Journal of Transport Economics and Policy, Volume 47, Part 1, January 2013, pp. 107–121

The Economic Cost of Airline Flight Delay

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Abstract

Flight delay has become widespread in the United States with nearly one-quarter of all flights delayed by more than 15 minutes in 2007. This paper determines the economic costs of delayed flights, including the direct effects of increased airline cost and the indirect effects of lost labour productivity for business travellers, an opportunity cost of time for leisure travellers, and changes in consumer spending on travel and tourism goods and services. US net welfare would increase by $17.6 billion for a 10 per cent reduction in flight delay and by $38.5 billion for a 30 per cent reduction.

Date of receipt of final manuscript: May 2012

1.0 Introduction

Flight delay has become a widespread problem at many airports in the United States. Between 2002 and 2007, while the number of flights increased by 40.7 per cent, the number of flights that arrived over 15 minutes late increased by 106.4 per cent (Bureau of Transportation Statistics, 2009). In 2007, nearly one-quarter of all flights were delayed by at least 15 minutes (BTS, 2009). While the number of flights and delay decreased between 2007 and 2009 by 12.9 per cent and 32.8 per cent due to the recession, the Federal Aviation Administration (FAA) has forecasted nearly a 50 per cent increase in flight operations between 2010 and 2025 (FAA, 2009). Without upgrades in aviation infrastructure or other mechanisms, such as congestion pricing, this growth will likely result in higher levels of flight delay.

Flight delay is costly for airlines and their passengers. For airlines, flight delays lead to additional costs, mainly for crew, fuel, aircraft, and maintenance. A recently completed comprehensive study on flight delay by the National Center of Excellence for Aviation Operations Research (NEXTOR) estimated that flight delay cost airlines \$8.3 billion in 2007. For passengers, the extra time of air travel due to flight delays result in lost business productivity and lost opportunities for leisure activities. Based on estimates of passenger time lost due to schedule buffer, delayed flights, flight cancellations, and missed connections, NEXTOR estimated a \$16.7 billion cost to passengers in 2007.[1]

However, neither the increase in direct cost incurred by airlines or the opportunity cost of passenger time provides an accurate measure of the economic cost of flight delay for several reasons. First, a portion of the increase in airline input cost, such as fuel or labour, is a transfer from the buyers of air passenger services, not a loss in economic welfare. A more appropriate measure of the economic loss would consider the impacts of an input-using technical change. Delayed flights require airlines to use more inputs to provide that same level (or possibly reduced level) of output. If inputs such as capital and labour are fully employed and are in fixed supply, then the input-using technical change from delayed flights implies that fewer goods and services can be produced in the economy, resulting in an economic loss.

Second, flight delays experienced by business travellers reduce the number of productive hours, leading to reductions in labour productivity that will increase the cost of doing business for the industries that rely heavily on air transportation for their business travel. These changes in cost will affect the price of the goods and services produced by these industries, which in turn will affect their level of output and input usage. Here again, a more appropriate measure would consider the labour-using technical change induced by delayed flights.

Finally, the economic effects of delayed flights are not limited to the airline industry and their passengers. Increases in airfares due to increased airline cost from delayed flights will alter consumer spending on leisure travel and other tourism-related products and services, such as hotels and restaurants. This spillover will affect the level of output in the

[1] Other studies that estimate the cost of flight delay include the Air Transport Association (ATA, 2009) and the Senate Joint Economic Committee (JEC, 2008). In these studies, the cost of delay ranges from \$6.1 to \$19 billion for airlines and \$3.3 to \$12.0 billion for passengers.

tourism-related industries as well as their use of scarce resources. Given the existing taxes and subsidies in the US economy, these induced changes in output and input use in the non-airline industries will lead to second-best gains or losses in allocative efficiency.

The objective of this paper is to determine the economic impacts of flight delay on the US economy, including the direct effects of induced technical change in the airline industry, the indirect effects on industries that rely on air travel for their business travel or are dependent on tourism, and the opportunity cost of time for leisure travellers. To capture these direct and indirect effects, a version of the USAGE applied general equilibrium model (AGE) (USITC, 2009) that incorporates flight delay is utilised. Based on available flight delay data, we define flight delay in our model as the percentage of flights that arrived at (or departed from) the gate 15 minutes or more after the scheduled arrival (departure) time.

2.0 Model Description

The USAGE model is similar to the MONASH model of Australia (Dixon and Rimmer, 2002), based on data for the United States. The model database contains information on 539 commodities produced by 535 industries and assumes all primary factors of production are fully employed. This large degree of commodity and industry disaggregation reduces the possibility that important economic linkages are obscured in the model simulations. Unlike other models, the USAGE model links the demand for air transportation to the demand for leisure travel, the demand for air transportation by firms, and the demand for air freight services. In addition, the air transportation sector is disaggregated into two industries that provide either domestic or international flights. This will allow the analysis to focus on the impact of reducing domestic flight delays. One limitation of the model database is that it does not directly distinguish between passenger and freight services.

