share. The airports in this set are considered to be the projected most preferred destinations from this origin airport. For this origin airport, we also created an observed preferred destination set (OPDS) using its observed destination airports in the 2008 ETMS. Then, we calculate the percentage of the airports in the OPDS contained in the PPDS, and we use this percentage to measure the performance of our model. The comparison is presented for each aircraft type in Table 4.23. In the comparison, we considered 2490 origin airports for piston, 1706 for turboprop, and 1441 for jet.

For each origin airport, we calculated the percentage of the airports in its OPDS contained in its PPDS. Based on this percentage, we put the origin airport into one of the ten percentage intervals (see Table 4-23). For example, for an origin airport, if 82% of the airports in its OPDS are contained in its PPDS, then this airport will be put into interval 80%-90%. In Table 4-23, we presented the percentage of origin airports that are in each percentage interval. For the origin airports in each percentage interval, we also calculated the minimum, mean and maximum number of destination airports. Take the first percentage interval (i.e., 0%-10%) for piston aircraft as an example, about 12.29% of the total origin airports have about less than 10% of their OPDS contained in their PPDS. For the origin airports in this percentage interval, the minimum number of destination is one (i.e., some origin airports only have one observed destination airport in the 2008 ETMS), the mean number of destination is about 1.42, and the maximum number of destinations is 6.

4.9 Validation Procedures using GAATA and ETMS Data

This section provides validation of the combination of the three models developed in the previous section. More specifically, we applied the three models and compared the final outputs with the statistics (distribution of distance travelled) in ETMS 2011 data. In addition, we applied the three models for years

2006 to 2010 and compared the total number of hours flown by itinerant operations by aircraft type with the statistics reported in the GAATA survey (2006-2010).

4.9.1 Comparison of distribution of distance flown between ETMS 2011 and our forecast:

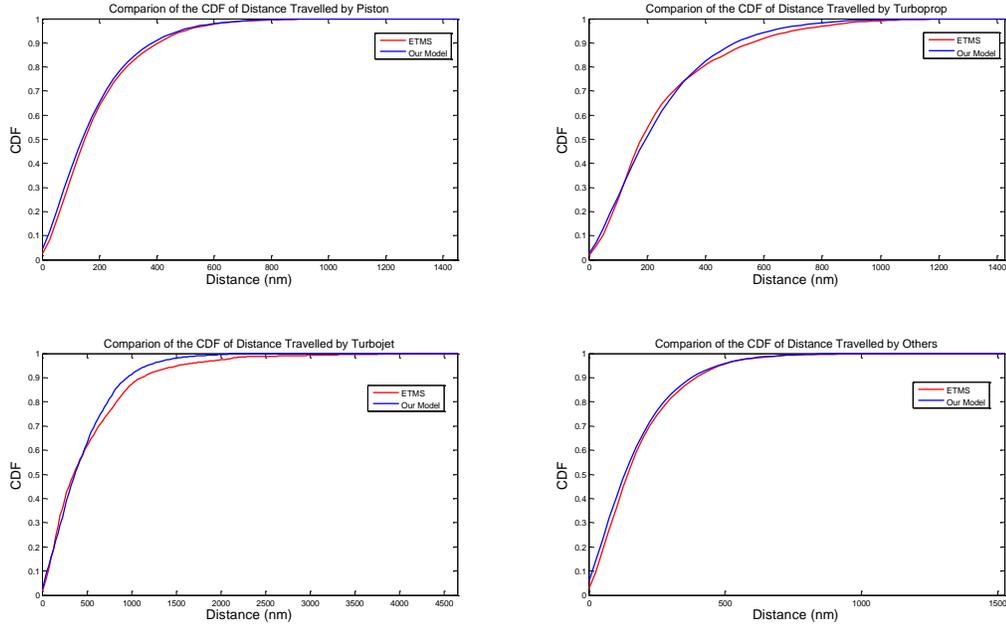


Figure 4-12 Comparison of distance travelled by aircraft type.

4.9.2 Comparison of hours flown (itinerant) total and by aircraft type between GAATA and our estimation:

Table 4.24 Comparison of hours flown (itinerant) total and by aircraft type between GAATA and our estimation

	Our Estimation (Itinerant)				GAATA Survey (Itinerant)				Error			
	Piston	Turboprop	Turbojet	Non-fixed-wing	Piston	Turboprop	Turbojet	Non-fixed-wing	Piston	Turboprop	Turbojet	Non-fixed-wing
2006	10,798,537	1,622,246	2,658,940	1,898,928	10,829,873	1,178,568	3,120,038	1,958,731	-0.29%	37.65%	-14.78%	-3.05%
2007	10,793,600	1,624,287	2,662,888	2,259,467	10,376,426	1,265,760	2,830,337	2,232,773	4.02%	28.33%	-5.92%	1.20%
2008	9,188,751	1,424,597	2,468,750	1,951,847	9,605,116	1,074,926	2,853,925	2,074,832	-4.33%	32.53%	-13.50%	-5.93%
2009	10,983,287	1,685,512	2,789,798	2,606,095	9,222,237	1,077,842	2,457,712	2,212,282	19.10%	56.38%	13.51%	17.80%
2010	10,295,706	1,590,500	2,687,356	2,325,171	8,838,808	1,036,560	2,637,610	2,052,164	16.48%	53.44%	1.89%	13.30%

4.10 General Aviation Forecasts

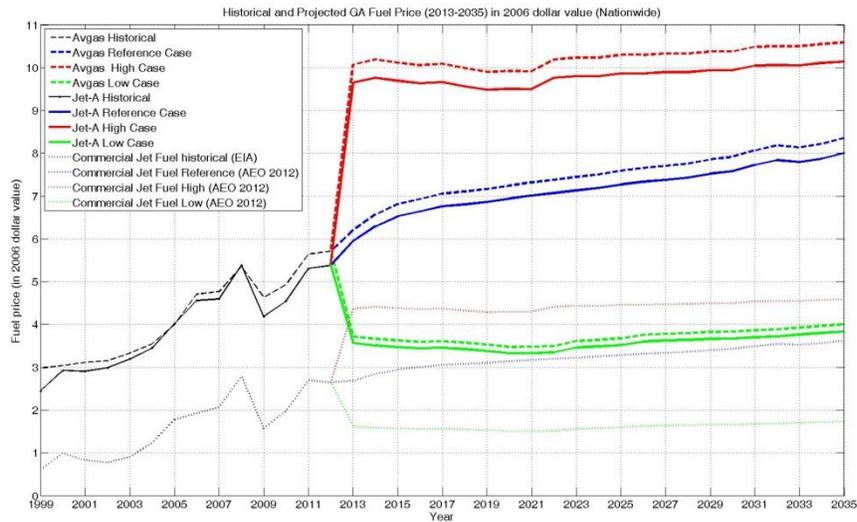


Figure 4-13 Projections of General Aviation fuel prices.

Following (Macharis et al., 2010), we adopted the projection of the price of kerosene-type jet fuel⁸ price given in Annual Energy Outlook 2012. Fuel projections are made by the U.S. Energy Information Administration (EIA) using the EIA National Energy Modeling System. To capture future uncertainties, the projection is given in three scenarios: high oil price case, low oil price case, and reference oil price case, with a different expectation on supply and demand in each scenario. The reference case is a “business-as-usual” trend estimate. High oil price case can be considered as a pessimistic forecast. It assumes a higher demand while lower supply. Low oil price case can be considered as an optimistic forecast. It assumes a lower demand while higher supply. Figure 4-13 shows the EIA’s nation-wide projected prices of kerosene-type jet fuel from 2013 to 2035. The fuel price in the high and low cases stays relatively stable through the projection period. The fuel price in the reference case, as consistent with the historical trend, increases steadily.

However, the projections from the EIA cannot be used directly in our models since they are not given in terms of the GA fuel price. A conversion between the prices of the two is needed. We found that the price of kerosene-type jet fuel is highly correlated with the fuel price for the GA. Therefore, to obtain the projection of fuel price for the GA, we assume the following relationship exists between prices of the two:

$$GA \text{ fuel} = \alpha \times \text{kerosene} - \text{type jet fuel} \quad (4.23)$$

Using historical data from 1999 to 2012, the coefficient is estimated for every FAA region and the nation as a whole by regression. The R-square ranges from. The nation-wide fuel price projections for the GA are presented in Figure 4-13.

⁸ kerosene-type jet fuel is used for commercial and military turbojet and turboprop aircraft engines.

4.10.1 Projection of County-level Socio-economic and Demographic Factors

EIA assumes different macro-level social-economic factors (e.g., GDP and income growth rate) in each scenario. However, the projections of county-level social-economic and demographic factors corresponding to EIA’s fuel price scenarios are not available to this study. Since our models are calibrated by using the historical county-level data provided by Woods and Poole, to maintain consistency, we adopted its projection as well. The projections of nation-wide fuel price to personal income ratio are presented in Figure 4-14.

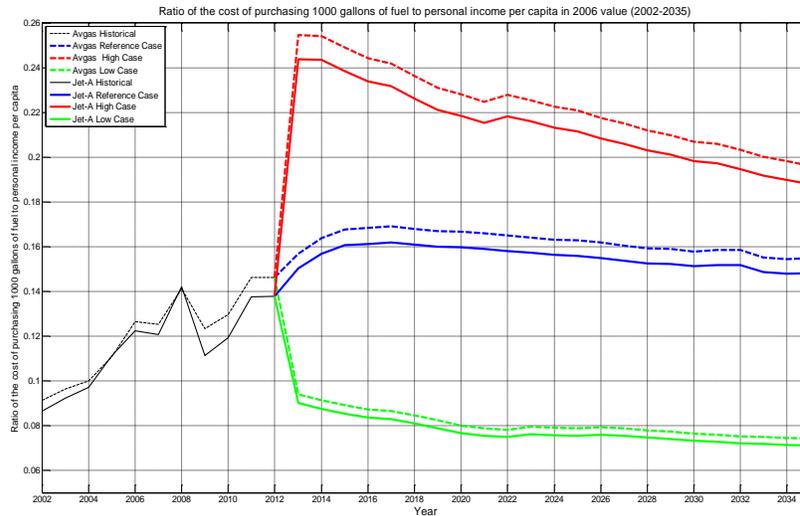


Figure 4-14 Projection of Supply Factors at the Airports.

The supply factors at the airports are assumed to be constant throughout the forecast period. This would 1) simplify our study by avoiding the efforts of making forecast of supply factors for every single airport in TAF 2) make the impact of fuel price easier to be identified.

4.10.2 TAF Forecast

Aviation activities forecast in TAF for towered airports usually undergo a systemic process. A forecast is produced by considering historical trend, local and national factors that influence aviation activities. Each estimate is examined for its reasonableness and consistency. Sometimes, other methods (e.g., regression and trend analysis) and forecast from other sources (e.g., local authorities and master plan forecast) are considered to improve the estimate. However, the forecast for many non-towered TAF airports are held constant unless otherwise specified.

4.10.3 Comparisons with TAF Forecast

In TAF, both the itinerant and local operation for towered airports are expected to recover after 2012 at around 0.4% per year. In 2023, the number of both operations is expected to recover to the level in 2010. In the year 2035, the number of itinerant and local operation is predicted to be 5.4% and 6.5% higher than that in 2010, respectively.

We compare our model forecast with those stated in TAF. The comparison is focused on towered airports only since their statistics are relatively accurate. The percentage marked on the curves represents the percentage of change in operation compared with that of in 2010.

Under a low fuel price scenario, our model predicts that the number of itinerant operation will increase significantly from 2013 to 2035. The growth rate is between 2%-3% from 2013 to 2022 and decreases to 1% from 2022 to 2035. By the year 2035, the number of itinerant operations could increase by 50% compared to the number of operations in 2010, and almost reach the level observed in the year 2000. The number of local operation is expected to increase at even faster rate, and reach 2010 activity levels in the year 2028.

Under the reference scenario, different from the monotonically increasing trend from TAF, our model predicts a decline of about 0.8% per year until 2015 for both itinerant and local operation. The recover begins at 2016 with a recover rate of about 0.9% per year for itinerant and 1.1% for local operation. The number of itinerant operation is expected to recover to the level in 2010 in the year 2027, and exceed the number in 2010 by 6.8% (5.4% in TAF) by 2035. The number of local operation is predicted to reach the level in 2010 in the year 2023, and exceed the number in 2010 by 16.8% (6.5% in TAF) in the year 2035.

Under the high fuel price scenario, in 2013, the number of itinerant and local operation is expected to decrease by 26% and 30%, respectively. However, from 2014, the number begins to recover. Our model predicts a 4.4% loss in the number for itinerant operation in the year 2035 compared that in 2010.

Table 4.25 Forecast of itinerant operations

Year	TAF itinerant growth rate at towered airport				TAF itinerant growth rate at non-towered airport			
2000	-0.66%				4.10%			
2001	-6.91%				3.86%			
2002	-0.53%				0.90%			
2003	-5.29%				0.48%			
2004	-1.69%				0.77%			
2005	-4.05%				-2.00%			
2006	-3.14%				0.04%			
2007	-1.81%				0.83%			
2008	-7.11%				-1.15%			
2009	-11.28%				-1.10%			
2010	-5.09%	Itinerant growth rate at towered airport (our model)			-1.34%	Itinerant growth rate at non-towered airport (our model)		
2011	-2.51%	High Fuel Price Scenario	Low Fuel Price Scenario	Reference Fuel Price Scenario	0.44%	High Fuel Price Scenario	Low Fuel Price Scenario	Reference Fuel Price Scenario
2012	-1.77%	-5.17%	-5.17%	-5.17%	0.50%	-5.48%	-5.48%	-5.48%
2013	0.39%	-22.20%	23.88%	-2.45%	0.41%	-22.27%	23.75%	-2.54%
2014	0.40%	0.72%	2.03%	-1.36%	0.42%	0.54%	1.85%	-1.54%
2015	0.40%	1.60%	1.79%	-0.47%	0.42%	1.42%	1.61%	-0.64%
2016	0.40%	1.57%	1.66%	0.48%	0.41%	1.39%	1.47%	0.30%
2017	0.40%	1.12%	1.10%	0.42%	0.42%	0.95%	0.93%	0.25%
2018	0.40%	1.75%	1.70%	0.96%	0.42%	1.58%	1.53%	0.79%
2019	0.41%	1.70%	1.90%	0.91%	0.43%	1.53%	1.73%	0.74%
2020	0.41%	1.17%	1.99%	0.70%	0.43%	1.02%	1.83%	0.54%
2021	0.41%	1.35%	1.29%	0.84%	0.44%	1.19%	1.13%	0.68%
2022	0.41%	-0.02%	1.06%	0.93%	0.45%	-0.17%	0.91%	0.77%
2023	0.41%	1.13%	-0.24%	0.89%	0.45%	0.95%	-0.42%	0.70%
2024	0.42%	1.25%	0.93%	0.89%	0.46%	1.09%	0.77%	0.72%
2025	0.42%	0.95%	0.78%	0.71%	0.47%	0.79%	0.62%	0.55%
2026	0.42%	1.31%	0.26%	0.90%	0.47%	1.15%	0.10%	0.74%
2027	0.42%	1.15%	0.97%	0.99%	0.48%	0.99%	0.82%	0.83%
2028	0.43%	1.26%	1.09%	0.95%	0.49%	1.11%	0.93%	0.80%
2029	0.43%	1.06%	0.92%	0.68%	0.50%	0.90%	0.76%	0.53%
2030	0.43%	1.25%	1.17%	0.89%	0.50%	1.09%	1.01%	0.73%
2031	0.43%	0.79%	0.91%	0.41%	0.51%	0.64%	0.76%	0.26%
2032	0.44%	1.22%	1.02%	0.58%	0.52%	1.08%	0.87%	0.43%
2033	0.44%	1.29%	0.75%	1.55%	0.53%	1.14%	0.61%	1.40%
2034	0.44%	1.00%	0.77%	0.75%	0.54%	0.86%	0.62%	0.60%
2035	0.44%	1.08%	0.78%	0.48%	0.54%	0.94%	0.64%	0.33%
Average	0.33%	-0.07%	1.81%	0.27%	0.47%	-0.23%	1.64%	0.10%

Table 4.26 Forecast of local operations.

Year	TAF local operation growth rate at towered airport				TAF local operation growth rate at non-towered airport			
2000	1.46%				3.92%			
2001	-5.53%				3.86%			
2002	-1.66%				0.47%			
2003	-5.81%				-0.54%			
2004	-3.39%				0.16%			
2005	-2.34%				0.49%			
2006	-2.80%				0.49%			
2007	1.28%				0.28%			
2008	-5.11%				1.07%			
2009	-12.35%				-0.68%			
2010	-7.03%	Local operation growth rate at towered airport (our model)			-1.35%	Local operation growth rate at non-towered airport (our model)		
2011	-2.96%	High Fuel Price Scenario	Low Fuel Price Scenario	Reference Fuel Price Scenario	0.23%	High Fuel Price Scenario	Low Fuel Price Scenario	Reference Fuel Price Scenario
2012	-2.14%	-5.76%	-5.76%	-5.76%	0.40%	-6.37%	-6.37%	-6.37%
2013	0.48%	-25.48%	29.10%	-2.65%	0.38%	-25.75%	28.62%	-3.01%
2014	0.48%	1.18%	2.74%	-1.29%	0.38%	0.69%	2.24%	-1.76%
2015	0.48%	2.21%	2.43%	-0.24%	0.38%	1.73%	1.96%	-0.71%
2016	0.48%	2.15%	2.25%	0.85%	0.38%	1.69%	1.79%	0.40%
2017	0.48%	1.63%	1.61%	0.81%	0.38%	1.17%	1.15%	0.35%
2018	0.49%	2.39%	2.33%	1.44%	0.39%	1.93%	1.87%	0.99%
2019	0.49%	2.33%	2.57%	1.39%	0.39%	1.87%	2.11%	0.93%
2020	0.49%	1.70%	2.67%	1.13%	0.40%	1.25%	2.21%	0.69%
2021	0.49%	1.91%	1.84%	1.30%	0.40%	1.47%	1.40%	0.86%
2022	0.50%	0.29%	1.57%	1.41%	0.41%	-0.16%	1.12%	0.95%
2023	0.50%	1.64%	0.02%	1.35%	0.42%	1.19%	-0.43%	0.90%
2024	0.50%	1.79%	1.41%	1.36%	0.42%	1.35%	0.96%	0.91%
2025	0.50%	1.45%	1.24%	1.17%	0.43%	0.99%	0.78%	0.71%
2026	0.51%	1.87%	0.63%	1.39%	0.43%	1.41%	0.17%	0.93%
2027	0.51%	1.68%	1.47%	1.49%	0.44%	1.23%	1.02%	1.04%
2028	0.51%	1.82%	1.61%	1.45%	0.45%	1.37%	1.16%	1.00%
2029	0.51%	1.58%	1.41%	1.13%	0.46%	1.12%	0.96%	0.68%
2030	0.52%	1.81%	1.71%	1.38%	0.46%	1.35%	1.26%	0.93%
2031	0.52%	1.26%	1.40%	0.81%	0.47%	0.82%	0.96%	0.37%
2032	0.52%	1.77%	1.53%	1.01%	0.48%	1.33%	1.09%	0.57%
2033	0.52%	1.85%	1.21%	2.16%	0.48%	1.41%	0.78%	1.72%
2034	0.53%	1.51%	1.23%	1.21%	0.49%	1.08%	0.80%	0.77%
2035	0.53%	1.61%	1.25%	0.89%	0.50%	1.18%	0.82%	0.46%
Average	0.39%	0.26%	2.48%	0.63%	0.43%	-0.19%	2.02%	0.18%

Table 4.27 Forecast of itinerant operations by aircraft type.

