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The effect of FAA expenditures on air travel delays

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Abstract

The Federal Aviation Administration (FAA) seeks to prevent the nation's aviation system from becoming congested. To reduce delays, the FAA makes investments in air traffic control. We assess the efficacy of these investments by developing an empirical model of delays that is motivated by air traffic control operations. We find that FAA spending has reduced the costs of delays to travelers and operators but that the FAA could generate greater benefits if spending were increased and efficiently allocated toward airports that experience the greatest delays.

Keywords: Air transportation; Congestion; Airport delays

1. Introduction

Forecasts of airline travel in the United States by the Federal Aviation Administration (FAA) primarily rely on changes in two variables: income and population. As long as these variables grow, air travel is expected to grow. Indeed, the FAA projects more than 1 billion passengers will take to the skies by 2015. Of course, more airline travel creates more congestion at airports and more delays for air travelers, resulting in ever greater social costs.

Economists' proposed solution to the problem—charging aircraft peak-period congestion tolls—has been thoroughly studied. Both its economic effects on travelers, commercial carriers, general aviation, and airport authorities (e.g., Morrison and Winston, 1989; Daniel, 2001) and on the pattern of airport traffic (Daniel, 1995; Daniel and Pahwa, 2000) have been quantified. Research has also determined optimal congestion charges at airports that are dominated hubs (Brueckner, 2002; Mayer and Sinai, 2003; and Morrison and Winston, in press), at airports subject to oligopolistic competition (Pels and Verhoef, 2004), and at airports that earn rents from concessions in terminals and on airport land (Zhang and Zhang, 2003). Finally, although in practice investments in runways are very costly and time consuming because of regulatory hurdles, studies have assessed their social benefits (Morrison and Winston, 1989) and optimal level under alternative airport ownership and airline market structures (Zhang and Zhang, 2006).[1]

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[1] Airports seeking to build a new runway must satisfy Environmental Protection Agency environmental impact standards and account for communities' input, especially their opposition. This process can prevent a runway from being built or indefinitely delay it.

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Unfortunately, the FAA has shown little interest in using the price mechanism to reduce delays and has done little to help airports make (efficient) investments in runway capacity; thus, its investments in air traffic control constitute its primary approach toward reducing delays. Surprisingly, little effort has been made to assess the efficacy of FAA's expenditures. We do so here by developing an empirical model of delays that is motivated by air traffic control operations and by estimating the effect of FAA spending on travel delays. We find that current FAA spending has reduced the costs of delays to air travelers and operators. But we also find that FAA spending would provide greater benefits to travelers and operators if it were increased and optimally allocated toward airports that experience the greatest delays. The FAA could produce additional benefits by implementing new technologies that expand runway and airspace capacity in a more timely fashion. Given the expected growth in air travel, it is incumbent on the FAA to make efficient use of its preferred mechanism—public spending—to reduce delays. Its failure to do so will compound the inefficiencies that it has allowed to go unabated by not advancing efficient runway pricing and investment.

2. An empirical framework for assessing the effect of FAA expenditures on delays

In the transportation literature, air travel delays for a cross section of airports would typically be specified as a function of the ratio of (average) peak-period air traffic volume and runway capacity and other airport characteristics. However, delays at a given airport may also be affected by the effectiveness of the air traffic control system in monitoring operations that take off and land at or traverse the airspace of a given airport. Thus, we briefly describe how the system works and then specify a model of air travel delays.

The US air traffic control system divides the 3.5 million square miles of domestic airspace into aerial highways over which most airplanes are dispatched single file. The FAA's en route and terminal facilities seek both to ensure that air travel is safe and to prevent the system from becoming congested. En route facilities include Air Route Traffic Control Centers (ARTCCs) that provide air traffic control service to aircraft operating under instrument flight rules within controlled airspace.[2] Terminal facilities include radar towers at airports and terminal radar approach facilities (TRACONs) within a 50-mile radius of an airport; both provide service to aircraft that are arriving, departing, and transiting the controlled airspace. Takeoffs and landings are called operations; aircraft that fly through a given airport's airspace but land at a different airport are called overflights. The largest airports tend to have both a radar tower and a TRACON on site; medium-sized airports tend to have one or the other on site; some of the smallest airports have neither on site, in which case they may be served by a TRACON at the closest airport.[3] Flights that take off and land at such airports are called seconds. Currently, the FAA system includes 150 radar towers, 35 TRACONs, and 21 ARTCCs.