The USAGE model is a recursive-dynamic model with perfectly competitive markets.[2] The dynamic feature of the model allows forecasted changes in economic activity, such as Gross Domestic Product (GDP), that affect the demand for air transportation and therefore the level of flight delays to be incorporated in the analysis. The model is solved for the period 2005–13, using a baseline forecast developed by the US International Trade Commission (ITC, 2009). The baseline includes projections on GDP, employment, select industry output, and other macro variables from sources such as the Congressional Budget Office (CBO). It also includes projections on changes in consumer preferences and rates of technical change based on historical simulations that allow the USAGE model to be consistent with available statistical information.[3]

[2]The assumption of perfect competition implies that industries earn zero economic profits and the percentage change in price is equal to the percentage change in cost in each industry.

[3]In historical simulations, observed variables, such as GDP, trade and production values, are made exogenous and shocked by their observed movements. Variables associated with consumer tastes and preferences and technology are endogenous. Examples of changes in consumer tastes include increased preferences for computers and home audio equipment, and decreased preferences for newspapers and greeting cards.

Like most AGE models, the USAGE model uses equivalent variation (EV) to measure the change in economic welfare of the single representative consumer in the model. In this paper, EV is defined as the income change, at base (2005) prices, that would be equivalent to the change in utility from a reduction in flight delay. As shown by Hanslow (2000), the change in EV in AGE models includes the welfare effect of technical change plus changes in allocative efficiency induced by a reduction in flight delay.

2.1 Disaggregation of domestic air transportation

Because flight delay mainly affects passengers rather than freight, domestic air transportation in the USAGE database is disaggregated into two industries and two commodities: domestic air passenger services and all other domestic air transportation services.[4] The output of the domestic air transportation industry is divided between either air passenger services or other air transportation based on who purchases the services.[5] All purchases for intermediate use (except by the Postal Service) and leisure travel are assumed to be air passenger services. All use of air transportation for domestic air freight services and intermediate use by the Postal Service are allocated to other air transportation. Based on these assumptions, approximately 69.5 per cent of base year (2005) value of domestic air transportation output represents air passenger services. The intermediate inputs used by domestic air transportation are divided between air passenger and other air transportation proportionally, based on the above output share. The exception is that all own-use of air transportation is regarded as air passenger services.

2.2 Incorporating flight delay

The level of flight delay, relative to uncongested travel time, can be measured in several ways. One method would be to estimate the total hours of delay experienced by passengers. NEXTOR (2010) estimated that passenger delay in the US in 2007 equalled approximately 468 million hours. This estimate included four different types of delay: airline schedule buffer, flight delays, capacity-induced delay, and voluntary schedule adjustments (see Table 1).[6] Because comprehensive estimates of the total hours of delay are not available over time, it is not possible to estimate how the total hours of delay change with the level of air travel. An alternative measure of flight delay, which is readily available over time, is the percentage of flights that arrived at (or departed from) the gate 15 minutes or more after the scheduled arrival (departure) time. To use this measure, we assume that the total hours of delay change proportionally with changes in

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[4]Because domestic cargo carriers, such as UPS and FedEx, mainly fly at night, they are less likely to experience congestion-related delays.

[5]Because the US input–output accounts provide information on dollar values, we follow the standard convention of setting all prices equal to one and defining quantities as the amount that is worth one dollar in the initial equilibrium. This eliminates the need to collect price information across a large number of goods and by class of traveller. Reporting model results as percentage changes allows one to interpret the change in output in any physical unit, such as revenue passenger miles.

[6]Capacity-induced delay occurs when congestion at an airport causes carriers serving that airport to schedule flights at less-desirable time. Voluntary schedule adjustments represent the additional travel time that results when travellers opt for an earlier flight in order to assure that they arrive at their destinations at the desired times. It is the personal analogue of schedule buffer.

Table 1
Hours of Passenger Delay, 2007

	Million hours
Delay	
Airline schedule buffer [1]	158.750
Passenger flight delay [2]	250.176
Capacity-induced delay [3]	45.508
Voluntary schedule adjustment [4]	13.716
Total	**468.151**

Sources and Notes:
1. Table 3-9 (NEXTOR, 2010).
2. Table 3-6 (NEXTOR, 2010).
3. Table 3-17 (NEXTOR, 2010).
4. Table 3-15 (NEXTOR, 2010).

delay relative to the schedule. Based on what we have informally learned about airline scheduling practices, this appears to be a conservative assumption. In particular, schedule buffering, which is the practice of building extra time into flight schedules to increase the probability that delayed flights will arrive when scheduled, appears to increase more rapidly with the growth in the number of flights than the percentage of flights delayed.