Year	Reference Fuel Price Scenario (Itinerant)				High Fuel Price Scenario (Itinerant)				Low Fuel Price Scenario (Itinerant)			
	Piston	Turboprop	Turbojet	Non-fixed-wing	Piston	Turboprop	Turbojet	Non-fixed-wing	Piston	Turboprop	Turbojet	Non-fixed-wing
2011	0.71%	0.65%	1.33%	-3.41%	0.71%	0.65%	1.33%	-3.41%	0.71%	0.65%	1.33%	-3.41%
2012	-6.32%	-5.82%	-3.35%	-5.14%	-6.32%	-5.82%	-3.35%	-5.14%	-6.32%	-5.82%	-3.35%	-5.14%
2013	-3.70%	-3.45%	-1.72%	0.97%	-30.70%	-28.45%	-18.62%	3.52%	29.63%	27.55%	20.94%	8.51%
2014	-2.21%	-2.07%	-0.70%	0.45%	0.56%	0.48%	1.05%	0.63%	2.10%	1.95%	2.26%	1.29%
2015	-1.06%	-0.99%	0.07%	0.56%	1.96%	1.75%	1.80%	0.30%	1.79%	1.67%	2.06%	1.19%
2016	0.19%	0.18%	0.90%	0.65%	1.88%	1.70%	1.80%	0.36%	1.61%	1.53%	1.97%	1.15%
2017	0.14%	0.11%	0.82%	0.62%	1.18%	1.04%	1.39%	0.49%	0.98%	0.90%	1.44%	0.87%
2018	0.87%	0.77%	1.27%	0.66%	2.18%	1.94%	1.92%	0.32%	1.69%	1.56%	1.97%	1.18%
2019	0.82%	0.71%	1.22%	0.66%	2.10%	1.85%	1.87%	0.36%	1.92%	1.78%	2.15%	1.30%
2020	0.52%	0.44%	1.05%	0.63%	1.26%	1.11%	1.44%	0.48%	2.00%	1.87%	2.24%	1.35%
2021	0.72%	0.61%	1.16%	0.66%	1.53%	1.34%	1.57%	0.48%	1.21%	1.09%	1.60%	0.99%
2022	0.84%	0.72%	1.23%	0.65%	-0.55%	-0.55%	0.42%	0.78%	0.95%	0.85%	1.40%	0.87%
2023	0.75%	0.68%	1.24%	0.66%	1.16%	1.04%	1.42%	0.53%	-0.57%	-0.57%	0.24%	0.16%
2024	0.79%	0.68%	1.20%	0.64%	1.39%	1.21%	1.49%	0.47%	0.80%	0.70%	1.27%	0.79%
2025	0.57%	0.45%	1.04%	0.61%	0.94%	0.78%	1.22%	0.53%	0.63%	0.52%	1.12%	0.70%
2026	0.82%	0.68%	1.19%	0.63%	1.48%	1.27%	1.52%	0.47%	0.04%	-0.05%	0.64%	0.42%
2027	0.95%	0.79%	1.27%	0.64%	1.23%	1.04%	1.38%	0.50%	0.86%	0.73%	1.29%	0.80%
2028	0.89%	0.74%	1.23%	0.63%	1.41%	1.20%	1.48%	0.48%	0.99%	0.86%	1.40%	0.87%
2029	0.54%	0.41%	1.00%	0.60%	1.10%	0.92%	1.30%	0.51%	0.80%	0.67%	1.24%	0.77%
2030	0.82%	0.66%	1.17%	0.62%	1.39%	1.17%	1.46%	0.49%	1.09%	0.94%	1.46%	0.91%
2031	0.18%	0.07%	0.76%	0.56%	0.71%	0.55%	1.07%	0.55%	0.79%	0.65%	1.22%	0.77%
2032	0.41%	0.28%	0.90%	0.58%	1.35%	1.13%	1.44%	0.49%	0.92%	0.78%	1.33%	0.83%
2033	1.71%	1.48%	1.74%	0.69%	1.44%	1.21%	1.49%	0.49%	0.62%	0.48%	1.08%	0.68%
2034	0.64%	0.48%	1.04%	0.59%	1.03%	0.83%	1.25%	0.52%	0.64%	0.49%	1.09%	0.68%
2035	0.29%	0.14%	0.80%	0.55%	1.15%	0.94%	1.31%	0.52%	0.66%	0.51%	1.10%	0.69%
Average	0.04%	-0.02%	0.71%	0.24%	-0.34%	-0.39%	0.42%	0.23%	1.86%	1.69%	2.02%	0.77%

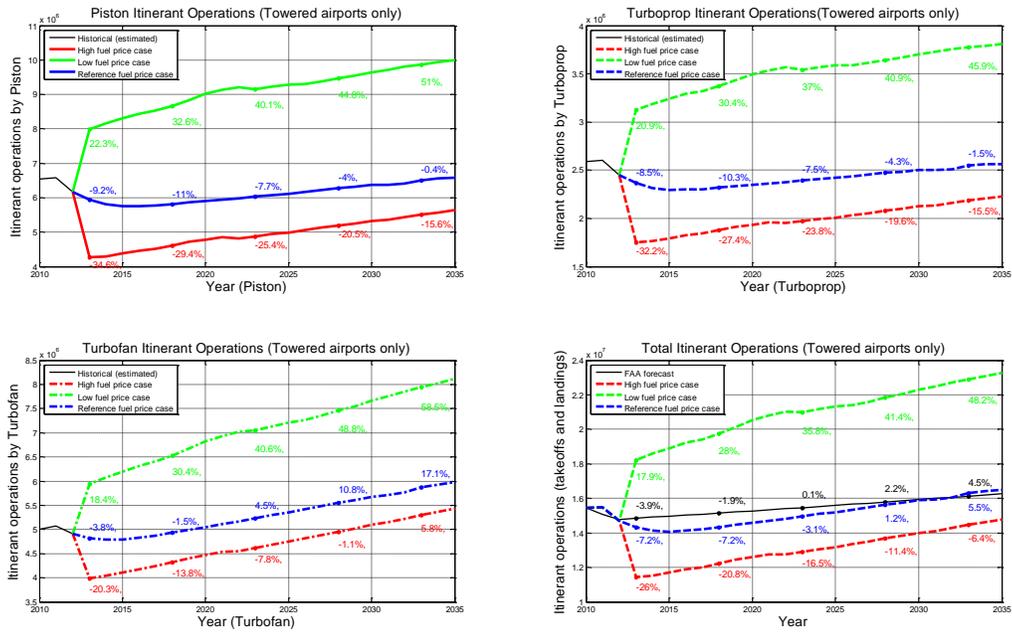


Figure 4-15 Itinerant operations at towered airport (percentage of changes is compared with the one in 2010).

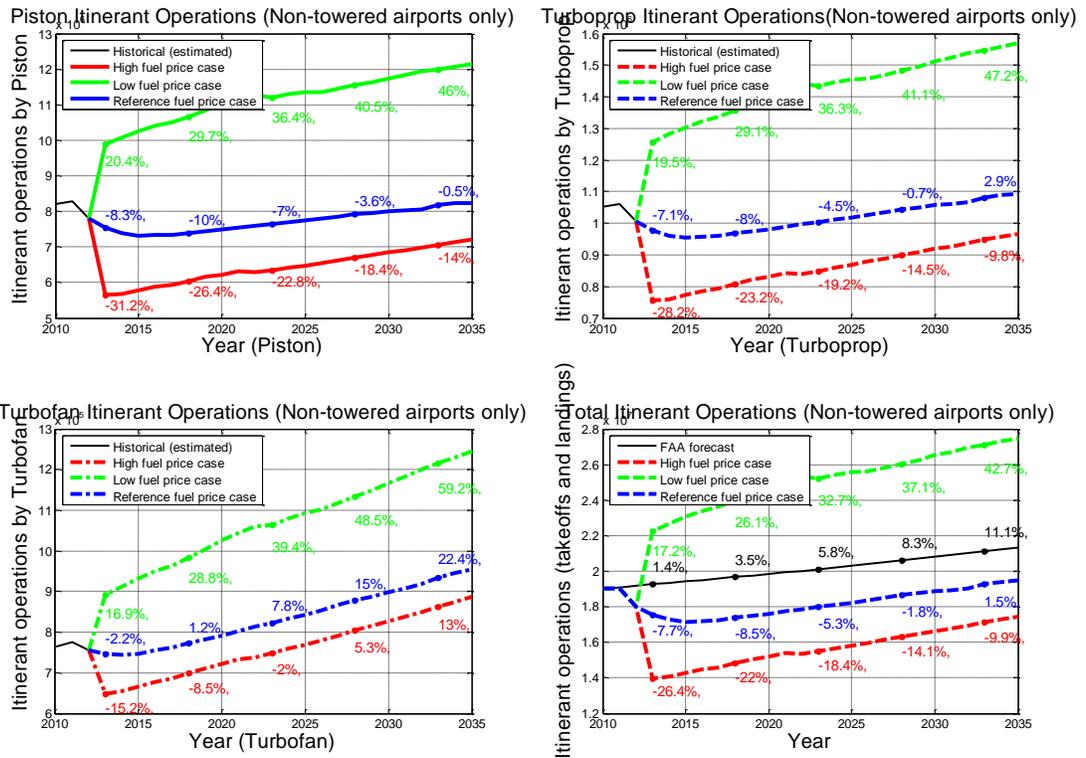


Figure 4-16 Itinerant operations at non-towered airport (percentage of changes is compared with the one in 2010).

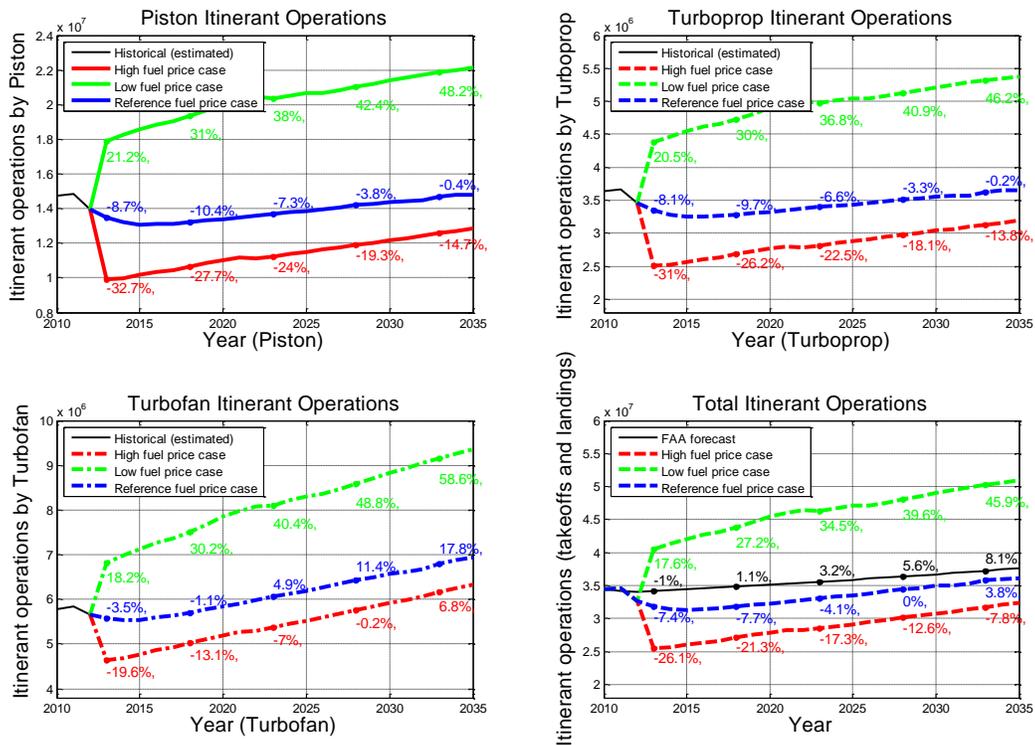


Figure 4-17 Itinerant operations at all airports (percentage of changes is compared with the one in 2010).

Table 4.28 Forecast of hours flown by itinerant operations by aircraft type.

Year	Reference Fuel Price Scenario (Itinerant)				High Fuel Price Scenario (Itinerant)				Low Fuel Price Scenario (Itinerant)			
	Piston	Turboprop	Turbojet	Non-fixed-wing	Piston	Turboprop	Turbojet	Non-fixed-wing	Piston	Turboprop	Turbojet	Non-fixed-wing
2011	1.22%	1.16%	1.66%	-7.03%	1.22%	1.16%	1.66%	-7.03%	1.22%	1.16%	1.66%	-7.03%
2012	-7.09%	-6.54%	-4.08%	2.47%	-7.09%	-6.54%	-4.08%	2.47%	-7.09%	-6.54%	-4.08%	2.47%
2013	-2.94%	-2.73%	-1.11%	-2.48%	-24.96%	-23.00%	-13.26%	-22.36%	25.66%	23.98%	17.96%	24.04%
2014	-2.64%	-2.43%	-1.05%	3.98%	-8.13%	-7.67%	-6.16%	56.12%	4.88%	4.62%	4.53%	-17.26%
2015	-1.29%	-1.16%	-0.12%	2.29%	1.56%	1.44%	1.48%	1.36%	1.78%	1.72%	2.05%	0.54%
2016	-0.06%	-0.01%	0.69%	2.00%	1.99%	1.86%	1.90%	-0.46%	1.60%	1.57%	1.95%	0.63%
2017	0.13%	0.15%	0.81%	0.61%	1.43%	1.34%	1.60%	-0.77%	1.01%	0.99%	1.46%	0.23%
2018	0.72%	0.68%	1.15%	1.19%	1.95%	1.79%	1.75%	0.72%	1.60%	1.54%	1.91%	1.26%
2019	0.81%	0.76%	1.22%	0.38%	2.19%	2.01%	1.96%	-0.53%	1.87%	1.79%	2.11%	1.01%
2020	0.56%	0.54%	1.09%	0.22%	1.53%	1.42%	1.67%	-0.93%	1.97%	1.89%	2.22%	0.96%
2021	0.68%	0.64%	1.13%	0.66%	1.50%	1.38%	1.56%	0.23%	1.25%	1.20%	1.64%	0.22%
2022	0.81%	0.76%	1.22%	0.58%	-0.02%	0.01%	0.87%	-1.40%	0.95%	0.92%	1.40%	0.54%
2023	0.77%	0.75%	1.25%	0.38%	0.70%	0.66%	1.05%	2.28%	-0.46%	-0.41%	0.34%	-0.62%
2024	0.78%	0.73%	1.20%	0.49%	1.36%	1.25%	1.48%	0.29%	0.69%	0.66%	1.19%	1.53%
2025	0.60%	0.54%	1.08%	0.26%	1.08%	0.98%	1.36%	-0.29%	0.63%	0.58%	1.14%	0.49%
2026	0.77%	0.71%	1.17%	0.70%	1.37%	1.24%	1.45%	0.62%	0.08%	0.06%	0.69%	0.08%
2027	0.92%	0.85%	1.27%	0.53%	1.33%	1.21%	1.49%	-0.18%	0.79%	0.74%	1.26%	1.19%
2028	0.91%	0.83%	1.26%	0.36%	1.40%	1.27%	1.50%	0.24%	0.98%	0.92%	1.40%	0.78%
2029	0.60%	0.54%	1.08%	0.15%	1.21%	1.09%	1.42%	-0.18%	0.81%	0.75%	1.27%	0.53%
2030	0.77%	0.69%	1.17%	0.72%	1.35%	1.20%	1.46%	0.38%	1.06%	0.98%	1.47%	0.90%
2031	0.30%	0.25%	0.88%	-0.04%	0.90%	0.80%	1.26%	-0.40%	0.82%	0.75%	1.27%	0.47%
2032	0.38%	0.32%	0.90%	0.79%	1.23%	1.10%	1.37%	0.84%	0.92%	0.85%	1.35%	0.78%
2033	1.51%	1.37%	1.60%	1.54%	1.47%	1.32%	1.55%	0.15%	0.65%	0.59%	1.14%	0.43%
2034	0.84%	0.75%	1.24%	-0.60%	1.16%	1.04%	1.39%	-0.23%	0.65%	0.58%	1.13%	0.63%
2035	0.36%	0.29%	0.91%	0.21%	1.16%	1.02%	1.36%	0.33%	0.67%	0.59%	1.15%	0.63%
Average	0.02%	0.02%	0.71%	0.42%	-0.45%	-0.42%	0.36%	1.25%	1.80%	1.70%	1.98%	0.62%

Table 4.29 Average cruise speed by aircraft type.

Aircraft Type	Piston	Turboprop	Turbojet	Non-fixed-wing (single engine piston)
Cruise Speed (nm/h)	154	255	406	144

Table 4.30 Forecast of hours flown by aircraft type 2011-2035.

Hours flown	Reference Fuel Price Scenario (Kinerant)				High Fuel Price Scenario (Kinerant)				Low Fuel Price Scenario (Kinerant)			
	Piston	Turboprop	Turbojet	Non-fixed-wing	Piston	Turboprop	Turbojet	Non-fixed-wing	Piston	Turboprop	Turbojet	Non-fixed-wing
2011	1.22%	1.16%	1.66%	-7.03%	1.22%	1.16%	1.66%	-7.03%	1.22%	1.16%	1.66%	-7.03%
2012	-7.09%	-6.54%	-4.06%	2.47%	-7.09%	-6.54%	-4.06%	2.47%	-7.09%	-6.54%	-4.06%	2.47%
2013	-2.94%	-2.73%	-1.11%	-2.48%	-24.96%	-23.00%	-13.26%	-22.96%	25.66%	23.98%	17.96%	24.04%
2014	-2.64%	-2.43%	-1.05%	3.98%	-8.13%	-7.67%	-6.16%	56.12%	4.88%	4.62%	4.53%	-17.26%
2015	-1.29%	-1.16%	-0.12%	2.29%	1.56%	1.44%	1.48%	1.36%	1.78%	1.72%	2.05%	0.54%
2016	-0.06%	-0.01%	0.69%	2.00%	1.99%	1.86%	1.90%	-0.46%	1.60%	1.57%	1.95%	0.63%
2017	0.13%	0.15%	0.81%	0.61%	1.43%	1.34%	1.60%	-0.77%	1.01%	0.99%	1.46%	0.23%
2018	0.72%	0.68%	1.15%	1.19%	1.95%	1.79%	1.75%	0.72%	1.60%	1.54%	1.91%	1.26%
2019	0.81%	0.76%	1.22%	0.38%	2.19%	2.01%	1.96%	-0.53%	1.87%	1.79%	2.11%	1.01%
2020	0.56%	0.54%	1.09%	0.22%	1.53%	1.42%	1.67%	-0.93%	1.97%	1.89%	2.22%	0.96%
2021	0.68%	0.64%	1.13%	0.66%	1.50%	1.38%	1.56%	0.23%	1.25%	1.20%	1.64%	0.22%
2022	0.81%	0.76%	1.22%	0.58%	-0.02%	0.01%	0.87%	-1.40%	0.95%	0.92%	1.40%	0.54%
2023	0.77%	0.75%	1.25%	0.58%	0.70%	0.66%	1.05%	-2.28%	-0.46%	-0.41%	0.34%	-0.62%
2024	0.78%	0.73%	1.20%	0.49%	1.36%	1.25%	1.48%	0.29%	0.69%	0.66%	1.19%	1.53%
2025	0.60%	0.54%	1.08%	0.26%	1.08%	0.98%	1.36%	-0.29%	0.63%	0.58%	1.14%	0.49%
2026	0.77%	0.71%	1.17%	0.70%	1.37%	1.24%	1.45%	0.62%	0.08%	0.06%	0.69%	0.08%
2027	0.92%	0.85%	1.27%	0.53%	1.33%	1.21%	1.49%	-0.18%	0.79%	0.74%	1.26%	1.19%
2028	0.91%	0.83%	1.26%	0.36%	1.40%	1.27%	1.50%	0.24%	0.98%	0.92%	1.40%	0.78%
2029	0.60%	0.54%	1.08%	0.15%	1.21%	1.09%	1.42%	-0.18%	0.81%	0.75%	1.27%	0.53%
2030	0.77%	0.69%	1.17%	0.72%	1.35%	1.20%	1.46%	0.38%	1.06%	0.98%	1.47%	0.90%
2031	0.80%	0.25%	0.88%	-0.04%	0.90%	0.80%	1.26%	-0.40%	0.82%	0.75%	1.27%	0.47%
2032	0.38%	0.32%	0.90%	0.79%	1.23%	1.10%	1.37%	0.84%	0.92%	0.85%	1.35%	0.78%
2033	1.51%	1.37%	1.60%	1.54%	1.47%	1.32%	1.55%	0.15%	0.65%	0.59%	1.14%	0.43%
2034	0.84%	0.75%	1.24%	-0.60%	1.16%	1.04%	1.39%	-0.23%	0.65%	0.58%	1.13%	0.63%
2035	0.36%	0.29%	0.91%	0.21%	1.16%	1.02%	1.36%	0.33%	0.67%	0.59%	1.15%	0.63%
Average	0.02%	0.02%	0.71%	0.42%	-0.45%	-0.42%	0.36%	1.25%	1.80%	1.70%	1.98%	0.62%

4.11 Nation-wide Models to Evaluate the Impact of Fuel Price

Complementary to the airport-level models, we developed two nation-wide econometric models. One is to model the impact of fuel price on aircraft utilization rate (i.e., average hours flown by an aircraft); and the other one is to model the impact of fuel price on total number of hours flown. In the airport-level models, we included supply factors, local socio-economic and demographic factors around an airport.

- 1) From the viewpoint of an airport, “higher” supply factors mean stronger capabilities to serve the flight operations. This would have two effects. The first one is more aircraft owners would be attracted to base their aircrafts at the airport. More aircrafts based at an airport means more GA demand. The second one is that more GA operations would be attracted (from other originating airports) to the airport. For example, an airport with a runway with runway length greater 4000 ft definitely will attract more jet operations than the airport without one.
- 2) From a nation-wide perspective, supply factors at an airport may have little effects in generating nation-wide GA demand; however, they play an important role in determining the distribution of the GA demand. For example, an airport with a concrete or asphalt runway does attract more GA operation than the one without.

In the previous sections, we adopted a down-top method. We model the GA demand at the airport-level first, then aggregate the demand to a nation-wide level. This method can be understood as modeling the “distributed” demand at each airport.

In the nation-wide model we mainly focus on the nation-wide socio-economic and demographic factors. We did not consider supply factors at airports because distribution of demand among airports is of less interest at the nation-wide level. Table 4.30 lists the social-economic and demographic factors considered in the two nation-wide models

Table 4.31 Social-economic and demographic factors considered in the model.

Factors	Data source
F2I ratio (Jet-A)	Bureau of Economic Analysis & EIA
F2I ratio (Jet-A) one-year lag	
F2I ratio (Jet-A) two-year lag	
GDP growth rate	Bureau of Economic Analysis
GDP growth rate one-year lag	
GDP growth rate two-year lag	
Number of student pilots	FAA aero space forecasting
Number of student pilots one-year lag	
Number of student pilots two-year lag	
Disposable income per capita (chained 2005 dollars)	Bureau of Economic Analysis
Disposable income per capita (chained 2005 dollars) one-year lag	
Disposable income per capita (chained 2005 dollars) two-year lag	
Durable good price index (2005=100)	Bureau of Economic Analysis
Services price index (2005=100)	Bureau of Economic Analysis
Gross domestic product (chained 2005 dollars)	Bureau of Economic Analysis
Total number of active aircraft by aircraft engine types	GAATA survey

The Fuel-to-Income (F2I) ratio has been studied in the airport-level models and shown to have significant impact on the GA activities. It is necessary to point out that the fuel price considered here is the nation-wide historical price for commercial aviation. It is provided by the EIA. In the airport-level models, we used fuel price obtained from business aviation. This is because the prices of fuel paid by business aviation are given different for various FAA regions. This variation is important since airport-level models generated “distributed” GA demand. In the nation-wide model, we used the nation-wide historical price for commercial aviation provided by EIA because: 1) geographic variation in fuel price is less important in nation-wide level model, and 2) more data points can be obtained in a nation-wide model (i.e., years 1990 to 2010).

However, we found that many nation-wide social-economic and demographic factors are highly correlated with each other. For example, services price index, durable good price index, and disposable income per capita are highly correlated (coefficient of correlation is at least -0.95 or 0.95). Therefore, we carefully selected those factors to avoid possible multicollinearity. The calibration results are presented in Tables 4.31 and 4.32.

Table 4.32 Calibration results of utilization rate for piston, turboprop and turbofan.

Analysis of Variance								
	DF	SSE	MSE	Root MSE	R-Square	Adj R-square	F Value	Pr > F
Single-engine Piston	8	0.021	0.003	0.051	0.924	0.895	32.310	<.0001
Multi-engine Piston	8	0.016	0.002	0.045	0.902	0.865	24.530	0.000
Piston	8	0.016	0.002	0.045	0.935	0.911	38.370	<.0001
Turboprop and Turbofan	9	0.011	0.001	0.035	0.906	0.885	43.400	<.0001

Utilization Rate of Piston (average hours flown per aircraft)						
Aircraft Engine Type	Single-engine Piston		Multi-engine Piston		Piston	
	Coefficient	P-value	Coefficient	P-value	Coefficient	P-value
Intercept	0.177	0.911	1.910	0.196	0.387	0.783
F2I Ratio (Av gas)	-0.685	0.000	-0.232	0.042	-0.603	0.000
GDP Growth Rate (1 year lag)	1.898	0.063	4.027	0.001	2.307	0.019
Number of students	0.264	0.093	0.215	0.118	0.260	0.068

Utilization Rate Turboprop and Turbofan Combined (average hours flown per aircraft)		
Aircraft Engine Type	Turboprop and Turbofan	
	Coefficient	P-value
Intercept	5.647	<.0001
GDP Growth Rate	2.099	0.005
GDP Growth Rate (1 year lag)	3.121	0.000

Table 4.33 Calibration results of total hours flown for piston, turboprop, turbofan, and the others.

Analysis of Variance								
	DF	SSE	MSE	Root MSE	R-Square	Adj R-square	F Value	Pr > F
Piston	9	0.066	0.005	0.068	0.832	0.796	23.110	<.0001
Turboprop and Turbofan	9	0.030	0.002	0.046	0.983	0.980	276.190	<.0001
The others	9	0.021	0.002	0.049	0.849	0.815	25.290	0.000
Total	14	0.010	0.001	0.027	0.904	0.883	43.740	<.0001

Total Number of Hours Flown		
Aircraft Engine Type	Piston	
	Coefficient	P-value
Intercept	-18.255	0.116
F2I Ratio	-0.242	0.000
GDP Growth Rate	2.497	0.030
Total Number of Active Aircraft	0.725	0.060
Total Number of Hours Flown		
Aircraft Engine Type	Turboprop and Turbofan	
	Coefficient	P-value
Intercept	3.815	<.0001
GDP Growth Rate (1 year lag)	3.668	0.031
F2I Ratio (1 year lag)	-0.088	0.031
Total Number of Active Aircraft	1.161	0.001
Total Number of Hours Flown		
Aircraft Engine Type	The others	
	Coefficient	P-value
Intercept	-1.600	0.520
GDP Growth Rate	1.797	0.045
Total Number of Active Aircraft	1.601	<.0001
Total Number of Hours Flown by All Aircraft		
	Coefficient	P-value
Intercept	8.086	<.0001
F2I Ratio (1 year lag)	0.704	<.0001
GDP Growth Rate (1 year lag)	-0.107	<.0001
Total Number of Active Aircraft	1.798	0.001

For the hours flown by piston, its elasticity to F2I ratio is about -0.24. This indicates that a 10% increase in the ratio would lead to about 2.4% decrease in the hours flown by piston. In addition, its elasticity to total number of active piston aircraft is about 0.72. It means that a 10% increase in the total number of active piston aircraft would lead to about 7.2% increase in the hours flown.

For the hours flown by turboprop and turbojet, its elasticity to F2I ratio is about -0.08. It indicates that a 10% increase in the ratio would lead to about 0.8% decrease in the hours flown by turboprop and turbojet. This means that compared with piston turboprop and turbojet are less sensitive to the fuel price. This result is consistent with the results we obtained in Sections III and VI. As mentioned earlier, a possible explanation is more turboprop and turbojet aircraft are used for business purpose than piston aircraft are. Moreover, our calibration shows that a 10% increase in the total number of active turboprop and turbojet could result in about an 11.6% increase in the hours flown.

For the hours flown by the other aircraft type, the F2I (current, one-year lag, and two-year lag) is not significant. This might be because fuel consumption rate of those aircraft type is relatively less than the three aircraft engine types mentioned above.

For the hours flown by all aircraft type, its elasticity to F2I ratio is about -0.1, which means a 10% increase in the ratio would lead to 1% decrease in the total hours flown. Its elasticity is about 0.7%, which indicates that a 10% increase in the number of active aircraft would bring about 7% increase in the hours flown.

Using the nation-wide level models, we present the projections of hours flown by piston, turboprop and turbojet in

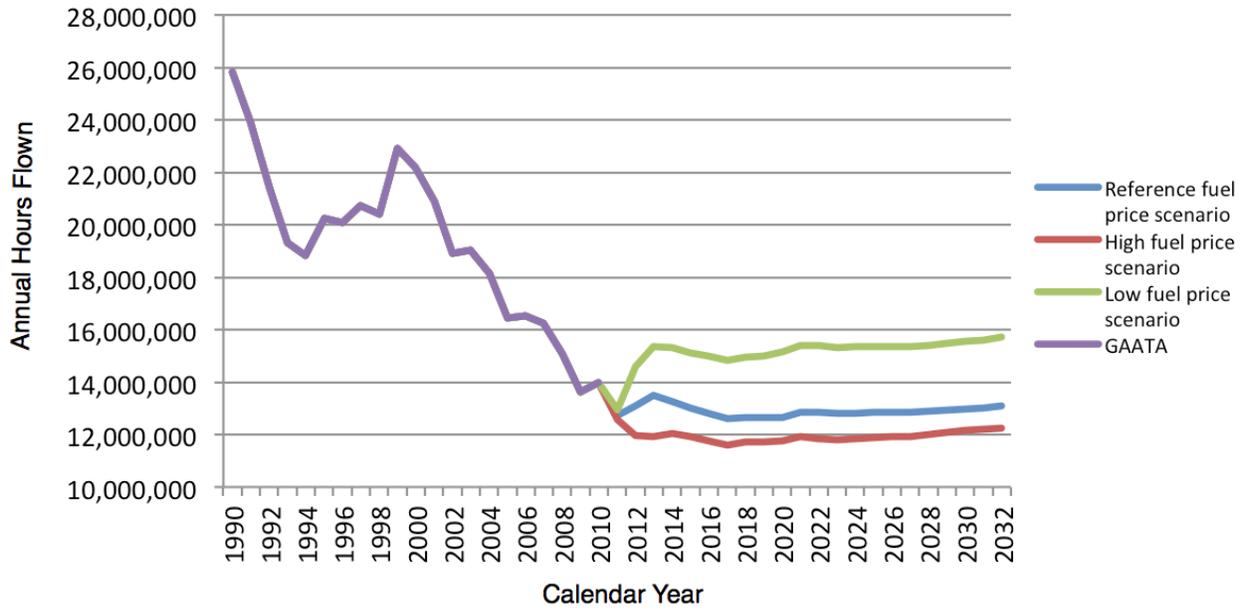


Figure 4-18, Figure 4-19 and Figure 4-20. We compare the projections in Tables 4.33 and 4.34. In general the trends observed with these models provide similar future as that obtained using airport-level variables. The overall picture of future general aviation activity for piston aircraft is shown in Figure 4-18. Under the reference EIA 2012 fuel price scenario, piston operations will experience a flat response in the next few years. According to these models, the turbofan operations will fare better with positive trends but well below the predictions stated in the FAA Aerospace Forecasts 2013-2033.

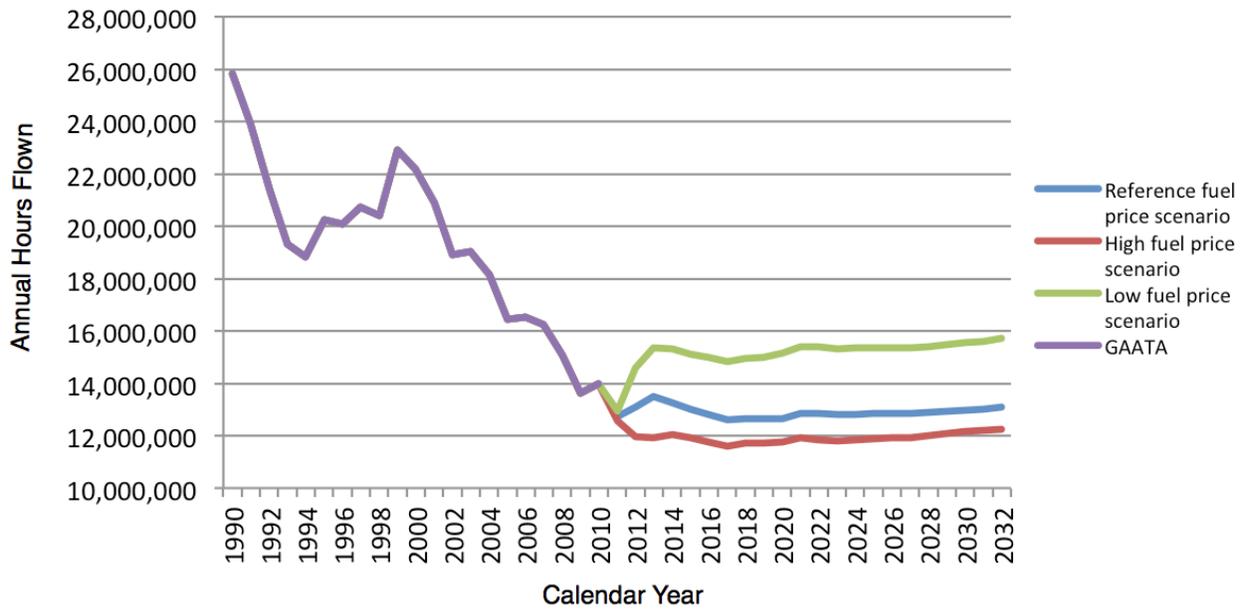


Figure 4-18 Forecast of hours flown by piston aircraft.

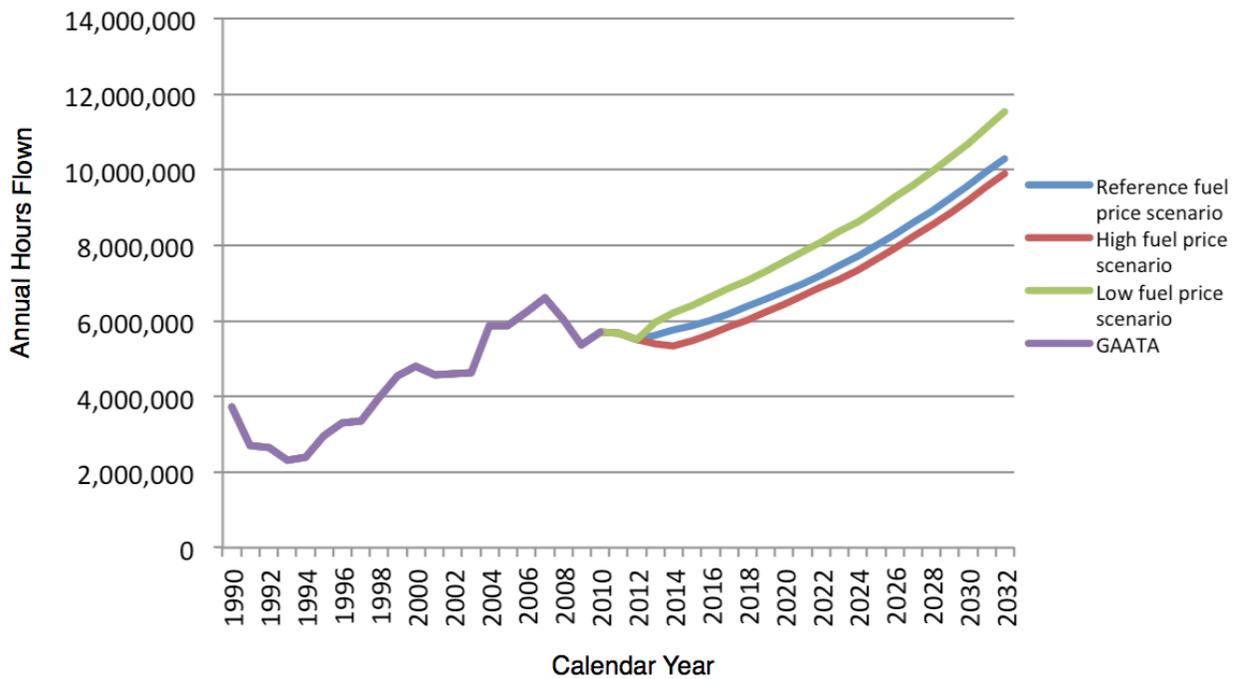


Figure 4-19 Forecast of hours flown by turboprop and turbojet aircraft.

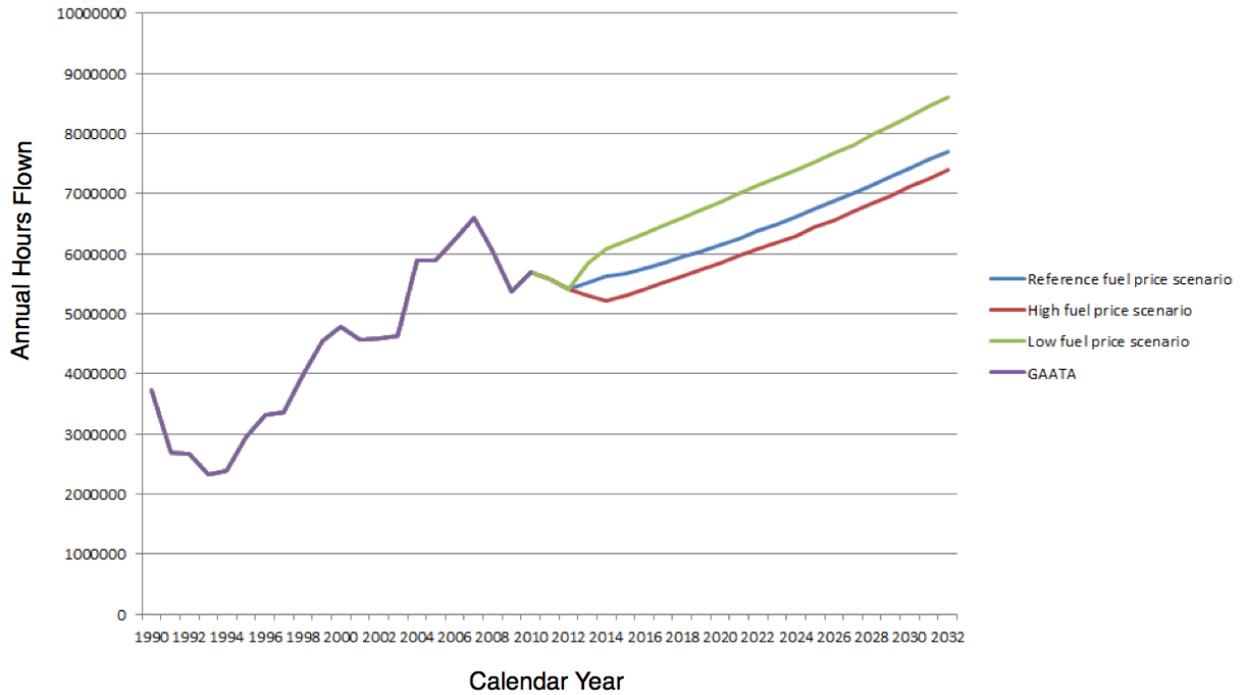


Figure 4-20 Forecast of hours flown by turboprop and turbojet (forecast using 2% growth rate for turbojet).

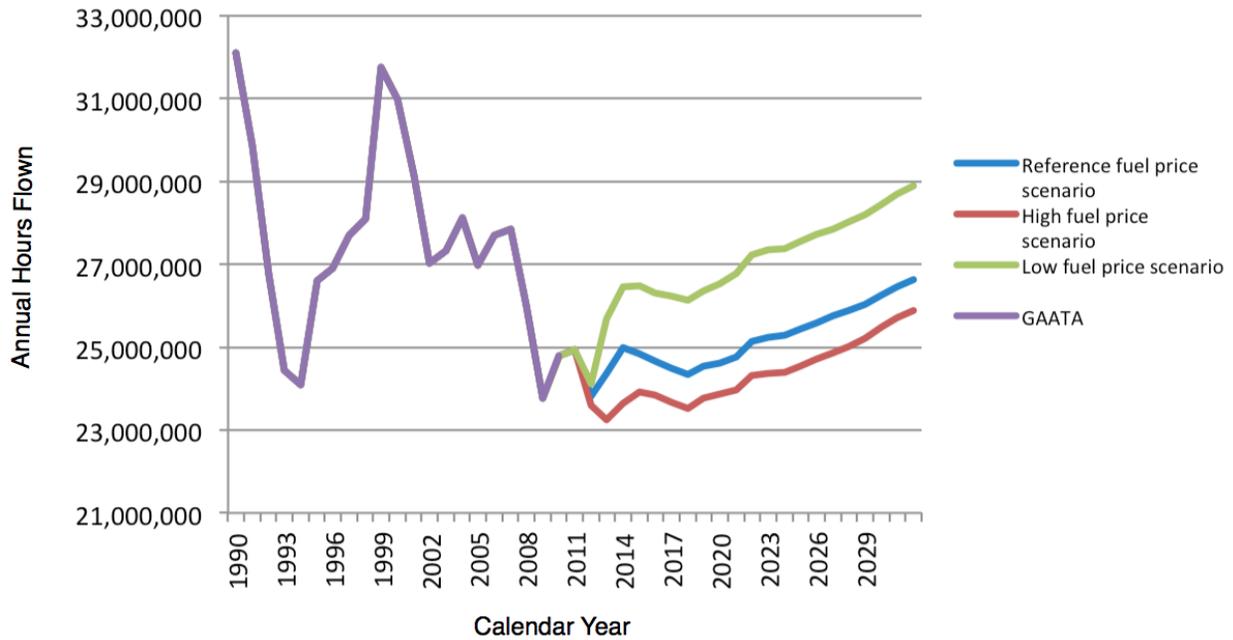


Figure 4-21 Forecast of total hours flown by General Aviation aircraft.

Table 4.34 Summary of forecast of hours flown.

	Piston			Turboprop + Turbojet			Total		
	Reference fuel price scenario	High fuel price scenario	Low fuel price scenario	Reference fuel price scenario	High fuel price scenario	Low fuel price scenario	Reference fuel price scenario	High fuel price scenario	Low fuel price scenario
2011	-10.71%	-10.71%	-10.71%	-1.69%	-1.69%	-1.69%	2.84%	2.84%	2.84%
2012	-1.04%	-8.56%	10.43%	-2.81%	-2.81%	-2.81%	-5.78%	-5.78%	-5.78%
2013	2.41%	-4.41%	6.01%	2.61%	-1.49%	8.64%	-0.54%	-4.31%	4.91%
2014	1.97%	5.52%	2.17%	2.59%	-0.93%	4.87%	2.14%	-1.26%	3.69%
2015	-1.32%	1.61%	-0.26%	2.26%	2.94%	3.41%	2.14%	4.38%	1.77%
2016	-1.30%	-0.91%	-1.37%	2.68%	3.37%	3.44%	-0.37%	1.45%	0.07%
2017	-1.73%	-1.72%	-1.16%	3.10%	3.50%	3.49%	-0.46%	-0.35%	-0.68%
2018	-1.27%	-1.13%	-0.79%	2.95%	3.18%	3.20%	-0.73%	-0.82%	-0.43%
2019	0.52%	1.12%	0.89%	3.04%	3.33%	3.27%	-0.47%	-0.49%	-0.22%
2020	-0.22%	0.01%	0.58%	3.14%	3.48%	3.44%	0.81%	1.10%	0.95%
2021	0.30%	0.17%	0.54%	3.13%	3.35%	3.52%	0.30%	0.37%	0.71%
2022	1.63%	0.92%	1.76%	3.33%	3.53%	3.45%	0.67%	0.49%	0.80%
2023	-0.08%	0.02%	-0.53%	3.51%	3.22%	3.54%	1.62%	1.24%	1.70%
2024	-0.18%	-0.19%	-0.06%	3.64%	3.73%	3.26%	0.41%	0.44%	0.24%
2025	0.05%	0.13%	0.25%	3.74%	3.86%	3.74%	0.33%	0.27%	0.42%
2026	0.30%	0.43%	-0.17%	3.58%	3.65%	3.59%	0.53%	0.56%	0.67%
2027	0.31%	0.26%	0.33%	3.68%	3.81%	3.47%	0.70%	0.74%	0.45%
2028	0.00%	0.29%	0.26%	3.77%	3.81%	3.76%	0.68%	0.63%	0.70%
2029	0.03%	0.34%	0.17%	3.79%	3.88%	3.84%	0.48%	0.65%	0.65%
2030	0.59%	1.03%	0.75%	3.70%	3.81%	3.78%	0.56%	0.73%	0.62%
2031	0.11%	0.41%	0.38%	3.77%	3.91%	3.88%	0.93%	1.19%	1.00%
2032	0.18%	0.40%	0.31%	3.65%	3.78%	3.83%	0.66%	0.83%	0.79%
Average	-0.43%	-0.68%	0.44%	2.78%	2.60%	3.32%	0.34%	0.22%	0.72%

Table 4.35 Comparison of forecast of hours flow between two models.