A logistic function is used to determine the level of delay associated with a given level of air passenger output. The delay function is specified as:

$$delay = \left[\frac{1}{1 + \exp^{-tval}}\right][1 + policy], \tag{1}$$

where *delay* is the percentage of flights delayed, *tval* is the value of the exponent in the logistic function and *policy* is an exogenous change in delay used in the policy simulation. The value of *tval* is defined as:

$$tval = \ln[(1/IDELAY) - 1] - DADJ \times \left[\frac{x_a - x_{a0}}{x_{a0}} - 1\right] \times 100, \tag{2}$$

where *IDELAY* is the percentage of flight delays in the base year, *DADJ* is a parameter, x_a is the level of air passenger output, and x_{a0} is the level of air passenger output in the base year. The first term in equation (2) determines the initial value of *tval* required for the logistic function to equal the initial percentage of flights delayed. The second term in equation (3) describes how *tval* changes as the level of air passenger output changes. The value of the parameter *DADJ* is calibrated to an econometric estimate of the relationship between the percentage of flights delayed and air passenger output discussed below. The advantages of a logistic function are that it is a smooth and twice differentiable function and can represent both linear and non-linear responses over a range of air passenger output levels by choosing alternative values of *DADJ*.

A logistic function is also used to represent the relationship between the percentage of flights delayed and airline costs (*aircost*):

$$aircost = \frac{1}{1 + \exp^{-A \times delay}}, \tag{3}$$

where A is a parameter whose value determines the increase in airline costs from an increase in flight delay. The percentage change in *aircost* is treated as a neutral technical change and included in the input demand and the zero profit equations for the air passenger industry.

Finally, a logistic function is used to represent the relationship between the percentage of flights delayed and labour productivity (*lprod*) in industry i that use air passenger services for business travel. Formally:

$$lprod_i = \frac{1}{1 + \exp^{-B \times \lambda_i \times delay}}, \tag{4}$$

where B is a parameter whose value is the average change in labour productivity from a given change in percentage of flights delayed and λ_i is a parameter that determines how intensively industry i uses air passenger services. The values of λ_i are the relative cost shares of air passenger services for the ith industry and will equal 1 if the cost share of air passenger services in industry i equals the average air passenger cost share across all industries in the base year. Thus, the more intensively an industry uses air passenger services, the greater the effect of a change in delay will be on that industry. The percentage change in $lprod_i$ is treated as a biased labour technical change and is included in the labour demand and the zero profit conditions for all industries that use air passenger services as an intermediate input.

2.3 Calibration of delay logistic functions

To estimate the relationship between delay and the level of air travel, we use monthly data on the percentage of flights delayed by at least 15 minutes and the number of flight operations from January 2000 to September 2009 (Bureau of Transportation Statistics, 2009). Two alternative models are estimated: a linear and log-linear relationship between flight delay and flight operations, including month and year fixed effects.

As shown in Table 2, both models fit the data well, explaining over 80 per cent of the monthly variation in the percentage of flight delays. All coefficients are statistically significant at the 1 per cent level except for February and the constant term in both models. The elasticity of delay with respect to flight operations is similar in both models:

Table 2

Estimated Relationship between Percentage of Flight Delays and Flight Operations

	Linear Model		*Log-Linear*[a]	
Variable	*Coefficient*	*Std Error*	*Coefficient*	*Std Error*
Flight operations (millions)	0.5532	0.0143	1.6934	0.3006
Constant[b]	0.0364	0.0684	0.0609	0.2301
N	117		117	
R^2	0.8042		0.8148	

Notes:
[a] In the log-linear specification, the natural log of percentage flight delays and flight operations (millions) is utilised.
[b] The estimate coefficients for the month and year fixed effects are available from the authors upon request. The base month is December and the base year is 2000 in both models.

Table 3
Calibrated Elasticity and Parameter Values for Delay Functions

Elasticity/Parameter	*Mean*[a]	*Minimum*	*Maximum*
Delay elasticity	1.5	1.0	2.0
DADJ	0.01702	0.01268	0.021175
IDELAY	20%		
Airline cost elasticity	0.18	0.06	0.30
A	2.375	1.275	4.45
Average % change in labour productivity	0.0125	0.005	0.02
B	0.00625	0.0036	0.0089

Note:
[a] The mean values represent the base value of the elasticities and parameters. The minimum and maximum values represent the values used in sensitivity analysis.

1.5 for the linear model evaluated sample means and 1.6 for the log-linear model. Thus, the value of *DADJ* in equation (2) is chosen such that a 1 per cent increase in air passenger output yields a 1.5 per cent increase in delay. Alternative elasticity values of 1.0 and 2.0, which correspond to a 95 per cent confidence interval for the estimated elasticity, are utilised in a sensitivity analysis.

The value of parameter *A* in equation (3) is determined based on estimates from a short-run trans-log cost function that includes arrival delay and schedule buffer (NEXTOR, 2010). The estimated trans-log cost function is not used in this analysis because it assumes a fixed level of capital, which would not be a good assumption given the eight-year time period of the model. Instead, the estimated cost elasticity with respect to delay, which includes both arrival delay and schedule buffer, is used to choose the value of *A*. The mean value of the estimated cost elasticity is 0.18, with a 95 per cent confidence interval (0.06, 0.30) (see Table 3). Because of the relatively small delay cost elasticity, the logistic function for airline costs as a function of flight delay takes an approximately linear form. While one may expect a more than proportional increase in cost for large increases in delay and the opposite for a large decrease in delay, we believe that for modest changes in delay, a linear relationship is a good approximation.