Hours flown	Reference Fuel Price Scenario		High Fuel Price Scenario		Low Fuel Price Scenario	
	Nation-wide	Airport-Level (by itinerant)	Nation-wide	Airport-Level (by itinerant)	Nation-wide	Airport-Level (by itinerant)
2011	2.84%	0.15%	2.84%	0.15%	2.84%	0.15%
2012	-5.78%	-5.33%	-5.78%	-5.33%	-5.78%	-5.33%
2013	-0.54%	-2.56%	-4.31%	-22.50%	4.91%	24.02%
2014	2.14%	-1.44%	-1.26%	1.17%	3.69%	1.74%
2015	2.14%	-0.56%	4.38%	1.49%	1.77%	1.68%
2016	-0.37%	0.38%	1.45%	1.44%	0.07%	1.55%
2017	-0.46%	0.32%	-0.35%	0.99%	-0.68%	0.99%
2018	-0.73%	0.86%	-0.82%	1.65%	-0.43%	1.61%
2019	-0.47%	0.81%	-0.49%	1.58%	-0.22%	1.81%
2020	0.81%	0.60%	1.10%	1.06%	0.95%	1.90%
2021	0.30%	0.75%	0.37%	1.25%	0.71%	1.20%
2022	0.67%	0.84%	0.49%	-0.13%	0.80%	0.98%
2023	1.62%	0.79%	1.24%	1.06%	1.70%	-0.34%
2024	0.41%	0.80%	0.44%	1.17%	0.24%	0.86%
2025	0.33%	0.63%	0.27%	0.85%	0.42%	0.70%
2026	0.53%	0.83%	0.56%	1.23%	0.67%	0.18%
2027	0.70%	0.92%	0.74%	1.06%	0.45%	0.91%
2028	0.68%	0.88%	0.63%	1.19%	0.70%	1.02%
2029	0.48%	0.61%	0.65%	0.98%	0.65%	0.85%
2030	0.56%	0.83%	0.73%	1.18%	0.62%	1.11%
2031	0.93%	0.35%	1.19%	0.72%	1.00%	0.85%
2032	0.66%	0.53%	0.83%	1.17%	0.79%	0.97%
2033	-	1.52%	-	1.23%	-	0.71%
2034	-	0.69%	-	0.95%	-	0.72%
2035	-	0.43%	-	1.04%	-	0.74%
Average	0.34%	0.09%	0.22%	-0.30%	0.72%	1.79%

4.12 Conclusions to Section 4

A series of models were developed to estimate the impact of oil prices to general aviation operations. Models developed include: a) an econometric airport-level demand model to forecast itinerant and local operations; b) a logistic airport-level market share model to predict the share of GA operations by engine type; c) a two-level GA demand distribution model to distribute operations among a set of airports; and d) econometric nationwide models to estimate the number of hours flown by GA engine type.

Using the airport-level demand model developed and given other factors fixed (including income), a 10% increase in fuel price would produce a 5.2% reduction in the number of local general aviation operations. Employing the same airport-level demand model developed and given other factors fixed (including fuel price), a 10% decrease in per capita income would translate into an 11.1% increase in the fuel-to-income ratio and produce a 5.8% decrease in the number of local general aviation operations.

Using the airport-level demand model developed and given other factors fixed (including income), a 10% increase in fuel price would result in a 4.3% decrease in the number of itinerant general aviation operations. Employing the same airport-level demand model developed and given other factors fixed

(including fuel price), a 10% decrease in per capita income would translate into an 11.1% increase in the fuel-to-income ratio and produce a 4.8% decrease in the number of itinerant general aviation operations.

Considering the EIA 2012 oil price reference case scenario, the models developed predict a decline in total number of GA operations at a rate of 0.8% per year until the year 2015. The decline applies to the sum of local and itinerant operations for all GA aircraft. The models developed predict a modest growth of 0.9% and 1.1% for itinerant and local operations, respectively, after the year 2016. At such growth rates, the recovery of total local GA operations is expected to reach year 2010 levels in the year 2023. It is important to mention that the more recent EIA 2013 trends would tend to accelerate this recovery by 5 years. This indicates that aviation activity as measured by GA local operations is very sensitive to fuel price forecasts.

While the general aviation trends in aircraft utilization have been in the decline in the past decade, there have been periods of time when the opposite trend has been observed. For example, in the period 1992-1999 a positive growth in GA operations was observed when the GDP grew by 32% (in constant \$2000 dollars) coupled with a very low fuel-to-income ratio. According to long-term economic forecasts (including those of EIA), the fuel-to-income ratio parameter is expected to peak in the year 2015 and then decrease modestly over time thus causing a potentially favorable trend for GA activity.

Under EIA reference oil price conditions, the projections of GA traffic activity presented in this report, are less optimistic than those presented in the FAA Aerospace Forecast 2013-2033. The study projects a weak recovery in GA operations after the year 2016 because the price of fuel compared to the per capita income ratio is expected to peak in 2015 based on EIA 2012 projections. New EIA oil price projections could accelerate the weak recovery by one year.

Nationwide models developed as part of the study to evaluate the impacts of fuel price on GA aviation activity provide similar trends as those predicted using airport-level models. For example, a 10% increase in fuel-to-income ratio would yield a 2.4% reduction in the number of hours flown by piston-powered aircraft. Similarly, the same nationwide model predicts that a 10% increase in the fuel-to-income ratio would translate to a 0.8% decrease in hours flown by turboprop and turbojet aircraft nationwide.

5 Impact of Oil Prices and Airline Fuel Efficiency on the U.S. Economy

The prices of oil and jet fuel have significantly increased since the 1990s (Table 5.1). The increase in the price of jet fuel has made fuel costs the primary operating cost for airlines and air cargo carriers. With increasing demand for oil in developing countries, such as China and India, along with declining productivity in some major oil producing regions, the US Energy Information Agency (EIA) “reference” forecast is for the real price of oil to increase by over fifty percent between 2010 and 2020. In a scenario of higher levels of world economic growth and demand for liquid fuels derived from oil, along with less abundant supply of oil, more of which is supplied by non-OPEC producers, the EIA projects real price of oil could increase by 125 percent between 2010 and 2020. Given the importance of air transportation for business travel, to the travel and tourism industries, and transportation goods between buyers and sellers on the U.S. economy, it is important to determine how future changes in oil prices will affect air transportation and the U.S. economy. The importance of this issue is also highlighted by the recent FAA Modernization and Reform Act of 2012, which explicitly requires an analysis of the impacts of increasing fuel prices (FAA, 2012).

There are two main objectives of this section. First, to determine the effects of increases in oil prices on air passenger and air cargo carriers, the industries that rely on air transportation, such the tourism industries, and on the U.S. economy. Second, this section will investigate the impacts of potential adjustments by airline and cargo carriers to increase fuel efficiency in response to higher oil price on the U.S. economy. Estimates of the relationship between mission fuel efficiency on an available seat mile (ASM) basis from MWH (2013) will be utilized in this analysis.

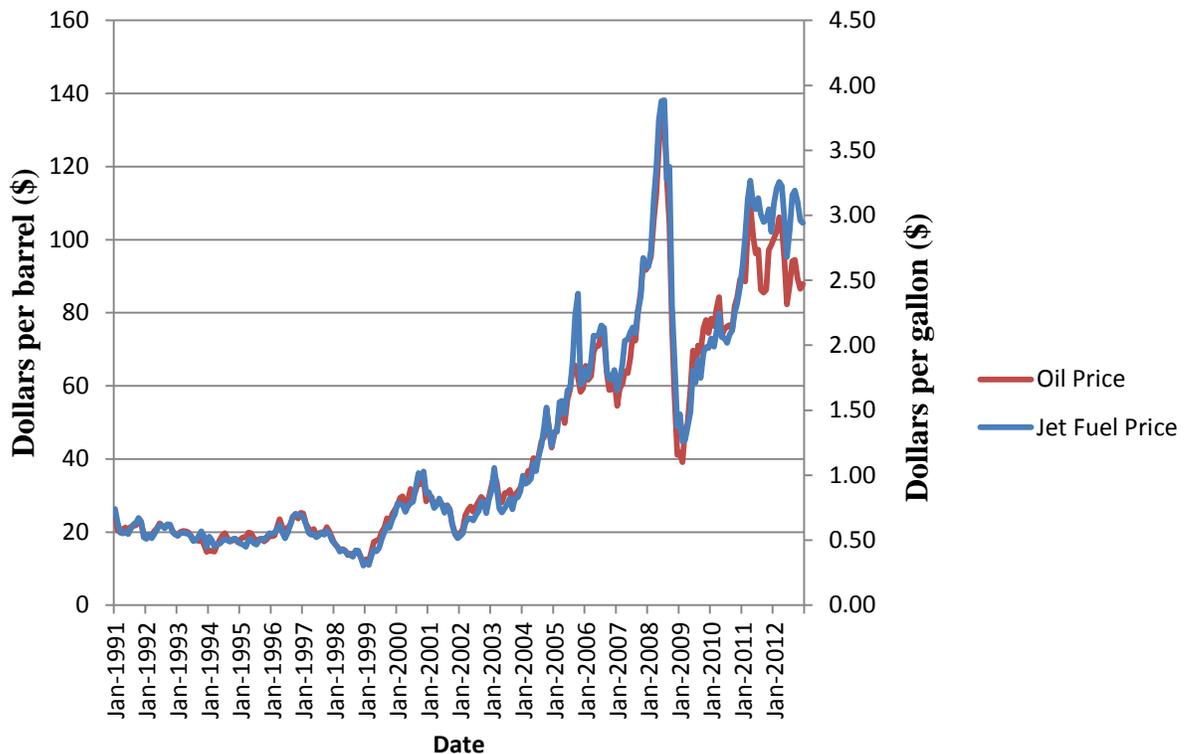


Figure 5-1 Oil and jet fuel prices in United States (EIA, 2013).

5.1 Empirical Model

To determine how increases in oil price will affect the air transportation industries and the U.S. economy will require a model that explicitly models the linkages between oil industry and the users of products derived from oil, such as motor fuels, and how the demand for labor and capital, which are the main component of household income, are affected. One empirical method that is capable of modeling these linkages is a computable general equilibrium (CGE) model. For this project, the USAGE model is utilized.

5.1.1 USAGE Model Description

The USAGE model is based on the MONASH model (Dixon and Rimmer, 2002) of Australia that has been developed for the U.S. International Trade Commission (USITC). Like most CGE models, it assumes that all markets are perfectly competitive and all markets clear in all time periods. As will be discussed in more detail later in the report, for this report the database for the model contains information on 184 commodities produced by 183 industries. This large degree of commodity and industry disaggregation will reduce the possibility that important economic linkages will be obscured in the model simulations. Unlike other CGE models, the USAGE model links the demand for air transportation to the demand for domestic and foreign leisure travel, the demand for air transportation by industries (e.g., business travel), and to the shipment of commodities to purchasers (e.g., air cargo services). In addition, the air passenger transportation sector is disaggregated into two industries that provide either domestic or

international flights in order to incorporate different projections on domestic and international leisure travel by US residences, and the growth of leisure travel by foreign residents to the United States.

The USAGE model is a recursive-dynamic model that is capable of identifying the adjustment time paths for the endogenous variables in the model (e.g., prices, quantities, etc.). The dynamic feature of the model will allow forecasted changes in economy activity, such as Gross Domestic Product (GDP), that will affect the demand for air to be incorporated in the analysis. A baseline forecast that contains changes real GDP, employment, consumer preferences, rates of technical change, etc. is developed for the period of 2010 through 2020. As will be discussed in more detail in later sections, this baseline includes projections on real GDP growth, employment growth, growth in real wages and consumer prices, and other macro variables from sources such as the Congressional Budget Office (CBO) and the Bureau of Labor Statistics (BLS). But it also includes projections on changes in consumer preferences and rates of technical change based on comparisons of US input-output and final demand data in 2010 with projections of that same data for the year 2020. Finally, the baseline also incorporates the projected growth in the real price of oil and natural gas from the EIA's 2012 "reference" scenario.

One drawback with using the USAGE model for this analysis is that increases in the price of oil will have global effect, not just in the United States. Increases in the price of oil will impact the price of imported goods into the US and the export demand for US goods and services by foreign agents. To mitigate the impact on US imports, several assumptions are made. First, to prevent undue substitution between domestic and imported goods caused by the import prices that do not reflect a change in the price of oil, the elasticities of substitution between domestic and imported goods (e.g., Armington elasticities) are all set equal to zero. Second, to ensure that cost of production for US industries is not understated, the price of imported oil, natural gas, refined petroleum products (e.g., motor fuels), other petroleum products, and air passenger transportation are adjusted such that they are equivalent to the domestic price of these products. Finally, in the USAGE model, the export demand for US goods and services is purely a function of the export price of US goods and services, using a constant elasticity of demand functional form. Since this specification implicitly assumes that the prices of competitors' products are held constant, this specification will likely result in lower US exports that would be expected if the prices of competing products also changed in response to the increase in the price of oil. Thus, the quantity of US exports for each product, which is endogenously determined in the forecast or baseline model simulation, is assumed to remain constant in the policy simulation that introduces the increased price of oil.

5.2 Model Data

To implement any CGE model requires a starting point that represents an initial equilibrium and initial values for model parameters, such a demand elasticities and elasticities of substitution. The initial equilibrium must satisfy several requirements: (1) supply must equal demand for all products and factor markets (e.g., labor and capital); (2) income must equal expenditure; and (3) total revenue must equal total cost for all perfectly competitive markets. One data source that satisfies these requirements is the national input-output (IO) accounts for a given year. For the US, there are several sources and types of IO data available. The Bureau of Economic Analysis (BEA) develops a "benchmark" IO account, which is a based on the five-year economic census. It is the most comprehensive IO data available, but the latest year available is 2002 (BEA, 2008). The BEA also publishes annual IO data, which typically begins with the latest benchmark data and then updates its values to match observed macro-economic values of GDP, imports, exports, etc. for a given year. The Bureau of Labor Statistics (BLS) also uses the BEA data to

produce their own annual IO data. In this report, the BLS IO data for 2010 is used to represent the initial equilibrium in the USAGE model (BLS, 2012). This data was chosen because the BLS also publishes a projected IO data for the year 2020, which will be used to determine changes in technology and consumer tastes and preferences between the base year of 2010 and the year 2020, which is the end point of this analysis.

5.2.1 Input-Output Data

The BLS data contains four different types of information. First is a “make” matrix that details the sales of all commodities produced by each industry. For example, in 2010, the air transportation industry produced \$831 million of construction services, \$128,981.1 million of air transportation services, and \$156.4 million of computer programming and design services (all values in 2005 dollars). The second type of data is the “use” matrix that details the purchases of all intermediate inputs used by each industry. For example, the air transportation industry purchased \$20,196.9 million in petroleum products (e.g., fuel, lubricating oils, etc.), along with a host of other inputs. The third type of data is the value of “final demand,” which includes the value of private consumption, investment, changes in inventories, government purchases, total imports, and exports for each commodity. The last type of data is the value of rail, truck water, air, and pipeline transportation services used to get commodities from the producing industry to buyers; and the wholesale and retail services used to connect the buyers and sellers of commodities. These margin data are available for commodities sold to consumers, as investment goods, exported, commodities going into or out of inventory, and to state, local, or federal government agencies.

5.2.1.1 Margins on Intermediate Inputs

Several data categories used in the USAGE model are not available in the BLS data. First, the value of transportation and wholesale/retail services needed to get intermediate inputs from the supplier to the buying industry is not reported in the BLS data. However, these data are available in the 2002 Benchmark IO data. To incorporate, the 2002 Benchmark data are aggregated to the BLS commodity and industry definitions. Then the “power of the margin” is computed for each margin type (air, rail, water, truck, and pipeline transportation; and wholesale and retail services) using equation (1):

$$MAR1_POW(i, j, m) = \frac{MAR1_BEA(i, j, m)}{BAS1_BEA(i, j)} \quad (5.1)$$

where, $MAR1_BEA(i, j, m)$ is value of margin activity m used for commodity i purchases by industry j , $BAS1_BEA(i, j)$ is the value of commodity i purchased by industry j at producer prices. The “power of the margin” is then multiplied by the value of commodity i purchased by industry j in the BLS data to get the value of margin activities for all intermediate inputs. For example, in the 2002 benchmark data, the intermediate use of beverages (e.g., soft drinks, beer, wine, etc.) by the air transportation industry required rail and truck transportation and wholesale activities. The power for each margin activity in the 2002 benchmark data is shown in the top half of Table 5-1. Each power is then multiplied by the value of beverages purchases by the air transportation industry in the 2010 BLS data (\$46.542 million) to obtain an estimate of the value of rail and truck transportation and wholesale activities need to get the beverages from the manufacturer to the air carriers. For example, \$59.011 million in wholesale services are required to get the purchased beverages from the manufacturer to the air carriers. This procedure is used for all intermediate inputs used in all industries.

Because the BLS intermediate use data are computed on a “producer price” basis, the values of all transportation and wholesale/retail margin services for intermediate inputs are treated as a direct purchase of those services by that industry. For example, the \$59.011 million in wholesale services indirectly used in the purchase of beverages by air carriers is treated as a direct purchase of wholesale services by the air transportation industry. Thus, the total sum of wholesale services required for all intermediate inputs purchased by the air transportation industry is subtracted from the initial value of wholesale services by the air transportation industry in the BLS data. As shown in the bottom half of Table 5-1, after adjusting for the margin activities for intermediate inputs, the air transportation industry has minimal direct purchases of the margin commodities. This is also common for most industries in the data. If total estimated value of the indirect use of a margin commodity, such as wholesale services, for the purchase of all intermediate inputs exceeds the initial direct purchase of that commodity in the BLS data, the estimated indirect value used for each intermediate input is reduced proportionally until the total value of indirect use equals the initial direct use.

Table 5.1 Estimated margin requirements for beverages purchases by air transportation industry.

Commodity <i>Power of margin</i>	Power	Expenditure \$ millions
Rail transportation	0.0187	0.870
Truck transportation	0.0592	2.755
Wholesale	1.2679	59.011
Initial beverage expenditure in 2010 BLS (millions)	\$46.542	
<i>Air transportation expenditures</i> (\$ millions)	<u>Initial</u>	<u>Revised</u>
Air transportation	7.144	0.420
Rail transportation	53.960	0
Water transportation	98.545	0
Truck transportation	343.208	0
Pipeline transportation	158.143	0
Wholesale	1,460.673	314.764
Retail	4.236	0

5.2.1.2 Use of Imported Commodities

While the BLS final demand data reports that total value of imports for each commodity, it does not contain any information on the uses of the imported commodity. For example, how much of the imported commodity is used as an intermediate input in industry j or is purchased by consumers? This information is required to implement the USAGE model. To disaggregate total imports by use, the 2002 Benchmark data is utilized by computing the import share of commodity i used by industry j , the import

share of commodity i used as an investment good,⁹ and the import share of commodity i used in private consumption.¹⁰ These shares are then multiplied by the appropriate expenditure value in the 2010 BLS data to decompose domestic and imported uses. After this decomposition, the total value of import use for each commodity is computed by summing across all uses. If this total does not match the value of total imports from the BLS final demand data for a given commodity, then the value of imports for each use is adjusted proportionally.

5.2.1.3 Incorporating Taxes and Disaggregating Value-Added

Another type of information not reported in the BLS data is on taxes collected by federal, state, and local governments. There are five types of taxes identified in the USAGE model: (1) output taxes, (2) taxes on intermediate input use, (3) taxes on investment goods, (4) consumption taxes, and (5) tariffs on imported goods. Similar to the determination of margin requirements for intermediate inputs, the value of output taxes, intermediate input taxes, and consumption taxes are determined based on the tax rates from the 2002 Benchmark data. However, the tax rates for refined petroleum products (e.g., motor fuels), tobacco products, and alcoholic beverages (which are part of the beverages industry) are adjusted to reflect federal excise taxes (Internal Revenue Service, 2012) and state and local taxes (Tax Policy Center; 2012, 2012b, 2012c) collected on these goods. Taxes on investments goods and exports are based on the tax rates in the 2005 USAGE model data base. Finally, the value of tariffs is the “calculated duties” obtained from the US International Trade Commission Interactive Tariff and Trade DataWeb (USITC, 2012).

Because taxes on intermediate inputs, investment goods, consumption, and exports are included as a wholesale and/or retail margin in IO data, the estimated taxes must be subtracted from these margins. For example, the crops industry is estimated to pay \$545.4 million in taxes on intermediate inputs using the above procedure, mostly for refined petroleum products (e.g., motor fuels) and agricultural chemicals. Thus, the wholesale and retail margins for each intermediate input that is assessed a tax is reduced by the value of the tax and proportional to the use of wholesale and retail services. For the crops industry, wholesale services are used more extensively than retail services when purchasing intermediate inputs. Thus, the total amount of retail services is reduced by \$479.57 million while retail services are reduced by \$65.8 million when adjusting for the intermediate taxes. The same procedure is used for investment taxes, consumption, and export taxes.

Because an output tax will reduce the revenues received by firms in an industry, to maintain zero profits in the industry, total industry costs must be reduced by the amount of the output tax. In order to avoid adjusting commodity supply and demand, the reduction in cost is accomplished by reducing the

⁹ Because the BLS data does not identify the value of commodity i that is used as an investment good by industry j , the total amount of imported commodity i used for investment purposes is first determined with the allocation across industries being made later in the process.

¹⁰ In the USAGE model, government consumption is directed to commodities produced by government industries. In this paper, these industries are general federal defense, general federal nondefense, general state and local government, and state and local government enterprises. Thus none of these commodities are imported.

amount of valued added in each industry by the amount of the tax. After this adjustment is made, value-added in each industry, which is aggregated in the BLS data, is decomposed in value-added attributable to labor and capital based on the shares of these primary factors in the 2002 Benchmark data. For example, in the 2002 Benchmark data the value-added in the crops sector was \$52,877.5 million, which \$14,569.3 million in labor payments and \$38,308.2 in capital rental payments. Thus, payments to labor accounted for 0.2755 of the total value-added in the industry. This share is applied to the total value-added in the BLS data, less the value of the output tax on crops and the taxes on intermediate and investment good purchases by firms in the crops industry.

Several industries, air transportation, religious organizations, the Postal Service, and state and local government passenger transit service, had a negative value of capital rental payments in the 2002 Benchmark data. For air transportation and religious organizations, this likely represents short-term versus long-term returns to capital. In order to eliminate these negative returns to capital, the value-added share of labor and capital for religious organizations from the 2005 USAGE model database was used to allocate labor and capital, and the value of labor payments in the 2002 Benchmark data was used for the 2010 labor payments in the air transportation industry. For the Postal Service and government passenger transit services, rather than having negative returns to capital, it is likely that these industries receive an output subsidy from the government. To allocate labor and capital payments for these industries, the value of labor payments in the 2002 Benchmark data and the value-added shares in the 2005 USAGE database are used. First, total value-added is assumed to equal the value of labor payments in the 2002 Benchmark data divided by the share of labor in value-added in the 2005 USAGE database. This implies that the payments to labor are equal to the 2002 Benchmark values and the capital rental payments are computed as a residual. The output subsidy is then equal to the computed total value-added less the value-added reported in the 2010 BLS data.

5.2.1.4 Commodity Use for Investment by Industry

While the 2010 BLS data contains information on the total value of each commodity used for investment purposes, it does not contain any information on the investment expenditures by each industry. The value of investment will be related to the growth in the capital stock in each industry in the 2010 base year, which in turn will be related to the return on capital, defined as the capital rental payment divided by the value of the capital stock at the beginning of 2010, and the depreciation rate. Since the capital rental payments for each industry have been previously identified, if one knows either the rate of return on capital or the value of the capital stock, one can then determine the value of the other variable.

The rate of return on capital for each industry is estimated from the econometric model:

$$k_ror_j = \beta_0 + \beta_1 k_va_j + \beta_2 va_shr_j + \beta_3 \ln(make_j) + \beta_4 import_shr_i + \varepsilon_j \quad (5.2)$$

where k_ror_j is the rate of return on capital in industry j , k_va_j is the share of capital in value-added in industry j , va_shr_j is the share of value-added in total cost of industry j , $make_j$ is the total sales of industry j , and $import_shr_i$ is the share of imports in total US demand of the main commodity produced by industry j . The independent variable k_va measures the relative amount of capital to labor used in industry j . As the amount of capital employed in industry j increases, holding all else constant, one would expect that marginal returns on capital should decrease. Conversely, an increase in the relative amount of value-added used in industry j , holding the share of capital in value-added constant, implies that relatively more labor is available which should increase the marginal productivity of capital, and therefore a higher

rate of return. Assuming that capital is relatively mobile across industries in the US, industries with sustained higher rates of return over time will accumulate more capital and be able to increase their output. Thus one would expect that industries with larger value of sales, all else constant, would have higher rates of return. A log-linear specification is used because the marginal effect of industry size likely diminishes as the industry grows in size. Finally, industries that face greater competition from imported products will likely have lower rates of return compared to industries that face lower import competition. Note that because equation (2) will be used to predict the capital rate of return for each industry, the independent variables included in the model are constrained to those values that are available from the BLS data.

Equation (2) is estimated using data from the 2005 USAGE database, aggregated to the BLS industry definitions. After omitting any industry without capital and all government sectors, leaves data for 154 industries. The estimated coefficients are reported in Table 5-2. All of the estimated coefficients for the independent variables are statistically different than zero at the 5% significance level or lower, and all have the correct sign. Using the estimated coefficients in Table 5-2, the rate of return on capital is estimated for each industry in the BLS data. Then given the estimated value of capital rental payments, the capital stock at the beginning of 2010 is computed.

Table 5.2 Estimated coefficients to determine industry rate of return.

Variable	Coefficient	Std. Error	<i>t</i> -statistic	<i>p</i> -value
k_va	-0.0789	0.0368	-2.14	0.034
va_shr	0.2065	0.0426	4.84	0
lmake	0.0159	0.0060	2.66	0.009
import_shr	-0.0230	0.0088	-2.61	0.010
constant	0.0870	0.0705	1.23	0.219
R ²	0.2908			

The next step is to determine the growth in the capital stock for each industry during 2010. Data on the current-cost value of the net capital stock of nonresidential fixed assets for 63 industries is available from the BEA (2012) for the years 1947 to 2011. The growth in the capital stock from 2010 to 2011 in this data for each of the 63 industries is used to determine the growth in the capital stock for the corresponding industries in the BLS data. The depreciation rate for each industry is set equal to the depreciation rates in the 2005 USAGE model database, aggregated to the BLS industry definitions. Then total investment expenditure made by each industry is determined by,

$$invest_j = end_capital_j - begin_capital_j(1 - deprec_j) \quad (5.3)$$

where $invest_j$ is the investment expenditure made by industry j , $end_capital_j$ is the value of the capital stock in industry j at the end of 2010 (or beginning of 2011), $begin_capital_j$ is the value of the capital stock in industry j at the beginning of 2010, and $deprec_j$ is the depreciation rate for industry j . Note that the ending value of the capital stock is equal to the beginning value times one plus the capital stock growth rate in 2010 from the BEA (2012) data.

Neither the 2002 Benchmark nor the 2010 BLS IO data contain information on the structure of commodity purchases for investment purposes by industry. While both provide the total value of a

commodity used as an investment good, neither identify which industries used that commodity. For example, the 2010 BLS data reports that \$169,215.6 million in motor vehicles (e.g., cars, light trucks, and heavy trucks) were used as an investment good in 2010. However, which industries purchased these vehicles was not identified. To make this allocation across industries, the structure of investment expenditure by commodity and industry in the 2005 USAGE database is used as a starting point. The values in this matrix are updated using a RAS procedure such that each row total equals the observed total expenditure for each commodity for investment purposes from the BLS data and each column total equals that value of investment expenditure by each industry identified using the procedure described in the previous paragraph.

Once the value of investment expenditure by commodity is determined for each industry, the margins on investment identified in the BLS data are allocated proportionally to each commodity. For example, the \$528.9 million in rail transportation margin for motor vehicles used for investment purposes is allocated to all industries that use motor vehicles as an investment good in proportion to their share of the total use of motor vehicles as an investment good. The value of taxes on investment goods are determined based on the tax rates from the 2005 USAGE database.

5.2.2 Industry and Commodity Aggregation

The BLS IO data are aggregated into 178 industries that produce 180 commodities. As shown in Appendix Table A.1, most industries are defined at the North American Industry Classification System (NAICS) 3-digit or 4-digit level. In general, each industry mainly produced its “own” commodity. For example, the crops industry mainly produces the crops commodity. Both scrap and used second hand goods are “produced” by a variety of different industries, generally as a by-product of these industries production process. There are two industries that produce mainly electricity (electricity and Federal electric utilities) and two industries that produce mainly passenger transportation services (passenger transportation and state of local government passenger transit services). The commodity “rest of the world adjustment” represents a statistical adjustment to US exports by the general Federal non-defense industry. Finally, non-comparable imports represent goods to which there is not comparable product being produced in the United States. Thus, there is no domestic production of non-comparable imports in the IO data.

5.2.2.1 Disaggregating Oil and Natural Gas

Even with a rich level of industry and commodity disaggregation in the BLS data, several industries/commodities required further disaggregation. First, because the focus of this research is the impact of high oil prices, the combined oil and gas extraction industry in the BLS data must be disaggregated into separate industries. To disaggregate these industries, data were collected on the value of production of oil and natural gas in the U.S. in 2010 (see Table 5.3).

Table 5.3 Value of US crude oil and natural gas production, exports, and imports in 2010.

Variable	Value
<i>Crude oil</i>	
Production (thousand barrels)	2,000,940
Price (\$/barrel)	74.71
Value of production (\$millions)	149,490.2
Imports (thousand barrels)	3,362,856
Exports (thousand barrels)	15,198
<i>Natural gas</i>	
Marketed production (MMcf)	22,402,141
Price (\$/1,000 cf)	4.476
Value of production (\$millions)	100,272.7
Imports (MMcf)	3,740,757
Exports (MMcf)	1,136,789

Source: U.S. Energy Information Administration (EIA) (2012b, 2012c, 2012d, 2012e)

The industry disaggregation process entails beginning with a single row and column for the combined oil and gas extraction industry in MAKE and USE matrices¹¹ in the 2010 BLS IO data and splitting that in two rows and columns: one for the new oil industry and one for the new gas industry. In the MAKE matrix, the column total represents the total value of all commodity sales by a given industry. For the combined oil/gas industry, this total is disaggregated into the total sales for the oil and natural gas industries based on the production shares in Table 5.3. In addition to oil and natural gas production, the combined oil/gas industry in the BLS data also produces several additional commodities, such as refined petroleum products and mining services. All of the production of refined petroleum products is allocated to the new oil industry, with all production of all remaining commodities being allocated to the new oil and gas industries proportionally in order to match total industry sales. There also is some minor production of oil and natural gas by other industries, such mining services and the gas distribution industries. This combined production in the original BLS data is allocated to oil and gas production based on the production shares except for the gas distribution industry, which is assumed to produce only natural gas.

In the USE matrix, all of the intermediate inputs purchased by the combined oil/gas industry (e.g., the elements in the oil/gas column) are allocated to the separate oil and natural gas industries by production share. Because oil and natural gas are either used as an intermediate input or exported (neither are directly consumed or used as an investment good), the sum of intermediate use plus exports must equal the total amount of oil and natural gas produced domestically, which is determined by the row sum in the

¹¹ The MAKE matrix defines the sales of commodities by each industry and the USE matrix defines the commodities used as intermediate inputs by each industry. The dimensions of both matrices are the number of commodities by the number of industries.

revised MAKE matrix for each commodity. The BLS value of exports for the combined oil/gas industry is allocated to the separate oil and natural gas industries based on the export shares in Table 5.3. By subtracting the value of exports from the total value of production in the disaggregated MAKE matrix gives the value of the row total in the USE matrix. While there are many industries that use oil and natural gas as an intermediate, the five main users are: oil and natural gas industries (e.g., own-use), electricity, Federal electric utilities, gas distribution, and refined petroleum products. The own-use of oil and natural gas is determined based on the production shares. The remaining industries are primarily either a large user of either oil or natural gas. Because natural gas is used more commonly in electricity generation, 90 percent of the combined oil/gas sales in the BLS data are allocated to natural gas and 10 percent to oil. For the gas distribution industry, it is assumed that 95 percent of the combined oil/gas sales in the BLS data are allocated to natural gas. Finally, 85 percent of the combined oil/gas sales to refined petroleum products in the BLS data are assumed to be oil. All other intermediate uses are allocated to the oil and natural gas industries proportionally such that the row targets are met.

To complete the disaggregation process, output taxes, value-added, margins on intermediate inputs, intermediate input taxes, and industry investment must also be disaggregated. To ensure zero profits in the oil and natural gas industries, the output tax, labor payments, and capital rental payments for the BLS combined oil/gas industry is allocated based on the production share. All margins and taxes on the intermediate use of the combined oil/gas commodity are allocated proportionally to oil and natural gas use in the disaggregate USE matrix. Likewise, all margins and taxes on intermediate inputs used by the combined oil/gas industry are allocated proportionally to oil and natural gas. Finally, all investment expenditures, including margins and taxes, are allocated to the oil and natural gas industries based on production shares

5.2.2.2 Disaggregating Petroleum

The petroleum and coal products manufacturing industry (NAICS 3241) in the BLS data includes petroleum refining (NAICS 32411), asphalt paving, roofing, and saturated materials manufacturing (NAICS 32412), and other petroleum and coal products manufacturing (NAICS 32419), which is primarily lubricated oils and grease. However, since petroleum refining will use crude oil more intensively as an intermediate input, this industry will be affected more by an increase in the price of oil. In addition, one of main products of petroleum refining industry is motor fuels, including jet fuel. To capture these distinctions, the petroleum industry in the BLS IO data is disaggregated into petroleum refineries and other petroleum products.

Estimates of the allocation of the total sales to petroleum refineries and other petroleum products is based on the share of total shipments of these industries from the Annual Survey of Manufacturers (ASM) over the period 2008 to 2010 (U.S. Census Bureau, 2012).

Table 5.4 Total value of shipments and value-added for NAICS 3241, 2008-2010.

	2008	2009	2010	Average share
	\$ millions			
Total Value of Shipments	769,698.98	495,776.67	627,571.68	
Petroleum refineries	732,565.81	461,591.60	588,663.68	0.940
Other Petroleum and coal products	37,133.16	34,185.07	38,908.00	0.060
Value-added	89,846.01	79,965.88	95,153.19	
Petroleum refineries	77,252.39	67,981.76	81,602.92	0.856
Other Petroleum and coal products	12,593.62	11,984.12	13,550.27	0.144
Share of value-added to shipments				
Petroleum refineries	0.105	0.147	0.139	0.130
Other Petroleum and coal products	0.339	0.351	0.348	0.346

Source: US Census Bureau (2012)

NAICS industries: petroleum refineries 32411; other petroleum and coal products, 32412 and 32419.

Table 5.4 shows that petroleum refineries accounted for 94 percent of the values of all shipments between 2008 and 2010. Thus, 94 percent of the total sales of the petroleum industry in the BLS data are allocated to petroleum refineries, with the remaining six percent allocated to other petroleum products. Similar to the combined oil/gas industry, the petroleum industry produces several different commodities, in addition to petroleum products. The production of nonmetallic mineral mining, cement, and lime, gypsum and other nonmetallic mineral products is allocated entirely to other petroleum (and coal) products, while the production of plastics is allocated entirely to petroleum refineries. All other commodities are allocated proportionally such that the total sales of petroleum refineries and other petroleum products equal their target values. There is also some minor production of petroleum products by other industries. With the exception of chemicals, synthetic fibers, and other chemicals, which are allocated based on the production share, all other industries are assumed to produce only other petroleum products.

The aggregate level of value-added (e.g., labor payments, capital rental payments, and output taxes) for the petroleum industry in the BLS data is allocated to the petroleum refineries and other petroleum products industries based on the estimated value-added for these industries in the ASM (Census Bureau, 2012). As shown in Table 5.4, over the three-year period, value-added was 13 percent of the total value of shipments for petroleum refineries and 34.6 percent of the total value of shipments for other petroleum products. Since there is little variation in these shares over the three-year period, with the exception of 2008 for petroleum refineries, the 2010 shares are used to allocate value-added in the BLS data. However, because the share of value-added to total sales in the BLS data for 2010 is 1.3 times larger than from the ASM data, the 2010 ASM value-added shares for petroleum refineries and other petroleum products are multiplied by 1.3 to match the BLS data. Thus target value-added value is \$74,950.25 million for petroleum refineries and \$12,259.85 million for other petroleum products. After allocating the level of output tax by the respective production shares, the labor and capital rental payments are allocated to each industry such that the total target value is achieved.

The total value of intermediate inputs, including margins and taxes, used by petroleum refineries and other petroleum products is equal to their total sales less their total value-added. Because of the higher value-added share for other petroleum products, a slightly higher percent of the total value of intermediated inputs, approximately 96 percent, is allocated to petroleum refineries than the production share. This share is used to allocate the value of each commodity used as an intermediate input in the BLS data to either petroleum refineries or other petroleum products. Once the total value is determined, the value of intermediate taxes and margins for the aggregate petroleum industry are allocated proportionally.

5.2.2.3 Air Transportation

The main advantage of using the USAGE model for this analysis is that it links the demand for air transportation to the demand for domestic and foreign leisure travel, the demand for air transportation by industries (e.g., business travel), and to the shipment of commodities to purchasers (e.g., air cargo services). To do so, three air transportation industries are identified in the model: domestic air passenger services, international air passenger services, and air cargo services. While it possible to distinguish air cargo services from air passenger services in the BLS data by assuming that the air transportation margins are provided by air cargo carriers, additional disaggregation is needed to distinguish domestic and international air passenger transportation services.¹² This is accomplished by combining the BLS data with data from the US Travel and Tourism Satellite Accounts (BEA, 2012b).

Table 5.5 lists the supply and demand for air transportation in the 2010 BLS data by sources. The total supply of air transportation services is \$133,008.3 million, with \$13,024.6 million for air cargo services and \$119,983.7 million for air passenger services. Note that the supply of air cargo services is determined by demand for of air transportation services used for margins. The demand for air passenger services is mainly a function of air passengers services used as an intermediate input by industries (e.g., business travel), the demand for air passenger services by domestic residents (e.g., domestic and international leisure travel), and “exports” of air passenger services non-US residents. Further, total demand can be decomposed into the demand for air passenger services from domestic carriers and from foreign carriers (e.g., imports).

¹² Due to a lack of data initially on the provision of cargo services by air passenger carriers, it is assumed that only the air cargo and couriers and messengers industries provide air cargo services.

Table 5.5 Supply and demand for air transportation services in 2010 BLS data.

	Value (\$millions)	
Total Supply	133,008.3	
Margin use	13,024.6	
Intermediate inputs	4,676.7	
Investment goods	2,765.8	
Consumption	3,450.2	
Exports	2,131.9	
Domestic passenger	119,983.7	
	Domestic	Imports
Total Demand	119,983.7	22,200.1
Intermediate inputs	32,897.3	5,951.0
Investment goods	438.8	0.0
Consumption	60,997.4	16,249.1
Exports	25,650.2	0.0

Source: BLS (2012b) and author's calculations

The next step is to decompose the demand for air passenger services into the demand for domestic and international air passenger services. Since foreign air carriers are not allowed to service domestic routes in the U.S., all imports in Table 5.5 are assumed to be for international air passenger services. The decomposition of demand for air passenger services from domestic carriers into domestic and international service uses data from the US Travel and Tourism Satellite Accounts (BEA, 2012b) in Table 5.6. For air passenger services used as an intermediate input, which includes both business and government use, approximately 69 percent is for domestic passenger services. Using the expenditure on domestic air passenger services by domestic residents in Table 5.6, the expenditure on international air passenger services by domestic residents from domestic carriers is computed as a residual. Table 5.7 lists the decomposition of air passenger services into domestic and international services.

Table 5.6 Domestic and international air passenger services by agent.

Agent	Domestic	International	Total Demand
	\$ millions		
Resident household	40,963	43,010	83,973
Business	12,541	7,781	20,322
Government	6,701	833	7,534
Non-resident households	8,754	29,900	38,654
Total Supply	68,959	81,524	

Source: Table 2 Supply and consumption of commodities, 2010; US Travel and Tourism Satellite Accounts, BEA(2012b)

Table 5.7 Demand for domestic and international air passenger services.

Demand type	Domestic		International	
	Domestic	Import	Domestic	Import
	\$ millions			
Intermediate inputs	22,724.4	0	10,172.9	5,951.0
Investment goods	438.8	0	0	0
Domestic residents	40,963.0	0	11,280.4	16,249.1
Foreign residents	8,754.0	0	25,650.2	0
Total demand/supply	72,880.2	0.0	47,103.5	22,200.1

Source: Virginia Tech calculations

5.2.2.4 Tourism

In the USAGE model, there are three tourism-related industries: domestic holidays by domestic residents (*holiday*), foreign holidays by domestic residents (*fgnhol*), and domestic travel and tourism by foreign residents (*exptour*). Expenditures by commodity by domestic residents for domestic travel and tourism are obtained from the US Travel and Tourism Satellite Accounts and are listed in Table 5.8 for 2010. Similarly, expenditures by commodity by foreign residents on domestic travel and tourism, listed in Table 5.9, are also obtained from the US Travel and Tourism Satellite Accounts. Finally, total expenditures on international travel and tourism by domestic residents is set equal to the value of travel by US residents abroad (\$56,959 million) from the Travel and Tourism Satellite Accounts, plus the expenditures on international air passengers services by domestic residents in Table 5.7. Because the Travel and Tourism Satellite Accounts do not identify expenditure by commodities for international travel, it is assumed that the expenditure shares are the same as foreign resident travelling in the United States.