The value of parameter *B* in equation (4) is chosen based on estimates of the hours of delay attributable to business travel relative to the total hours worked in the US economy. The total number of hours worked in the US economy is computed as the number of non-farm employees, including those in the public sector, multiplied by the average weekly hours of private sector production workers (Bureau of Labor Statistics, 2009). This assumes that the average weekly hours worked for all non-farm employees is the same as for production workers. Using these assumptions, there were approximately 242 billion hours worked by all non-farm employees in 2007.

To determine the total hours of delay attributable to business travellers, we multiply the share of trips that are work-related in the 2009 National Household Travel Survey (US Department of Transportation, 2009) — 21.1 per cent — by the total hours of delay in Table 1. Qualitative research (NEXTOR, 2010) suggests that the impact of delay on the productivity of business travellers depends on where the lost time is spent. An hour waiting in an airport terminal or lounge could be used more productively than an hour spent on board an aircraft waiting for departure. Unfortunately, estimates of where the lost time is spent are not available. Given this uncertainty, we assume that 50 per cent, 75 per cent, or 100 per cent of the total hours of delay are unproductive. In addition, since nearly 85 per cent of all work-related trips in 2009 that used air transportation were taken by individuals from households whose income is greater than $80,000 (2009 National Household Travel Survey), it is likely that the marginal value of labour for the business traveller is higher than for the average worker. Thus, we consider three alternative productivity assumptions: the business traveller has the same productivity, 2.5 times, and four times the productivity as the average employee. Using all assumptions, the total hours of unproductive delay for business travellers as a percentage of total hours of employment ranges from 0.02 per cent to 0.16 per cent, with an average of 0.077 per cent.

Because the value of the parameter *B* determines the change in labour productivity due to a change in the level of delay, we assume that the change in unproductive hours for business travellers is a proportional change in the percentage of flights delayed. Since the level of flight delay in 2007 was 19.1 per cent higher than the level of flight delay in 2005 (Bureau of Transportation Statistics, 2009), the level of unproductive hours in 2005 would be 16.1 per cent lower. Thus, multiplying the average percentage of unproductive hours (0.077) by 0.161 yields an average increase in labour productivity of 0.012 per cent. The base value of *B* (0.00625) is chosen such that a 16.1 per cent increase in delay will lead to a 0.012 per cent loss in average labour productivity. Alternative values of *B* are chosen to allow the average loss in labour productivity to range between 0.005 per cent and 0.02 per cent.

3.0 Model Simulation

The simulation used to assess the economic cost of flight delay is comprised of two parts. The first part is the forecast simulation, where information on economic growth and other relevant macroeconomic variables in the USITC baseline is introduced into the modified USAGE model. This simulation will determine how forecasted changes in income, consumer tastes, and technical change will affect the demand for air transportation and the amount of flight delay if no policies or actions are taken to reduce delays.

The second part of the analysis is the policy simulation, where it is assumed that some action or policy is implemented that reduces the number of delayed flights for a given level of airline output. In this simulation, the exogenous variable *policy* in equation (1) is shocked in order to achieve a 'target level' of reduction in the 2005 level of flight delay. By comparing the model results for the forecast and policy simulations, one is able to determine the impacts of a reduction in flight delays on the US economy.

3.1 Simulation results

The first column of Table 4 presents the key results for the forecast simulation using the base values of the delay parameters in Table 3. Real GDP, in 2005 dollars, is forecast to grow by 25.97 per cent between 2005 and 2013. Because the labour supply and employment hours are forecast to grow only by approximately 7 per cent during this period, the real wage is forecast to grow by 21.2 per cent. Aggregate real investment is forecast to

Table 4
Simulation Results

Variable	*Forecast simulation (% Change[a])*		*Policy simulations: reduction in base level of delayed flights (% Change Relative to Forecast[b])*			
			10%		*30%*	
	Sim	*Std Dev*	*Sim*	*Std Dev*	*Sim*	*Std Dev*
Real GDP	25.97	0.00006	0.053	0.022	0.092	0.033
Real wages	21.21	0.003	0.10	0.03	0.15	0.04
Average labour productivity	−0.02	0.007	0.026	0.009	0.038	0.013
Flights delayed	32.1	5.5	−31.9	2.8	−47.0	2.2
Air passenger output[c]						
Domestic	21.3	0.5	1.7	0.6	2.5	0.9
Business travel	20.6	0.3	1.0	0.3	1.5	0.6
Domestic leisure	15.9	0.7	2.6	0.9	3.9	1.5
Foreign visitors	59.6	0.9	2.2	0.8	3.4	1.3
International	40.8	0.1	0.5	0.2	0.7	0.2
Price of domestic air travel[d]						
From delay	5.7	2.1	−7.2	2.4	−10.7	3.7
Total	36.7	3.0	−8.0	2.7	−11.9	4.1
Domestic leisure travel						
Price	29.5	0.2	−0.5	0.2	−0.8	0.3
Travel	21.4	0.3	1.0	0.3	1.5	0.5
			$ millions (2005)			
Increase in real GDP			8,040.9	3,357.3	14,053.4	5,017.2
Net welfare gain			17,610.7	2,862.2	38,488.4	4,368.8
Equivalent variation			9,800.7	2,862.2	15,058.5	4,368.8
Leisure travel cost			7,810.0	0.0	23,429.9	0.0