Table 5.8 Expenditures by domestic households for domestic travel and tourism, 2010.

Commodity	\$ millions
Accommodations	65,177
Food services and drinking places	53,108
Domestic air passenger transportation services	40,963
Rail transportation services	640
Water transportation services	8,056
Transit and ground passenger transportation ^a	6,238
Scenic and sightseeing transportation services	2,982
Automotive equipment rental and leasing	7,516
Automotive repair services	5,722
Other personal services ^b	1,285
Travel arrangement and reservation services ^c	10,833
Motion pictures and performing arts ^d	8,189
Spectator sports	1,243
Recreation and entertainment ^e	47,482
Petroleum refineries ^f	34,295
Other state/local government enterprises ^g	487
Nondurable PCE commodities other than gasoline ^h	44,399
Total	338,615

Source: Table 3 Demand for commodities by type of visitor, 2010; US Travel and Tourism Satellite Accounts, BEA(2012b) and author's calculations

- a. Includes interurban bus and charter bus transportation, urban transit, and taxi service.
- b. Includes fees for parking lots and garages.
- c. Value reduced from \$16,500 million to total amount spent on travel arrangement by domestic consumers in the BLS data.
- d. One-third of total expenditure allocated to performing arts and two-thirds allocated to motion pictures.
- e. Allocated to promoters, artists/writers, museum/parks, and amusement/recreation based on input shares for domestic holiday in USAGE database.
- f. Refers to motor fuels.
- g. Refers to highway tolls.
- h. This residual category is allocated to all other commodities not included in this table based on input shares for domestic holiday in USAGE database.

Table 5.9 Expenditure by foreign residents for domestic travel and tourism, 2010.

Commodity	\$ millions
Accommodations	27,514
Food services and drinking places	22,509
Domestic air passenger transportation services	8,754
International air passenger transportation services	29,900
Rail transportation services	137
Water transportation services	0
Transit and ground passenger transportation ^a	870
Scenic and sightseeing transportation services	637
Automotive equipment rental and leasing	675
Automotive repair services	1,015
Other personal services ^b	148
Travel arrangement and reservation services ^c	1,586
Motion pictures and performing arts ^d	1,172
Spectator sports	376
Recreation and entertainment ^e	10,655
Petroleum refineries ^f	1,547
Other state/local government enterprises ^g	96
Nondurable PCE commodities other than gasoline ^h	<u>16,295</u>
Total	123,886

Source: Table 3 Demand for commodities by type of visitor, 2010; US Travel and Tourism Satellite Accounts, BEA(2012b) and author's calculations

- a. Includes interurban bus and charter bus transportation, urban transit, and taxi service.*
- b. Includes fees for parking lots and garages.*
- c. Value reduced from \$1,650 million to total exports of travel arrangement in the BLS data.*
- d. One-third of total expenditure allocated to performing arts and two-thirds allocated to motion pictures.*
- e. Allocated to promoters, artists/writers, museum/parks, and amusement/recreation based on input shares for domestic holiday in USAGE database.*
- f. Refers to motor fuels.*
- g. Refers to highway tolls.*
- h. This residual category is allocated to all other commodities not included in this table based on input shares for export tourism in USAGE database.*

5.2.2.5 Other Commodity/Industry Adjustments

Several final adjustments to the number of commodities and industries were required to solve problems encountered during preliminary model simulations. First, the BLS commodity “non-comparable imports” is eliminated from the model database. Because this commodity is not produced domestically, its presence created a singularity in the model equations, preventing the numerical solution of the model. Second, the BLS commodity and industry “Lessors of nonfinancial intangible assets” has also been removed from the model database. Because capital is the main input used in this industry, with a cost share of approximately 0.85, and capital is not freely mobile in the USAGE model, the price of this commodity was susceptible to large changes, making it more difficult to achieve convergence in the model results. Given the minor importance of these two commodities, removing them from the database will not have significant effects on the model results. The last adjustment was to combine the “transit and ground passenger transportation” industry with the “local government passenger transit” industry. Both of these industries mainly produce ground passenger transportation services. The problem that arose is that while these industries have different relative uses of motor fuels, with the local government passenger transit using motor fuels more intensively, they receive the same price for the ground passenger transportation services they produce (e.g., the ground passenger services provided by the transit and ground passenger transportation industry is a perfect substitute for ground passenger services provided by the local government transit industry). With separate industries, the large increase in oil and motor fuel prices lead to a large decrease in output by local government transit industry. Since this result is driven by the assumption of perfect substitutability, which may not be plausible, these two industries are combined to avoid this problem.

5.2.3 Oil Price Forecasts

The oil price forecasts are obtained from the EIA’s 2012 Annual Energy Outlook. For the baseline forecast, the price of oil for “reference scenario” is utilized. In the policy simulations, the price of oil for the “high oil price” scenario utilized. The oil price forecasts for these two scenarios, in 2010 dollars per barrel, are shown in Figure 5-2.

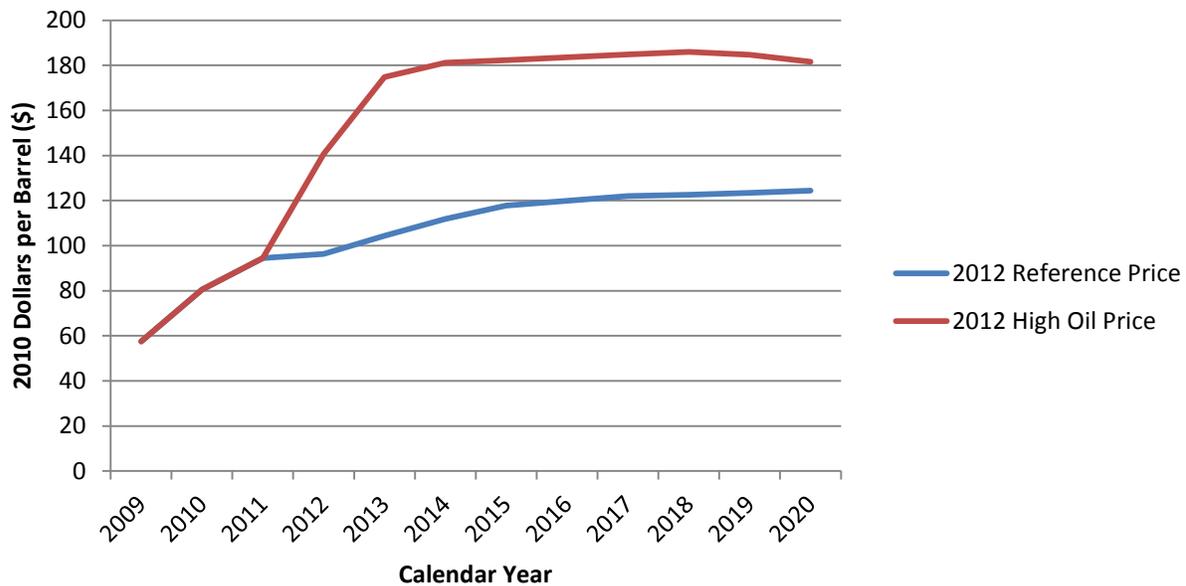


Figure 5-2 Oil price forecasts for baseline and high oil price scenarios (EIA, 2012).

5.3 USAGE Model Simulations

Like all dynamic models, the analysis of a change in an exogenous variable, such as a policy or in this report an increase in the price of oil, in the USAGE model consists of two parts. The first part is forecast simulation where the baseline forecast on real GDP, etc. is implemented in the model. The forecast simulation provides information on what the value of the endogenous variables, such as prices and quantities would be if no “policy change” occurs. In this case, we are estimating what would happen if the price of oil follows the EIA reference scenario forecast. The second part is the “policy” simulation where the change in “policy,” which in this case is the EIA’s “high” oil price, is implemented in the model. Then by comparing the differences in the endogenous variables between the policy and forecast simulations, one is able to determine how the policy change affects those variables.

Four different alternative fuel efficiency scenarios are analyzed in this report: (1) no change in fuel efficiency for passenger and cargo air carriers; (2) a “base” change in fuel efficiency; (3) a “high” increase in fuel; and (4) no change in fuel efficiency in response to changes in the price oil and fuels in the baseline but a high change in fuel efficiency in response to a larger oil and fuel price increase in the policy simulation. Alternative (1) represents what would happen if the airlines and cargo carriers did not respond at all to rising fuel prices and is the basis of comparison for the other three fuel efficiency alternatives.

5.3.1 Forecast Simulation with No Change in Fuel Efficiency

This section is composed of three parts: the baseline macroeconomic forecasts, implementing baseline technical change and changes in consumer preferences, and a discussion of adjustments made to imports and exports due to single region nature of USAGE model.

5.3.2 Macroeconomic Forecast

The growth in real GDP, consumer prices, and the real wage rate are obtained from the February 2013 Baseline Forecast from the Congressional Budget Office (CBO, 2013). In the CBO baseline, real GDP is forecasted to grow by 31.3 percent between 2010 and 2020. This forecast is slightly lower than the 35.6 percent growth in real GDP when comparing GDP in 2005 dollars in the 2010 BLS IO data to GDP in the BLS projected IO data for 2020. Because the projected IO data for 2020 is used to determine changes in consumer tastes and preferences and technical change between 2010 and 2020, the CBO annual forecast for the growth in real GDP are slightly revised upward in order for the total growth in real GDP between 2010 and 2020 to equal 35.6 percent. The growth in consumer prices is set equal to the forecasted growth in the Personal Consumption Expenditure (PCE) price index. The PCE index forecast is used, rather than the Consumer Price Index (CPI) because the base year of the PCE index is 2005, which more closely matches the 2010 base year of the IO data. The growth in real wages is computed as the ratio between the Employment Cost Index (ECI) and the PCE index. The annual baseline forecast for these three variables is shown in Figure 5-3.

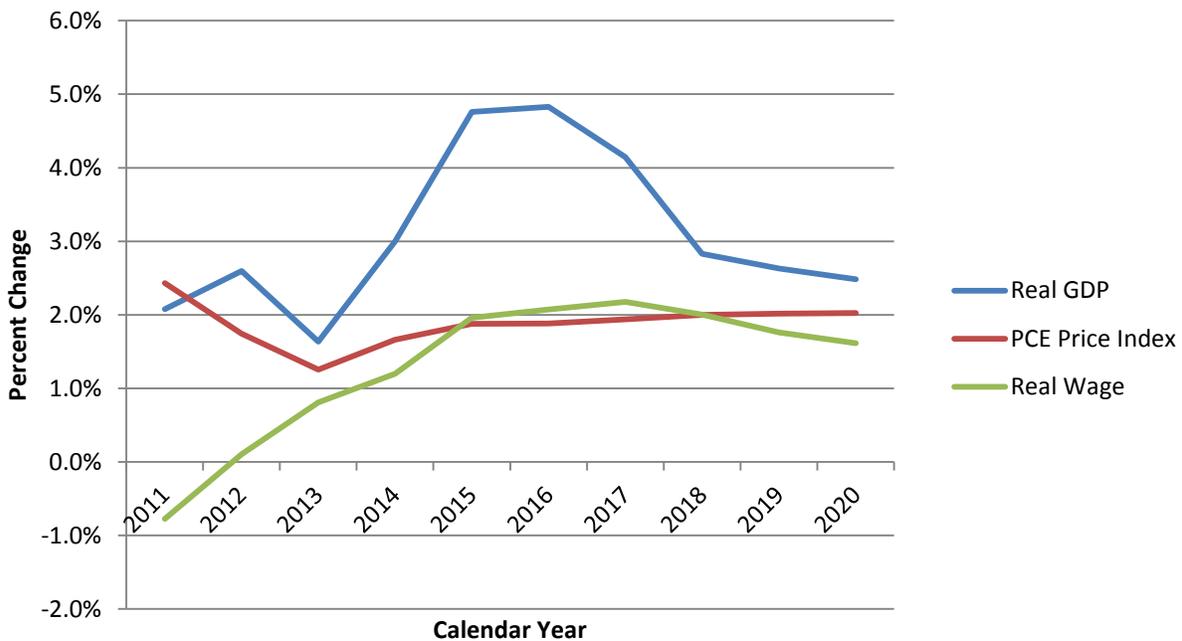


Figure 5-3 Baseline forecast for real GDP, consumer prices, and real wages.

The composition of real GDP changes in the BLS IO data between 2010 and 2020. Aggregate real investment and export volume are projected to grow faster than real GDP: real investment by 72.1 percent and exports by 63.4 percent. Real household consumption is projected to grow slightly less than real GDP, 34.5 percent compared with 35.6 percent. Real government expenditure is projected to grow much less than real GDP, at 6.4 percent. These changes in the composition of real GDP are implemented smoothly over the 10 year baseline, with the annual changes tracking the projected annual change in real GDP.

5.3.3 Changes in Technology and Tastes and Preferences

For firms in each industry, there are two types of technical change: a commodity-augmenting technical change that affects the mix of commodities produced in the industry, and an input-saving technical change that affects the mix of inputs used by firms in the industry. The commodity-augmenting technical change is determined by first computing the growth in the output of each commodity produced by a given industry between 2010 and 2020. Since the BLS IO data for 2010 and the projected IO data for 2020 use a constant 2005 dollar base, this growth rate is computed by dividing the value of a commodity produced by a given industry in 2020 by the value of that commodity produced in 2010. For example, in 2020, the crops industry is project to produce \$2,238.9 million of forestry products. In 2010, the crops industry produced \$1,745.6 million of forestry products. Thus, the growth rate for forestry products produced by the crops industry is 28.3 percent. In addition, the total value of production by the crops industry is projected to grow from \$117,781.2 million in 2010 to \$141,703.1 million in 2020, or 20.3 percent. Since the growth in the production of forestry products is greater than the overall growth in industry output in the crops, a commodity-augmenting technical change of 6.6 percent has occurred over the 2010 to 2020 period. This change assumed to occur evenly over the ten year period. This procedure is used to compute the commodity-augmenting technical change for each commodity produced by each industry.

A similar procedure is used to compute the input-saving technical change for each commodity used as an intermediate input by a given industry. The value of commodity i used in industry j in 2020 divided by its value in 2010. For example, own-use of the crops commodity as an intermediate input in the crops industry grew from \$6896.3 million in 2010 to \$8,058.0 million in 2020, or 16.8 percent. However, as noted above, production in the crops industry is projected to grow by 20.3 percent. Thus, the crops industry is projected to use less of the crops commodity to produce a unit of output in 2020 compared to 2010. Over the ten year period, the per-unit use of the crops commodity decreases by 2.9 percent. Again, it is assumed that this change occurs evenly over the ten year period.

A third type of technical change relates to changes in the trade and transportation commodities that are used to get products from producers to the purchasers. Because the BLS IO data only provides margin information for private household consumption and exports, technical change will only be incorporated for these margins. The procedure utilized will be similar to the procedures used commodity-augmenting and input-saving technical change. For the margins for private household consumption, a technical change occurs if the growth in the use of margin commodity m for commodity i , is different than the growth in the consumption of commodity i . For example, the use of rail transportation to get the crops commodity to consumers is projected to increase from \$197.7 million in 2010 to \$219 million in 2020, or 10.8 percent. During this same period, the value of the crops commodity consumed is also projected to grow 10.8 percent. Thus, no technical change occurs in the use of rail transportation for the crops commodity purchased by domestic consumers. The margins for private consumption are project to change very little between 2010 and 2020. However, the margins for exports are projected to decrease slightly for most commodities.

Because the 2010 IO data and the projected 2020 IO data are measured in constant dollars, the differences in the value of consumer expenditure on commodity i between 2010 and 2020 will be due to changes in income or changes in tastes and preferences. If the growth in expenditure on commodity i exceeds one plus the income elasticity for commodity i times the increase in real GDP, then consumer preferences are shifting towards that good. Some examples of commodities where this occurs are

computers, communication equipment, audio and video equipment, and home health care services. Commodities where consumer preferences are shifting away from that good include tobacco, couriers, child care, death care, and the postal service. Again these changes in consumer preferences are assumed to occur at a constant annual rate over the 10 year period.

To approximately replicate the increase in export volume for commodity *i* between 2010 and 2020, the shift in foreign export demand is determined using an iterative process. First, the forecast simulation is run with the base model parameters and the change in export volume and price for each commodity is obtained. Using the constant elasticity of demand function for exports in the USAGE model, the shift in the export demand function needed to equate growth in export demand at the commodity prices from the forecast simulation with the projected growth rate from 2010 to 2020 is computed. Then the forecast simulation is re-run and the new export growth rate for commodity *i* is compared with the project growth rate. If there are differences between these two growth rates, the shift in the export demand function is recalculated and the forecast simulation re-run. This process continues until growth in export demand in the forecast simulation is approximately equal to the project growth in exports.

The last demand shifter incorporate in the forecast simulation is for government demand. In the USAGE model, the government purchases four commodities, general federal defense, general federal non-defense, general state and local government, and other state and local government enterprises, in order to provide public goods. The underlying government preference structure in the USAGE model is Leontief. As mentioned earlier, total real government expenditure is projected to increase by 6.4 percent between 2010 and 2020. If the projected increase in government expenditure on an individual commodity is less than 6.4 percent, this implies a shift in demand away from that commodity. For example, projected spending by the federal government, as reflected by changes in expenditure on the two federal government commodities, decreases while project spending by state and local governments increase by approximately 18 percent. Thus, there is a shift in demand away from general federal defense and non-defense commodities and toward the two state and local government commodities.

5.3.4 Adjustment in Import Prices and Exports

As mentioned earlier, one drawback with using the USAGE model for this analysis is that it is a single region model, but increases in the price of oil will have global effect, not just in the United States. Increases in the price of oil will impact the price of imported goods, which cannot be capture directly by the model, as well as the export demand for US goods and services by foreign agents. To mitigate the impact on U.S. imports, several assumptions are made. First, to prevent undue substitution between domestic and imported goods caused by the import prices that do not reflect a change in the price of oil, the elasticities of substitution between domestic and imported goods (e.g., Armington elasticities) are all set equal to zero. Second, to ensure that cost of production for US industries is not understated, the price of imported oil, natural gas, refined petroleum products (e.g., motor fuels), other petroleum products, and air passenger transportation are adjusted such that they are equivalent to the domestic price of these products. Finally, because the export demand for U.S. goods and services is purely a function of the export price of US goods and services, not accounting for changes in the prices of competitors' products due to a change in the price of oil will likely result in lower US exports that would be expected if the prices of competing products also changed in response to the increase in the price of oil. Thus, the quantity of US exports for each product, which is endogenously determined in the forecast or baseline model simulation, is assumed to remain constant in the policy simulation that introduces the increased price of oil.

5.3.5 Implementing Changes in Fuel Efficiency

To determine the increase in fuel efficiency from higher oil and fuel prices, Equation (5.4) from MWH (2013) is used. This econometrically estimated equation relates the mission available seat miles (ASM) per gallon to the lagged jet fuel price. This equation is:

$$ASM_t = 50.358 + 4.235 \ln(FP_{t-3}) \quad (5.4)$$

where ASM_t is the available seat miles per gallon in time t and FP_{t-3} is the jet fuel price three time periods earlier.

To implement Equation (5.4) in the USAGE requires several additional assumptions. First, because the econometric model used by MWH uses quarterly data and assumes a three quarter lag between the change in fuel prices and a change in fuel efficiency, but the USAGE model is solved in one-year time periods, a one year lag between the change in oil and fuel prices and an observed change in fuel efficiency is used in the USAGE model. Second, because of aggregation in the underlying input-output data used by the USAGE model, the change in the price of “refined petroleum products,” which includes gasoline, diesel, as well as aviation fuel is used to determine the change in airline fuel efficiency. Third, while the price of oil is an exogenous variable in all simulations (in order to match the EIA forecasts), the price of refined petroleum products is an endogenous variable in all simulations. However, since oil is a key input in the production of refined petroleum products, the increase in the price of refined petroleum is linked with the increase in the price of crude oil. In initial simulations without any change in airline and air cargo fuel efficiency, on average a one percent increase in the price of crude oil lead to a 0.7 percent increase in the price of refined petroleum products. This ratio is used to compute the change in fuel prices from the exogenous change in oil price in order to forecast the change in fuel efficiency.

The estimated ASM fuel efficiencies for each year the forecast and policy simulations are given in Table 5.10. The fuel price in 2009 is the average of the monthly FOB spot price for kerosene-type jet fuel at the US Gulf Coast (EIA, 2013). The fuel price in 2010 is equal to the 2009 fuel price times one plus the percentage change in the oil price divided by 100, multiplied by 0.7 ($1.659 * 1.4002 * 0.7 = 2.124$). The same procedure is used to determine the fuel price in the remaining time periods. The “base” ASM per gallon fuel efficiency in 2010 for the forecast simulation is determined by using the coefficients in Equation (5.4) and the natural logarithm of the 2009 fuel price: $50.358 + 4.235 * 0.506 = 52.5$ ASM per gallon. The “high” ASM per gallon fuel efficiency in 2010 is determined by using the following: $50.358 + 4.799 * 0.506 = 52.79$, where 4.799 is the upper endpoint of the 95% confidence interval for the estimated coefficient of FP_{t-3} in Equation (5.4). The same procedure is used to determine the ASM per gallon fuel efficiency for all of the remaining years in the forecast simulation. For the policy simulation, the estimated ASM per gallon fuel efficiencies are higher due to the higher forecasted oil prices.