Notes:
[a] The percentage change reported for endogenous variables in the forecast simulation are relative to their base values.
[b] The percentage change in the policy simulation relative to the base value can be computed as [(1 + percentage change in forecast/100) × (1 + percentage change relative to forecast/100)−1] × 100. For example, real GDP increases by 26.04 per cent relative to its base value for a 10 per cent reduction in delayed flights: [(1 + 25.97/100) × (1 + 0.053/100)−1] × 100.
[c] Refers to output by US carriers for domestic and international flights.
[d] Because all industries are assumed to be perfectly competitive in the USAGE model, the percentage change in the output price must equal the percentage change in the cost of production in all industries. Thus the percentage change in the price of domestic air travel is equal to the change in airline cost for domestic flights.

grow 28.3 per cent (not shown in Table 4). Because of the faster growth in investment and therefore capital stocks, compared with the growth in labour supply, the increase in the real capital rental rate (8.8 per cent) is smaller than the increase in the real wage rate.

The resulting increase in economic activity and household income (through increased factor payments) results in a 21.3 per cent increase in the output of domestic air passenger services and a 40.8 per cent increase in the output of international air passenger services supplied by domestic air carriers. As a basis of comparison, our forecasted growth in the output of domestic air passenger services is larger than the forecasted 14.6 per cent increase in domestic revenue passenger miles by the FAA (2009) for the 2005 to 2013 period. Some of this difference may be explained by a lower forecasted growth in real US GDP (15.3 per cent) used by the FAA in their projections. However, our forecasted growth in the output of international air passenger services is similar to the FAA forecast of a 37.6 per cent increase in international revenue passenger miles provided by domestic carriers.

The increase in output of domestic air passenger services results in a 32.1 per cent (21.3×1.5 elasticity of delay) increase in passenger delay, from 20 per cent of all flights delayed in 2005 to 26.4 per cent of all flights delayed in 2013. This increase in delay results in a 5.7 per cent increase in airline cost (32.1×0.18 airline cost elasticity). Overall, due to increases in demand for domestic air passenger services, increases in input prices (such as the wage rate) and increased costs from delay, airline costs, and thus the price of air travel, increase by 36.7 per cent between 2005 and 2013. As a basis of comparison, our forecasted increase in the price of air travel is larger than the forecasted 18.1 per cent increase in the nominal revenue per passenger mile for domestic flights by the FAA (2009) for the 2005–13 period. There are several reasons why our forecast is higher. First, our larger forecasted growth in GDP will result in a larger increase in demand for air passenger services and, all else being constant, higher prices. Second, the FAA forecast does not consider the effects of flight delay on airline cost. Finally, the FAA forecast does not include fees, such as baggage fees. Between 2005 and 2009, baggage fees on domestic flights increased from $263 million to $2.32 billion, while cancellation fees increased from $754 million to $1.78 billion (Bureau of Transportation Statistics, 2011). On a percentage basis, these fees accounted for nearly 6 per cent of total passenger revenues in 2009. In our model, the price of air travel includes the air fare and any fees charged by airlines.

The increase in domestic air passenger services can be decomposed into changes in business travel, domestic leisure travel, and domestic travel by foreign visitors. In 2005, business travel accounted for 58 per cent of total revenue for domestic air passenger services, while domestic leisure travel accounted for 36 per cent and domestic travel by foreign visitors accounted for 6 per cent.[7] The largest increase in the use of domestic air passenger services is by foreign visitors. This reflects a historical increase in tourism by foreign visitors during the 1998–2004 period that is projected to continue during the 2005–13 period. While domestic leisure travel increases by 21.4 per cent, leisure travel by air increases by 15.9 per cent. This occurs because the price of domestic air travel increases by more than the price of domestic leisure travel, due to higher airline costs from delay, leading to a substitution away from expenditures on air travel to other travel modes and expenditures on other leisure goods. The higher cost of domestic air travel also dampens the increase in business travel, as firms substitute away from air travel to other intermediate inputs. Overall, business travel increases by 20.6 per cent in the forecast simulation.

3.2 Policy simulation

A reduction in flight delay has two economic effects. First, a reduction in delay will lead to a reduction in airline costs. Because of the assumption of perfect competition, this will

[7] This larger quantity share for business travel is likely due to higher fares.

also lead to a reduction in the price of air travel as well as the price of a domestic vacation for both domestic and foreign visitors, leading to an increase in domestic leisure travel. An increase in domestic leisure travel will also increase the demand for tourism related industries, such as hotels, restaurants, entertainment, and other forms of transportation such as car rentals. The decrease in price of air travel will also reduce the cost of business travel, leading to a reduction in firm costs and prices.[8]

The second effect is an increase in labour productivity from a reduction in the number of unproductive hours lost to delay. This increase in productivity will itself have three economic effects. First, it will reduce the demand for labour at constant prices because firms can produce the same level of output with less labour. Second, because labour is more productive, it becomes relatively less expensive to employ than capital. This will encourage firms to substitute labour for capital. Third, the increase in productivity will lead to lower firm costs and price. This reduction in price will lead to an increase in demand for the firm's product, thereby encouraging an increase in firm output and increasing the demand for labour. As shown in Table 4, the last two effects dominate the first, resulting in an increase in the demand for labour and an increase in real wages in the policy simulation compared to the forecast simulation.

One outstanding question is: to what extent can flight delays be reduced from improvements in aviation infrastructure or other measures, such as congestion pricing? Some flight delay will persist for reasons other than congestion, such as weather. In a March 2011 report on the implementation of the Next Generation Air Transportation System (NEXTGEN) programme, the FAA projects that improvements in air traffic management could reduce delays by 30 to 35 per cent (FAA, 2011), compared with making no improvements. When applied to the 32.1 per cent increase in flight delay in our forecast simulation, this corresponds to a 7.5–14.1 per cent reduction in the base level of delay. Based on this estimate, we use a 10 per cent reduction in the base level of delay in the policy simulation. Because this represents only one possible method to reduce flight delay, we also consider a scenario where the base level of delay is reduced by 30 per cent to represent the possibility of simultaneously implementing additional measures to reduce delay, such as congestion pricing.

In each scenario, the 'target' of reduction in the 2005 percentage of flights delayed is achieved by shocking the exogenous variable *policy* in equation (1). To focus the discussion, the 10 per cent delay reduction scenario is presented first, followed by a comparison with the 30 per cent reduction scenario. In this first scenario, the level of delay decreases to 18 per cent of all flights being delayed. This corresponds to a 31.9 per cent reduction in delayed flights compared to the forecast simulation (see third column in Table 4). This reduction in delayed flights leads to a 7.2 per cent reduction in airline prices and accounts for 90 per cent of the reduction in the price of air travel. A 30 per cent reduction in delayed flights would reduce airline costs by an additional 3.5 percentage points (to 10.7 per cent) and the price of domestic air travel would decrease by an additional 3.9 percentage points (see fifth column in Table 4).

[8]A decrease in flight delay may also reduce expenditures on food, beverages, magazines, and so on at airports. We do not include this effect in our model due to a lack of data.

The reduction in the price of domestic air travel leads to larger increases in business and leisure travel compared with the forecast simulation. For a 10 per cent reduction in delayed flights, the price of domestic leisure travel for domestic residents decreases by 0.5 per cent, which leads to a 1.0 per cent increase in domestic leisure travel. Because the cost of air travel decreases relative to other travel modes or leisure-related goods, domestic leisure air travel increases by 2.6 per cent. Similarly, the decrease in the price of domestic air travel reduces the cost of leisure travel for foreign visitors. Since domestic air travel comprises a smaller share of the total cost of domestic leisure travel for foreign visitors compared to domestic residents, there is a smaller increase in domestic leisure travel by foreign visitors and only a 2.2 per cent increase in domestic air travel by foreign visitors. Finally, because of smaller substitution possibilities between travel modes, business travel experiences the smallest increase (1.0 per cent). Overall, domestic air travel increases by 1.7 per cent. For a 30 per cent reduction in delayed flights, total domestic air travel would increase by another 0.8 percentage points. Domestic leisure travel by air would increase by 1.3 percentage points, domestic air travel by foreign visitors would increase by 1.2 percentage points, and business travel would increase by 0.5 percentage points.

The macroeconomic effects of a reduction in flight delay arise from a reduction in the cost of domestic air travel and an increase in domestic labour productivity. Note that in the forecast simulation, average labour productivity decreases by 0.02 per cent due to the increase in percentage of delayed flights. Reducing the number of delayed flights leads to an increase in labour productivity. Both the cost reduction and increase in labour productivity generates a larger growth in real GDP between 2005 and 2013. A 10 per cent and 30 per cent reduction in delayed flights increases real GDP growth by 0.053 per cent and 0.092 per cent, respectively. Based on the 2005 US GDP of $12,073.4 billion, this translates into an $8.0 billion and $14.1 billion increase in real US GDP. If this increase in real GDP were to occur evenly across the 2005–13 time period, it would imply an annual increase of $1.0 billion and $1.76 billion, respectively.