Once the ASM fuel efficiencies have been determined for all years, then the percentage changes are incorporated into the USAGE model as a refined petroleum product saving technical change for all the aviation industries (e.g., domestic air passenger transportation, international air passenger transportation, and air cargo). For example, in 2011, the first year in the model simulations, the “base” ASM efficiency for the forecast simulation increased from 52.5 in 2010 to 53.55, or a 1.992 percent increase. So the per-unit use of refined petroleum products by the air passenger and cargo industries is reduced by 1.992 percent for 2011.

Table 5.10 Changes in fuel prices and fuel efficiency.

Variable	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
<i>Forecast</i>												
Oil Price % Change		40.02	20.09	3.71	9.70	8.95	7.30	3.77	3.92	2.55	2.89	2.99
Fuel Price (FP)	1.659	2.124	2.365	2.437	2.611	2.789	2.956	3.063	3.171	3.252	3.335	3.424
Ln(FP)	0.506	0.753	0.861	0.891	0.960	1.026	1.084	1.119	1.154	1.179	1.204	1.231
ASM Efficiency												
Base		52.50	53.55	54.00	54.13	54.42	54.70	54.95	55.10	55.25	55.35	55.46
High		52.79	53.97	54.49	54.63	54.96	55.28	55.56	55.73	55.90	56.02	56.14
Percent Change												
Base			-	-	-	-	-	-	-	-	-	-
			1.992	0.850	0.236	0.539	0.513	0.449	0.274	0.268	0.192	0.194
High			-	-	-	-	-	-	-	-	-	-
			2.245	0.956	0.265	0.606	0.575	0.503	0.307	0.300	0.215	0.217
<i>Policy</i>												
Oil Price % Change		40.02	20.09	52.02	26.42	5.81	2.85	2.82	2.88	2.98	1.56	0.62
Fuel Price (FP)	1.659	2.124	2.377	3.269	3.973	4.172	4.289	4.409	4.527	4.652	4.721	4.757
Ln(FP)	0.506	0.753	0.866	1.184	1.379	1.428	1.456	1.484	1.510	1.537	1.552	1.560
ASM Efficiency												
Base		52.50	53.55	54.03	55.37	56.20	56.41	56.52	56.64	56.75	56.87	56.93
High		52.79	53.97	54.51	56.04	56.98	57.21	57.35	57.48	57.61	57.74	57.81
Percent Change												
Base			-	-	-	-	-	-	-	-	-	-
			1.992	0.889	2.498	1.491	0.368	0.208	0.206	0.198	0.203	0.109
High			-	-	-	-	-	-	-	-	-	-
			2.245	1.000	2.805	1.670	0.411	0.233	0.230	0.221	0.227	0.122
Policy Shock												
Base			0	-	-	-	0.145	0.242	0.068	0.070	-	0.085
				0.039	2.267	0.957					0.011	
High			0	-	-	-	0.165	0.272	0.077	0.079	-	0.095
				0.044	2.547	1.071					0.012	

The same procedure is used for all subsequent periods in the forecast simulation. In the policy simulation, additional gains in fuel efficiency, due to higher oil and fuel prices, are introduced. The estimated fuel efficiencies are computed for the higher price in the policy simulation and the difference between the fuel efficiencies between the two oil price scenarios is introduced into the policy simulation. For example, in 2013 the “base” ASM per gallon for the high oil price in the policy simulation is 55.37 while it is only 54.13 under the lower oil price in the forecast simulation. This implies that the fuel efficiency is 2.3 percent higher under the higher prices of the policy simulation, which is introduced by a further 2.3 percent reduction in the per-unit use of refined petroleum products by airline and cargo carriers.

5.3.6 Simulation Results

5.3.6.1 Price of Oil and Refined Petroleum Products

As shown in 5-2, the real price of oil (in 2010 dollars per barrel) for the reference case is projected to increase by 54.6 percent (2010 dollars per barrel). In nominal terms, which is computed by multiplying the change in the real price by the change in the GDP price deflator, the price of oil increases by 87.2 percent between 2010 and 2020 in the forecast simulation. As shown in Figure 5-2, the largest increases are project to occur in 2011, 2013, and 2014. This increase in the price of oil gives rise to a 60.9 percent increase in the nominal price of refined petroleum products (e.g., motor and jet fuels).

In the policy simulation, the 2012 EIA “high oil price” case is introduced into the model. In this scenario, the real price (in 2010 dollars) of oil is forecast to increase by 125.6 percent over the 2010 to 2020 period, or approximately a 45 percent larger increase than considered in the forecast simulation. As shown in Figure 5-4, most of this increase occurs in the 2011 to 2013 period. After 2014, the price of oil stabilizes. Including the changes in the GDP price deflator, the nominal price of oil increases by 179.6 percent, 49.4 percent more than in the forecast simulation. The increase in the price of oil also leads to an increase in the price of refined petroleum products, which increase by 123.6 percent in the policy simulation, 38.9 percent more than in the forecast simulation.

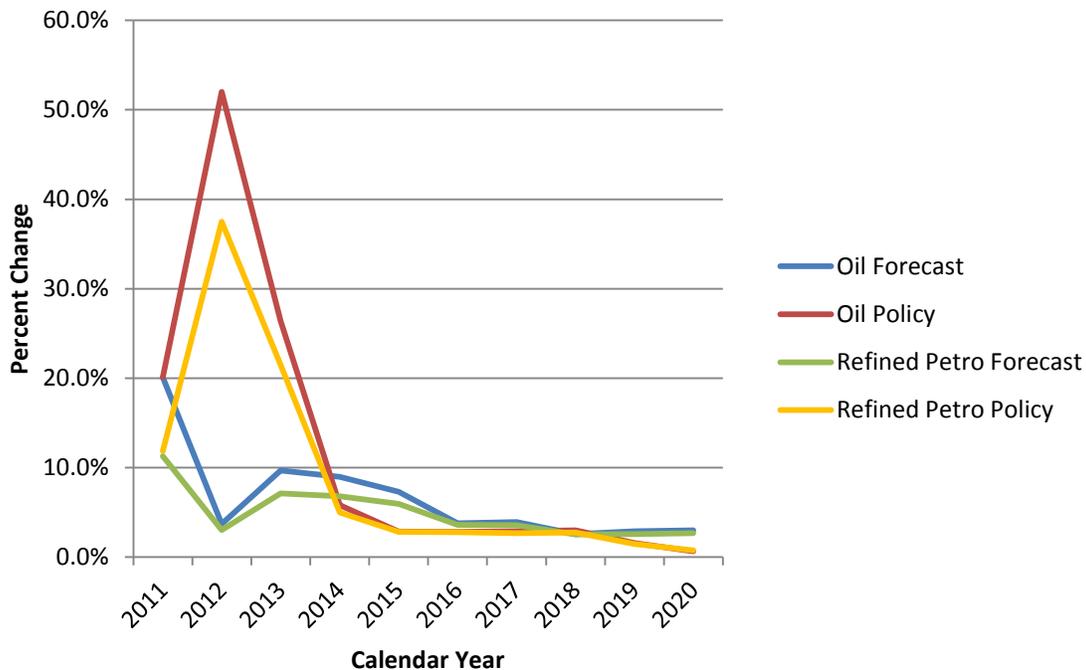


Figure 5-4 Growth in oil and refined petroleum prices in forecast and policy simulations.

5.3.6.2 Macroeconomic Effects of Oil Price Increase

The increase in the price of oil and refined petroleum products leads to an overall increase in the price of goods and services sold on the U.S. economy. As shown in Figure 5-5, the GDP price deflator increases by 0.3 percent compared to the forecast in 2012 and peaks at a 0.5 percent increase over the forecast in 2013 and 2014. At constant factor prices and income, this increase in the price of goods and services will lead to a reduction in both consumer demand and investment by firms. In 2012, aggregate investment drops sharply by 2.25 percent compared to the forecast simulation. It remains below the forecast level of investment in 2013 as well before rebounding in the later periods. Private consumption, which comprises nearly 70 percent of total real GDP in the U.S. economy, decreases by 0.7 percent in 2012 and 2013 compared with the forecast. This difference then slowly diminished until 2017 when it recovers to the level in the forecast simulation. The reduction in investment and private consumption leads to a reduction in the real wage rate and the hours of employment on the U.S. economy. Figure 5-6 shows the percentage reduction in the real wage rate and employment hours from the increase in oil prices in the policy simulation compared with the forecast simulation. Similar to investment, employment hours drop sharply in 2012 and 2013, but recover to slightly larger growth rates in 2014 to 2020. While the real wage also sharply drops in 2012 and 2013, it does not recover to the level in the forecast simulation until 2019.

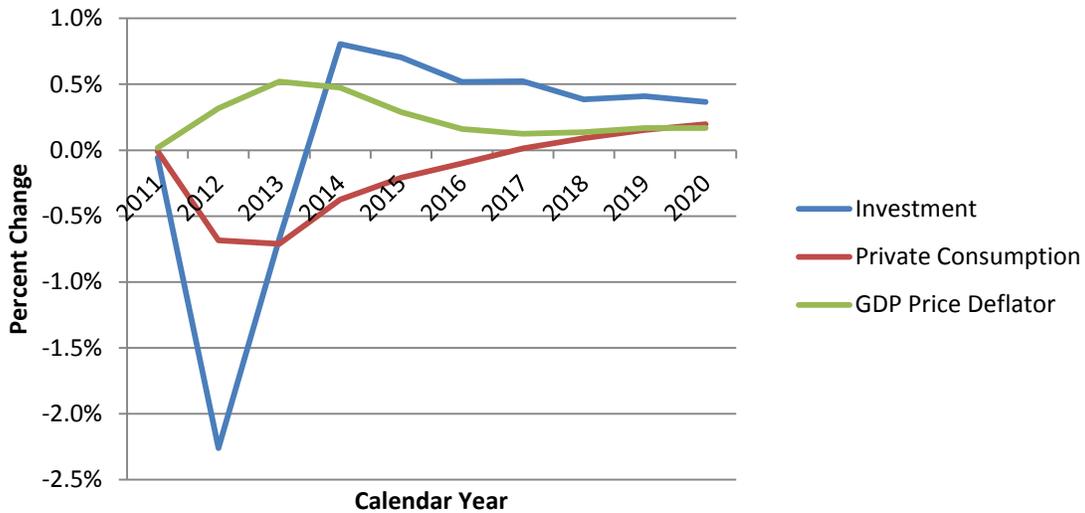


Figure 5-5 Percent change in GDP price deflator, investment, and private consumption relative to forecast

Overall, growth in real GDP of the U.S. economy is 0.7 percent lower in 2012 and 0.5 percent lower in 2013 compared with the growth in real GDP in the forecast simulation (see Figure 5-7). While the growth in real GDP recovers to the same level of the forecast simulation in 2016 and exceeds the project growth rate in 2017 through 2020, the cumulative growth over the 2010 to 2020 period is approximately 0.8 percent less than the cumulative projected growth.

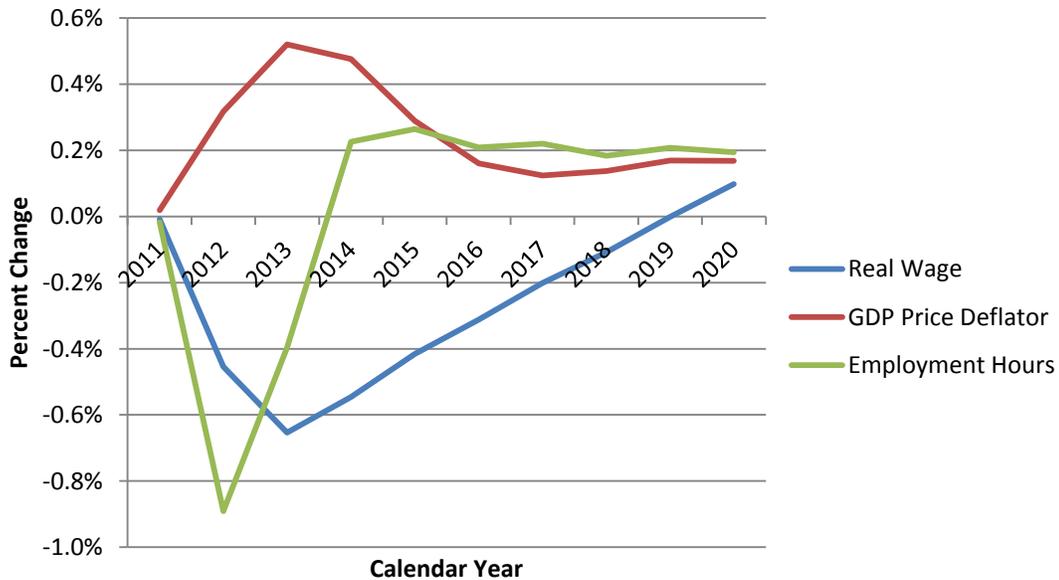


Figure 5-6 Percent change in GDP price deflator, real wage, and employment hours relative to forecast.

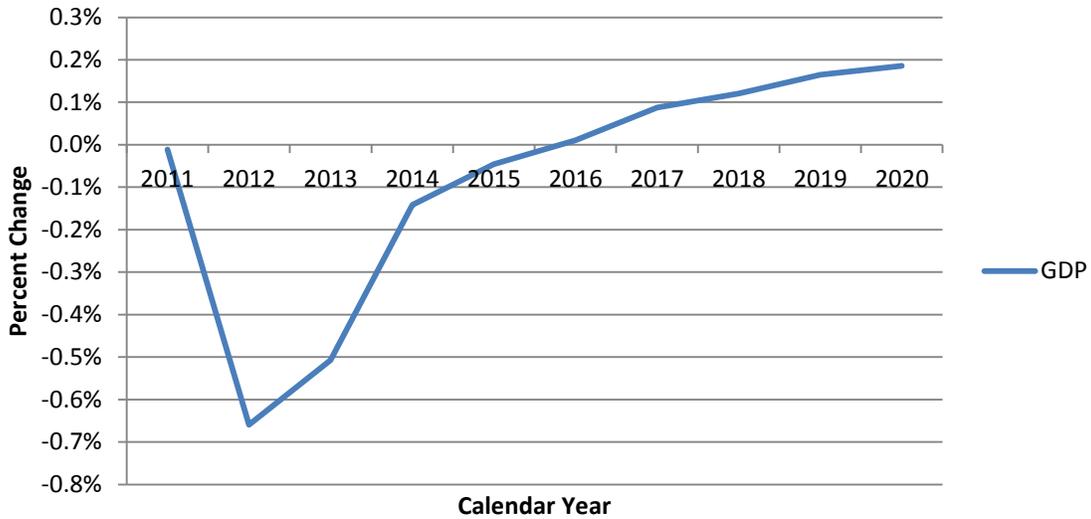


Figure 5-7 Percent change in real GDP growth relative to forecast simulation.

5.3.7 Impacts on Air Passenger Transportation

For the air passenger transportation industries, the demand for their services is derived from the demand by U.S. residents for domestic and international vacation travel, the demand by foreign residents for vacation travel in the U.S., and the intermediate demand by US firms for domestic and international business travel. For U.S. residents, the cost of motor fuels (e.g., refined petroleum products) and domestic air travel comprised approximately 27.5 percent of the cost of a domestic vacation in 2010. Similarly, motor fuels and air travel account from nearly one-half of the cost of a foreign vacation for U.S. residents. Thus, the higher oil and motor fuel prices in the policy simulation leads to higher prices for a domestic or international vacation for U.S. residents. As shown in Table 5.11, over the entire 10-year period, the price of both domestic and international air passenger transportation services are approximately 11 percent higher in the policy simulation compared with the forecast simulation if there is no change in fuel efficiency. This, along with the increase in the price of motor fuels, leads to the cost of a domestic vacation being 7.3 percent higher and the cost of a foreign vacation being 7.9 percent higher in the policy simulation compared with the forecast simulation. The higher prices, along with reductions in real GDP and thus real household income, cause US residents to reduce their consumption of domestic and foreign vacations by 6.1 and 6.5 percent respectively if there is no change in fuel efficiency. In addition, reductions in firm output due to reductions in investment and private consumption, also lead to lower demand for business travel in the policy simulation compared with the forecast simulation.¹³

¹³ No substitution is allowed between intermediate inputs in the USAGE model, so only changes in industry output will affect the demand for business travel by that industry.

Table 5.11 Cumulative growth rates for forecast and policy simulations.

Commodity <i>Output</i>	Alternatives			
	No Fuel	Base Fuel	High Fuel	Zero Base High Policy
	Percent Change			
Forecast				
Domestic Passenger	37.37	37.71	37.75	37.37
International Passenger	48.63	49.91	50.06	48.63
Air Cargo	48.39	48.36	48.36	48.39
Domestic Holiday	21.35	21.52	21.54	21.35
Foreign Holiday	18.57	19.23	19.31	18.57
Policy				
Domestic Passenger	32.66	33.10	33.15	32.91
International Passenger	46.57	47.97	48.14	46.90
Air Cargo	48.01	48.00	47.99	48.04
Domestic Holiday	13.93	14.26	14.29	14.33
Foreign Holiday	10.82	12.01	12.15	12.20
Difference				
Domestic Passenger	-3.43	-3.35	-3.34	-3.25
International Passenger	-1.39	-1.29	-1.28	-1.16
Air Cargo	-0.26	-0.24	-0.24	-0.23
Domestic Holiday	-6.12	-5.97	-5.96	-5.78
Foreign Holiday	-6.54	-6.05	-6.00	-5.37
<i>Price</i>				
Forecast				
Domestic Passenger	26.29	24.43	24.21	26.29
International Passenger	26.58	24.73	24.50	26.58
Air Cargo	30.25	28.23	27.99	30.25
Domestic Holiday	25.24	25.05	25.03	25.24
Foreign Holiday	24.01	23.26	23.17	24.01
Policy				
Domestic Passenger	40.24	36.51	36.07	36.08
International Passenger	40.42	36.70	36.25	36.26
Air Cargo	45.28	41.22	40.74	40.76
Domestic Holiday	34.45	34.07	34.02	34.02
Foreign Holiday	33.79	32.28	32.10	32.09
Difference				
Domestic Passenger	11.05	9.71	9.55	7.75

International Passenger	10.94	9.60	9.44	7.65
Air Cargo	11.54	10.13	9.96	8.07
Domestic Holiday	7.35	7.21	7.19	7.01
Foreign Holiday	7.89	7.31	7.25	6.52

The reduction in leisure and business travel from higher oil prices leads to a cumulative 3.4 percent reduction in domestic air passenger services and a 1.4 percent reduction in international air passenger service over the 2010 to 2020 period compared with the forecast simulation if there is no change in fuel efficiency. The smaller decrease in international air passenger service is due to the assumption that the strong growth in foreign residents visiting the US in the forecast simulation to continue in the policy simulation.¹⁴ In 2010, sales of international air transportation services by domestic air carriers to foreign residences accounted for just over half of all sales of international air transportation services provided by US airlines.

The difference in annual growth in domestic and international air passenger services provided by domestic air carriers between the policy and forecast simulations is shown in Figure 5-8. Both follow the sharp decrease in domestic and foreign vacation travel in 2012 and 2014 by US residents due to the decrease in household income and the increase in the cost of a vacation due to higher oil and motor fuel prices. While not shown in Figure 5-8, the decrease in business travel is not large as the decrease in vacation travel, resulting in a smaller decrease in domestic and international air passenger services than the decreases in vacation travel. The recovering of real GDP in 2014 and 2015 boosts both business travel, through increased output and thus demand for business travel, and leisure travel, through increased household income, leading to a recovering in the air passenger services as well. This pattern holds across all fuel efficiency alternatives.

If airlines improve their fuel efficiency in response to increase in fuel prices, then some of the increases in the cost of domestic and international air travel can be reduced. In the base and high fuel efficiency alternatives, airlines respond to high fuel prices in the forecast simulation by increasing fuel efficiency. This response results in a cumulative reduction of approximately 1.5 percent in the price of domestic and international air transportation in the forecast simulation compared with the no change in fuel efficiency alternative. With the advent of even higher increase in fuel prices in the policy simulation, airlines respond with even larger gains in fuel efficiency. This response results in the cumulative increases in domestic and international air transportation being 2.7 to 3.0 percent lower compared when no change in fuel efficiency alternative. For the alternative with no increase in fuel efficiency in the forecast simulation, but a “high” increase in the policy simulation (zero base, high policy), the cumulative increase in the price of air passenger transportation in the policy simulation is the same as the high fuel efficiency alternative, but the increase in forecast simulation is the same as the no fuel efficiency alternative. Thus, the cumulative increase in the price of air passenger services in the policy simulation is the smallest, 7.8 and 7.7 percent for domestic and international passenger services, of the three alternatives with increases in fuel efficiency.

¹⁴ “Export tourism,” which is the largest user of international air passenger services (54.4 percent of total output in 2010) is projected to grow 66.8 percent in the forecast simulation between 2010 and 2020.