The net welfare gain from a reduction in flight delay is comprised of two components: equivalent variation (EV) and an opportunity cost of delay for leisure travellers. A 10 per cent reduction in delayed flights leads to a $9.8 billion increase in EV. A 30 per cent reduction in flight delay would lead to a $15.1 billion increase in EV. To determine the relative importance of the reduction in airline costs compared to the gain in labour productivity, the model is resolved assuming that a reduction in flight delay does not impact the labour productivity of business travellers. Thus, all of the gain in EV for these simulations may be attributed to a reduction in the cost of domestic air travel. On average, the reduction in airline costs accounted for 70 per cent of the gain in EV.

Because leisure is not explicitly included in the USAGE model, the EV measure does not account for the opportunity cost of flight delay for domestic leisure travellers. To overcome this limitation, an estimate of this opportunity cost is imputed by determining the number of hours of delay experienced by leisure travellers and then multiplying by a time-value. Using one minus the share of trips that are work-related in the 2009 National Household Travel Survey, times the 468.1 million hours of delay annually from Table 3, times the percentage reduction in delayed flights, yields the annual reduction in the hours of delay experienced by leisure travellers. A 10 per cent and 30 per cent reduction in delayed flights reduces the hours of delay for leisure travel by 36.9 million and 110.8

million hours, respectively. The opportunity cost of delay for leisure travel is assumed to equal $26.43/hour, which is the value of personal air travel in 2000 (US Department of Transportation, 2003), adjusted for inflation to the 2005 base year.[9] Multiplying the reduction in the number of hours of delay by this time value yields a $976 million and $2.93 billion value of the annual reduction in the hours of delay experienced by leisure travellers. Since this benefit would accrue each year of the 2005–13 time period in the USAGE simulation, this annual benefit is multiplied by eight to obtain the total benefit of the reduction in the hours of delay for leisure travellers of $7.81 billion and $23.43 billion, respectively.

The net welfare gain for a reduction in delayed flights is the sum of the increase in EV and the reduction in the opportunity cost for leisure travellers. For a 10 per cent reduction in flight delay, net welfare increases by $17.61 billion, while a 30 per cent reduction in flight delay increases net welfare by $38.49 billion.

One limitation of the USAGE model is that there is a single, constant elasticity of substitution between all intermediate inputs. Thus, a reduction in the cost of air travel will lead to an increase in the demand for air travel relative to all travel-related inputs (such as hotels), not just alternative transportation modes. If the elasticity of substitution among transportation alternatives is larger than the elasticity of substitution between transportation and other travel-related inputs, then the model will underestimated the increase in demand for air travel from a reduction in airline costs and therefore underestimate EV and the net welfare change.

3.3 Sensitivity analysis

Because of uncertainty about the values of the parameters in the logistic flight delay functions in equations (1) to (4), a sensitivity analysis is performed for the elasticity of delay with respect to air passenger output, the airline cost elasticity, and the average percentage change in labour productivity using symmetric order three Gaussian quadratures. This procedure assumes that each uncertain parameter has an independent uniform distribution with known (or estimated) endpoints. A sample of parameters is drawn from these distributions and the model is resolved using each set of parameter values.[10] Table 3 lists the minimum and maximum values for the parameters *DADJ*, *A*, and *B* that are used in the sensitivity analysis.

By resolving the model using the alternative sets of delay parameters, the standard deviation for each endogenous variable can be computed. The model results are most sensitive to elasticity of delay with respect to air passenger output and the airline cost elasticity. The standard deviations for most variables in the policy simulations are about one-third of their simulation value. The standard deviation for the increase in GDP ranges from $3.36 billion to $5.02 billion. The standard deviation for EV is slightly lower, ranging from $2.86 billion to $4.37 billion. Note that because all simulations

[9]This value of time is approximately equal to 70 per cent of the wage rate.

[10]Stroud (1957) has shown that for a symmetric distribution, such as the uniform or triangular, the model needs to be resolved only $2n$ times, where n is the number of exogenous variables or parameters, in order to conduct a systematic sensitivity analysis. Arndt and Hertel (1997) have shown that systematic sensitivity analyses conducted using order three quadratures are as accurate as higher-order quadratures.

achieve either a 10 per cent or 30 per cent reduction in delayed flights, the opportunity cost of delay to leisure travellers is constant.

4.0 Summary and Conclusions

Increases in the number of airline flights have led to problems with congestion at peak hours of operations in many airports, leading to widespread flight delays. Between 2002 and 2007, the number of flights with arrival delays of at least 15 minutes more than doubled as the total number of flights increased by 40 per cent. With forecasts of large increases in flight operations between 2010 and 2025 by the FAA, the prospect of even higher levels of flight delay is likely if no actions are taken, which has generated several proposals to solve this problem.

The first set of proposals focus on investments in aviation infrastructure. One option would be to build additional runway capacity at delay-prone airports. Since space may not be available at all delay-prone airports, a second option would be to improve existing air traffic management systems. Improvements in communication, surveillance, navigation, and air traffic control could increase airport capacity and therefore possibly alleviate congestion, leading to a reduction in delayed flights. However, infrastructure investments are costly. For example, the infrastructure for FAA NEXTGEN programme has been estimated to cost between \$15 and \$22 billion between 2005 and 2025 (GAO, 2008). This study provides policy makers with estimates of the benefits of reducing flight delay that can be used when evaluating alternative infrastructure investments. Even for modest reductions in flight delay, the economic benefits are substantial. A 10 per cent reduction in delayed flights increases net US welfare by \$17.6 billion, while a more ambitious 30 per cent reduction increases net welfare by \$38.5 billion.