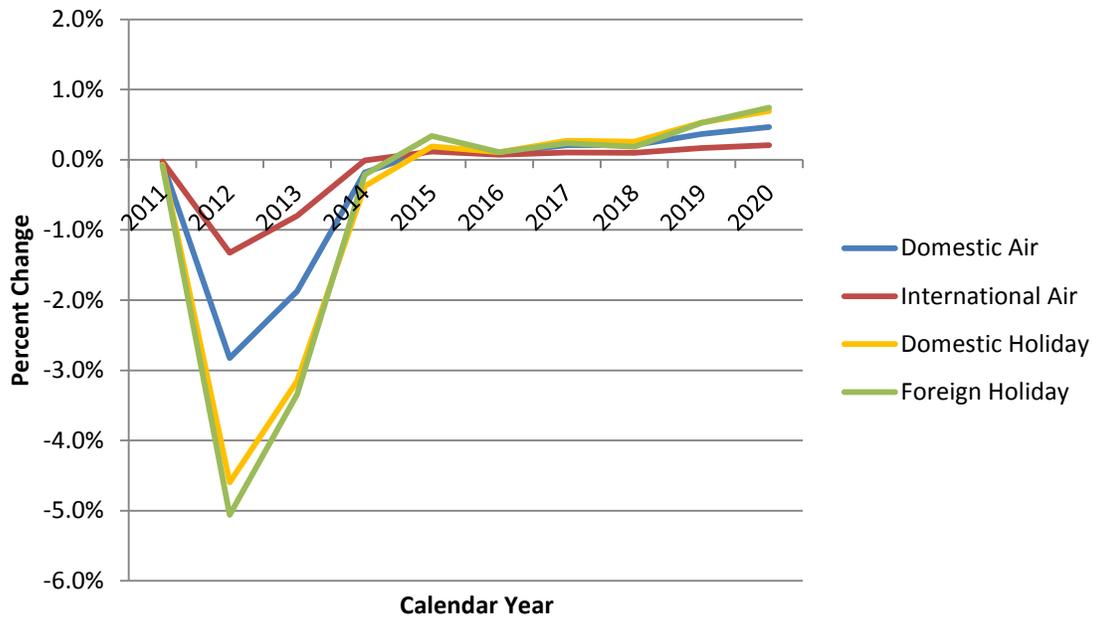


Figure 5-8 Percent change in output of air passenger services and the demand for domestic and foreign vacations by US residents relative to forecast simulation.

Figure 5-9 shows the annual relative differences in the price of domestic air passenger services between the three alternatives with increases in fuel efficiency and the “no fuel” efficiency alternative. Since most of the increase in the price of oil and motor fuels in the policy simulation occurs between 2012 and 2014, with a lag in the response in fuel efficiency, most of the price differentials occur between 2013 and 2015. Because the demand for business travel is not price sensitive in the USAGE model, reductions in the cost of air travel from increase fuel efficiency will have minimal impacts on business travel.¹⁵ Thus, the impact of lower prices from improved fuel efficiency will be primarily determined by the change in the demand for domestic and international vacations by U.S. residents.¹⁶

¹⁵ Only to the extent that a reduction in the cost of business travel will reduce the total cost of production for a given industry, which, by the assumption of perfectly competitive markets, would lead to lower prices and an increased demand for that industry’s product, would business travel be affected by a change in the price of air transportation. Since the cost share of air transportation is low for most industries, this affect would be minimal.

¹⁶ As noted earlier, the demand for exports, including “export tourism” is assumed to be the same in both the forecast and policy simulations.

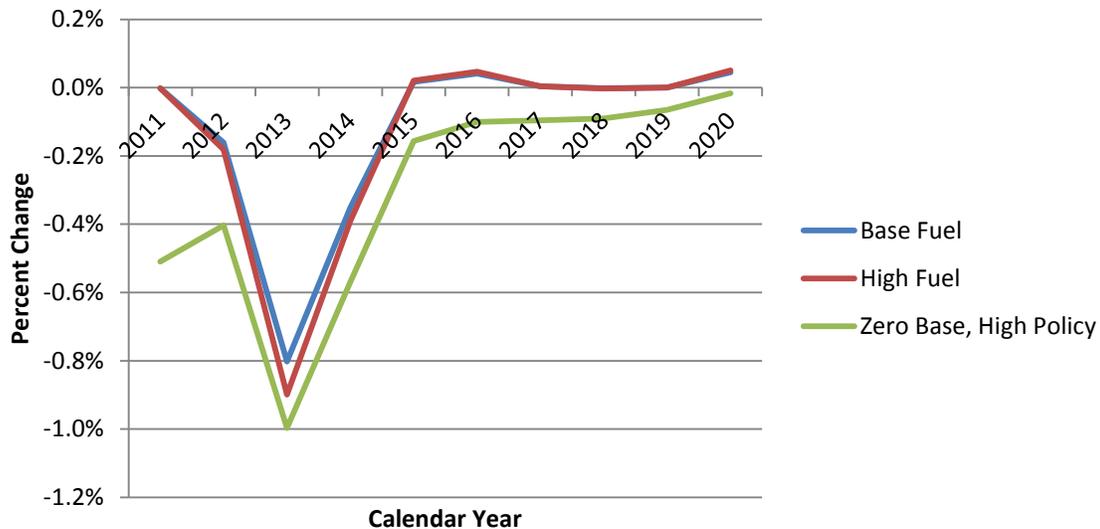


Figure 5-9 Percent change in the price of domestic air passenger services relative to “no fuel efficiency” alternative in the policy simulation.

Because of the higher cost share of air transportation for international vacation compared with domestic vacations, improved fuel efficiency will have a larger effect on the price of a foreign vacation than on a domestic vacation for US residents. Compared with the “no fuel efficiency” alternative, the price of a foreign vacation is 1.1 to 1.2 percent lower in the policy simulation for the alternatives where there is a gain in fuel efficiency. However, improvements in fuel efficiency only lead to a 0.3 percent smaller increase in the price of domestic vacations in the policy simulation compared with the alternative of no change in fuel efficiency. Because of these price changes, the “consumption” of foreign vacations is 1.1 to 1.2 percent higher in the policy simulation for the alternative with gains in fuel efficiency, compared to a 0.3 percent increase in the consumption of domestic holidays. Thus, not surprisingly, improvements in fuel efficiency will have a larger effect on international air passenger transportation than on domestic air passenger transportation.

5.3.7.1 Impacts on Air Cargo

In the USAGE model, the demand for air cargo services is derived from transportation services required to get a good from the manufacturer to the consumer of that good (e.g., as intermediate input, an investment good, an exported good, or a good purchased by consumers).¹⁷ No substitution is allowed between the different transportation modes required to get a specific good to a specific user in the model. Thus an increase in the use of an intermediate input, investment good, or consumer good, will lead to a proportional increase in the use of transportation services associated with that particular good. An increase in the price of air cargo

¹⁷ Note that transportation services are not required for services, such as electricity, legal services, and banks, where agents directly purchase these services.

service will lead to an increase in the cost of the goods that use this service, which in turn will affect the demand for these goods. However, since air cargo service is generally a very small portion of the price paid by the buyer, the demand effects will tend to be limited.

As shown in Table 5.5, the largest use of air cargo services is for intermediate inputs, followed by consumer goods, investment goods, and finally exports in 2010. Because investment goods tend to be physical goods rather than services,¹⁸ the use of air cargo services will tend to track the total use of goods for investment purposes. In the forecast simulation, aggregate real investment is projected to grow by 72.1 percent between 2010 and 2020. Thus, the use of air cargo services by the purchasers of investment goods grows by nearly an identical rate. The largest increase in the use of air cargo services were for computers; navigational, measuring, electro-medical, and control instruments; and software publishing, with these three commodities accounted for more than half of the total growth. In the policy simulations across all four fuel efficiency alternatives, aggregate real investment grows by 73.2 percent. Thus, the use of air cargo services increases in all fuel efficiency alternatives compared with the forecast simulation. In the policy simulations, the use of air cargo services for computers; navigational, measuring, electro-medical, and control instruments; software publishing; and agriculture, construction, and mining machinery had the largest growth compared with the forecast simulation.

Table 5.12 Cumulative growth rates for air cargo services by user for no fuel efficiency alternative.

Use	Forecast		Policy
	Percent Change		
Intermediate inputs	42.34		41.95
Investment	72.62		73.81
Consumption	35.76		33.88
Exports	47.52		47.52
Total	48.39		48.01

The growth in air cargo services used for good purchased by consumers also tends to follow the growth in real household consumption. In the forecast simulation, real household consumption is projected to grow by 34.5 percent. This growth in turns leads to a 35.8 percent increase in air cargo services for consumption goods. The largest increases were for apparel; pharmaceuticals and medicines; soap and cleaning compounds; computers, audio and video equipment; and other manufacturing. Across all four fuel efficiency alternatives, real household consumption only increases by 32.3 percent in the policy simulation. Thus, the use of air cargo services for consumption goods declines. The largest decreases were for crops; apparel;

¹⁸ There are some services, such as engineering and computer services that are utilized as investment goods in the BLS IO data.

pharmaceuticals and medicines; soap and cleaning compounds; other manufacturing; and publishing.

The growth in air cargo services used for intermediate inputs depends on several factors: the growth in industry output and the projected input-saving technical change. An increase in industry output will lead to an increase in the use of all intermediate inputs and therefore the use of air cargo services. However, an input-saving technical change will reduce the per-unit use of a given intermediate input, thereby leading to lower use of air cargo services. In the forecast simulation, the use of air cargo services for intermediate inputs grows by a cumulative 42.3 percent, which is slightly larger than the projected increase in real GDP of 36.1 percent. Thus the use of intermediate inputs that use air cargo services more intensively increases relative to those intermediate inputs that do not use air cargo services intensively. The use of crops; chemicals; paints, coatings, and adhesives; soap and cleaning compounds; other chemicals; computers; and semiconductors and other electronic components account for one-half of the increase in the use of air cargo services. In the policy simulations, real GDP only grows by 35.0 percent over the ten year period, implying lower overall economic activity, and a lower use of air cargo services for intermediate inputs. The growth in US exports will also lead to an increase in the demand for air cargo services. In the forecast simulation, US exports are projected to grow 63.4 percent. But because air cargo services are not required for every commodity exported, only about two-thirds of US exports in 2010 used air cargo services, the increase is less than proportional with a 47.5 percent cumulative growth. Exports of aerospace products and parts; crops; chemicals; soap and cleaning compounds; other chemicals; and software publishing are associated with the largest increases in the use of air cargo services for exports. Note that since commodity exports are held constant in the policy simulations, the cumulative growth rate also remains constant.

Figure 5-10 shows the annual changes in the use of air cargo services in the policy simulation for the no fuel efficiency alternative relative to the forecast simulation. For investment and consumption use, the differences track the overall changes in aggregate real investment and household consumption in Figure 5-5. Overall use of air cargo services decreases by 1.8 percent relative to the forecast in 2013 when the price of oil reaches its peak. After 2013, as consumption and investment recover, so does the use of air cargo services. By 2020, the use of air cargo services is nearly back to the level in the forecast simulation.

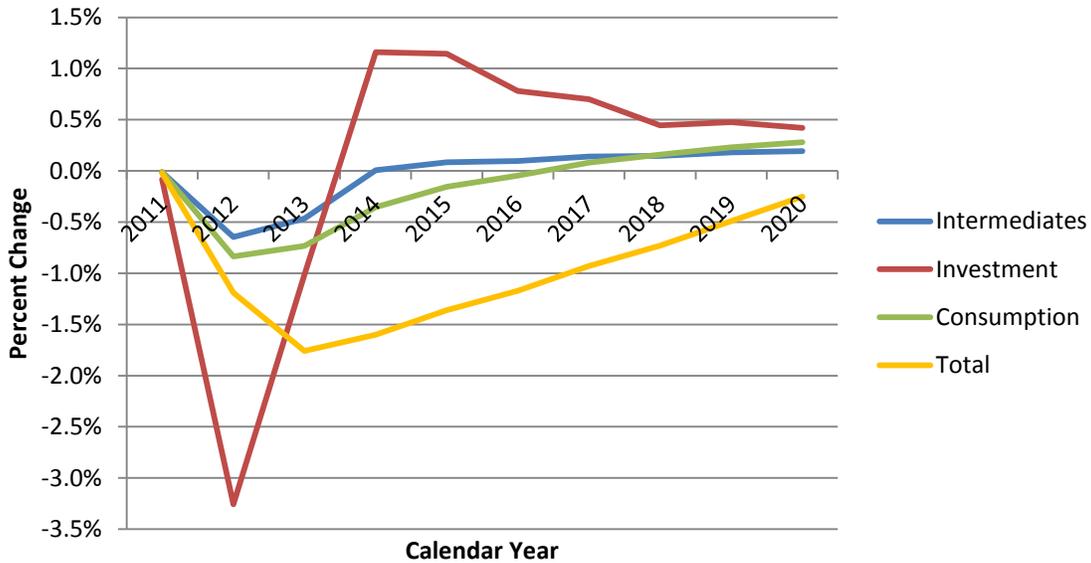


Figure 5-10 Percent change in air cargo services by user relative to forecast simulation, no fuel efficiency alternative.

The price of air cargo services is more sensitive to a change in the price of oil than is air passenger transportation due to a larger cost share of refined petroleum products compared with air passenger transportation (0.208 versus 0.193 in 2010). In the forecast simulations for the four fuel efficiency alternatives, the price of air cargo service increases by approximately 3.1 percent more than domestic air passenger transportation. With the higher oil prices in the policy simulations, this difference increases to 3.5 percent. The larger cost share of refined petroleum products in air cargo services also implies that improvements in fuel efficiency will lead to larger reductions in the price of air cargo services relative to air passenger transportation. In the policy simulations, improvements in fuel efficiency lead to 2.8 to 3.1 percent reductions in the price of air cargo services. In comparison, improvements in fuel efficiency lead to a 2.7 to 3.0 reduction in the price of domestic air passenger transportation in the policy simulations.

Figure 5-11 shows the annual relative differences in the price of air cargo services between the three alternatives with increases in fuel efficiency and the “no fuel” efficiency alternative. Figure 5-11 is very similar to Figure 5-9.

5.3.7.2 Macroeconomic Effects of Improvements in Fuel Efficiency

The overall macroeconomic effects of a reduction in domestic flight delay are measured using two metrics: the dollar increase in real GDP and the equivalent variation (EV). For both metrics, the changes are measured for the alternative with improvements in fuel efficiency relative the changes in real GDP and EV for the alternative without any improvement in fuel efficiency. For the “base fuel” and “high fuel” efficiency alternatives, real GDP is \$4.0 and \$4.3 billion higher in 2020 (for the policy simulation) compared to the alternative without gains in fuel efficiency. For the alternative with “zero forecast, high policy” alternative, real GDP is \$7.4 billion higher in 2020 than if there no gains in fuel efficiency.

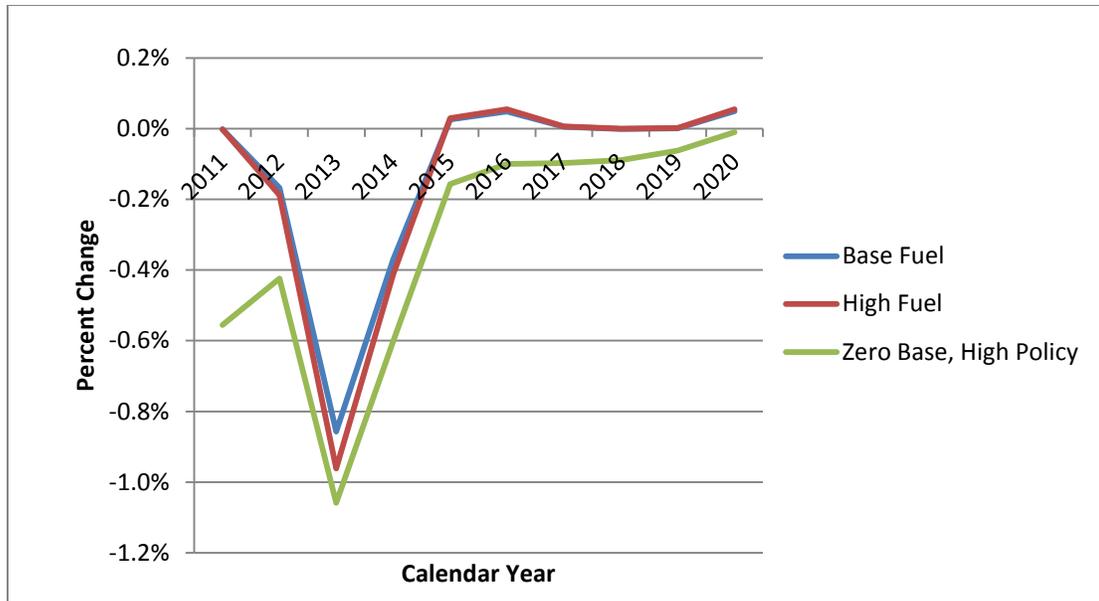


Figure 5-11 Percent change in the price of air cargo services relative to “no fuel efficiency” alternative in the policy simulation.

Equivalent variation is used to measure the change in welfare from improved fuel efficiency and refers to the additional amount of income, measured at initial prices that would be equal to the change in utility from the improvements in fuel efficiency. Equivalent variation is defined as $EV = e(p^0, u^1) - e(p^0, u^0)$ where e is the expenditure function, p^0 is the base price vector, u^0 is base level of utility, and u^1 is the level of utility obtained from the improved fuel efficiency. This welfare measure is used in computable general equilibrium models for several reasons. First, because the expenditure function can be derived from the utility function, it is easier to compute than computing the consumer surplus for each commodity. Second, because changes in utility due to changes in factor prices (e.g., income) are included, separate computations of producer surplus are not needed.¹⁹ On a discounted basis, the “base” and “high” fuel efficiency alternatives yield an increase of \$15.6 billion and \$17.6 billion in equivalent variation.²⁰ For the with “zero forecast, high policy” alternative, EV increased by \$35.0 billion compare to the alternative without improvements in fuel efficiency. This indicates that there are substantial welfare gains to

¹⁹ Unlike consumer surplus, EV is an exact measure of the welfare change. Consumer surplus is only an exact measure if consumer preferences can be represented by a quasilinear utility function.

²⁰ Because EV is measured in nominal terms each time period, its annual value is discounted to obtain the present value of the improvements in fuel efficiency. The discount rate is equal to one plus the real interest rate assumed in the USAGE model (0.0224) times one plus the percent change in the GDP price deflator. The average discount rate is approximately 0.045 in any given year.

the U.S. economy from passenger and cargo carriers implementing strategies to improve fuel efficiency.

5.4 Summary of Section 5

The prices of oil and jet fuel have significantly increased since the 1990s. This report assesses the impact of a large increase in oil prices on on air passenger and air cargo carriers, the industries that rely on air transportation, such the tourism industries, and on the U.S. economy. In addition, this report also investigated how potential adjustments by airline and cargo carriers to increase fuel efficiency in response to higher oil price would impact air fares, the travel and tourism industries, and the U.S. economy. Estimates of the relationship between mission fuel efficiency on an available seat mile (ASM) basis from MWH (2013) are used to determine potential adjustments in fuel efficiency.

The analysis in this report compares two different oil price scenarios: the 2012 EIA reference scenario and the 2012 “high oil price” scenario. The high price scenario assumes higher levels of world economic growth and demand for liquid fuels derived from oil, along with less abundant supply of oil, more of which is supplied by non-OPEC producers, the than the reference scenario. In the reference scenario, the real price of oil is project to grow by 54.6 percent. In the high price scenario, the real price of oil is project to grow by 125.6 percent.

Without any improvements in fuel efficiency, a 45 percent cumulative increase in the real price of oil between 2010 and 2020, compared with the 2012 EIA reference oil price, would result in an 11 percent increase in air fares for domestic and international air passenger transportation and an 11.5 percent increase in the price of air cargo services. If air passenger and air cargo carriers respond to higher oil and fuel prices by reducing fuel consumption per unit of output (e.g., ASM for passenger carriers) by the levels suggested by the analysis presented in Section 2 of this report, this would reduce the increase in air fares by 2.7 to 3.0 percent for passenger transportation and by 2.8 to 3.1 percent for air cargo transportation. Thus, changes in flight operations, such as cruise speed, and the use of more fuel efficient aircraft could lead to significant reduction in air fares in the face of much higher oil prices.

The reduction in air fares from increased fuel efficiency would not only benefit air carriers, but also industries related to travel and tourism. Without improvements in aircraft fuel efficiency, domestic leisure travel would decrease by 6.1 percent as the cost of travel (e.g., air fares, motor fuels) increase due to higher oil prices. Similarly, international leisure travel by US residents would decrease by 6.5 percent. By adopting strategies that improve fuel efficiency, the reduction in domestic leisure travel would be 0.2 to 0.4 percent less. While the change in domestic travel is small on a percentage basis, it represents a significant change given that US residents spent \$427.7 billion on domestic travel and tourism in 2010. The specific industries most affect include accommodation; amusement, gambling, and recreation; travel agents; and performing arts.

Adopting strategies that improve fuel efficiency also have positive macroeconomics effects on the U.S. economy. Improvements in aircraft fuel efficiency lead real GDP to be between \$4.0 and 7.4 billion higher in 2020 when compared to an alternative with no improvement in fuel efficiency. Aggregate U.S. welfare, as measured by equivalent variation increases between \$15.6 and \$35.0 billion on a discounted basis between 2010 and 2020 for the alternatives with increases

in fuel efficiency compared with the alternative with no increase in fuel efficiency.

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