A third option available to policy makers is congestion pricing, which would impose fees on aircraft operators or travellers to reduce the demand for air travel during peak periods of demand. The effectiveness of this option in reducing flight delay will depend on the willingness of travellers to consider off-peak flights. If the demand for flights during peak times is relatively inelastic, due to travellers' time preferences, then fees to reduce congestion at peak hours could be relatively large. For example, Ball *et al.* (2007) found that congestion pricing could be as high as \$1,200 per flight at New York's LaGuardia airport. Thus, the congestion fee would offset a significant portion of the reduction in airline operating costs from a reduction in delayed flights. In addition, measuring the economic impact of congestion pricing is difficult because congestion fees will vary across airports and time periods, and the economic benefits will depend on how the congestion fees are used. For example, congestion fees could be used to offset other aviation fees or to construct additional aviation infrastructure. At this point, there is no clear consensus on how these fees would be used.

References

Air Transport Association (2009): *Annual and Per-Minute cost of Delays to U.S. Airlines.* Available online at http://www.airlines.org/Pages/Annual-and-Per-Minute-Cost-of-Delays-to-U.S.-Airlines.aspx

Arndt, C. and T. W. Hertel (1997): 'Revisiting the fallacy of free trade', *Review of International Economics*, 5(2), 221–9.

Ball, M. O., L. M. Ausubel, F. Berardino, P. Cramton, G. Donohue, M. Hansen, and K. Hoffman (2007): 'Market-based alternatives for managing congestion at New York's LaGuardia Airport', in *Optimal Use of Scarce Airport Capacity*, Proceedings of AirNeth Annual Conference, The Hague, April 2007. Available on-line at http://www.cramton.umd.edu/papers2005-2009/ball-et-al-managing-congestion-at-laguardia.pdf

Bureau of Economic Analysis (2009): Travel and Tourism Satellite Accounts, 2007. Available on-line at http://www.bea.gov/industry/tourism_data.htm

Bureau of Labor Statistics (2009): Current Employment Statistics. Available on-line at http://www.bls.gov/ces/data.htm

Bureau of Transportation Statistics (2009): On-time performance. Available on-line at http://www.transtats.bts.gov/HomeDrillChart.asp

Bureau of Transportation Statistics (2011): Air Carrier Financial Schedule P-1.2. Available on-line at http://www.transtats.bts.gov/DataIndex.asp

Dixon, P. B. and M. T. Rimmer (2002): *Dynamic General Equilibrium Modelling for Forecasting and Policy: A Practical Guide and Documentation of MONASH*. Amsterdam: Elsevier.

Federal Aviation Administration (2009): *FAA Aerospace Forecast: Fiscal Years 2009–2025*. Available on-line at http://www.faa.gov/data_research/aviation/aerospace_forecasts/2009-2025

Government Accountability Office (GAO) (2008): 'Next generation air transportation system: status of systems acquisition and the transition to the next generation air transportation system', report prepared for the Congressional Requesters. Available on-line at http://www.aci-na.org/static/entransit/gao_nextgen_9-10-08.pdf

Hanslow, K. J. (2000): 'A general welfare decomposition for CGE models', Global Trade Analysis Project (GTAP) Technical Paper No. 19, Department of Agricultural Economics, Purdue University. Available on-line at http://www.gtap.agecon.purdue.edu/default.asp

Joint Economic Committee (JEC) (2008): 'Your flight has been delayed again: flight delays cost passengers, airlines, and the US economy billions'. Available on-line at: http://www.jec.senate.gov/index.cfm?FuseAction=Reports.Reports&ContentRecord_id=11116dd7-973c-61e2-4874-a6a18790a81b&Region_id=&Issue_id

National Center of Excellence for Aviation Operations Research (NEXTOR) (2010): 'Total delay impact study: a comprehensive assessment of the costs of impacts of flight delay in the United States'. Available on-line at http://www.isr.umd.edu/NEXTOR

Stroud, A. H. (1957): 'Remarks on the disposition of points in numerical integration formulas', *Mathematical Tables and Other Aids to Computing*, 11(60), 257–61.

US International Trade Commission (2009): *Effects of significant U.S. import restraints, sixth update 2009, Publication 4094*. Washington DC, August 2009. Available on-line at http://www.usitc.gov/publications/332/pub4094.pdf

US Department of Transportation, Federal Highway Administration (2003). 'Revised departmental guidance: value of travel time in economic analysis'. Available on-line at http://www.regs.dot.gov/docs/VOT_Guidance_Revision_1.pdf

US Department of Transportation, Federal Highway Administration (2009). National Household Travel Survey. Available on-line at http://www.nhts.ornl.gov