The FAA is responsible for hiring air traffic controllers and other air traffic control personnel and for supplying terminal and en route facilities with new equipment. Discussions with current and former FAA officials indicated that capital and labor are allocated at airports in accordance with "rules of thumb" that are roughly determined by the level of traffic that a controller can safely manage. Personnel and equipment are added to those parts of the system where traffic levels exceed a threshold, but as we discuss in more detail later the additions take time. Airlines, airports, trade associations, and members of Congress also influence how the FAA allocates its funds.

Air travel is delayed when an aircraft's actual, as opposed to scheduled, travel time (including both time on the ground and time in the air) exceeds its unimpeded travel time. According to the FAA, some 70 percent of delays are caused by weather that severely impairs visibility, 15–20 percent by traffic volume (i.e., operations, overflights, and seconds) that exceeds available airport capacity and airspace, and about 10 percent by miscellaneous problems such as air traffic control equipment malfunctions and runway closures. Airlines dispute this breakdown and argue that the FAA blames most delays on weather to avoid facing its shortcomings in management, staffing, procurement, and technology.[4]

Delays may also be influenced by airport characteristics. Travelers are likely to experience greater delay at airports with pronounced peak periods of traffic during the day. These airports are often, but not always, hubs. Travelers may also experience less delay on the ground at airports with a greater number of gates, if air-

[2] ARTCCs may also assist with aircraft flying under visual flight rules.

[3] In addition, some airports have limited radar, non-radar, and visual flight rules towers.

[4] *Frequent Flyer*, "The Delay Dilemma: Can the Air Traffic System be Fixed?" April 2000.

lines leave some of these gates unscheduled so they can promptly handle early or late arriving flights.[5]

Finally, it may be argued that delays are affected by airport concentration to the extent that the delay that airlines cause themselves is internalized. However, the internalization debate initiated by Brueckner (2002); and Mayer and Sinai (2003) is not relevant here because we are interested in *total* delay, which may be affected by FAA expenditures. A proper test of the internalization hypothesis would specify the delay that carriers impose on themselves as the dependent variable.[6]

Based on the preceding considerations, a plausible econometric specification of air carrier delay at an airport is given by:

$$\begin{aligned} Delay = exp(&\beta_1 * weather + \beta_2 * volume/capacity \\ &+ \beta_3 * overflights + \beta_4 * seconds \\ &+ \beta_5 * FAA\ expenditures + \beta_6 * peaking \\ &+ \beta_7 * gates + u), \end{aligned} \tag{1}$$

where the βs are estimable parameters and u is an error term. This specification of the delay function has the desirable properties of being homogeneous of degree zero in traffic volume (operations) and runway capacity, with marginal delay an increasing function of all airport activity (operations, overflights, and seconds) and a decreasing function of airport capacity.[7] A constant is not included in the specification because delay should be small (zero) when airport activity is zero.

3. Sample and variables

We estimate the preceding model using a sample consisting of 78 US airports that account for 67 percent of all domestic air carrier operations during FAA's fiscal year 2000 (October 1999–September 2000). We use this basic unit of observation because we are primarily interested in how airport delays are affected by FAA expenditures on terminal facilities that serve airports.[8] We chose the year 2000 as our period of analysis because we were able to obtain FAA expenditure data for that fiscal year only (see below). We also wish to avoid the tumultuous period in air travel that followed September 11.

The dependent variable in our analysis is the average air carrier delay during fiscal year 2000 at each airport experienced by passengers of commercial and commuter airlines. We initially estimated separate models for arrival and departure delay, but decomposing delay in this fashion did not lead to any notable changes in our findings. Average delays are calculated from individual flights and include gate delay, taxi-out delay, airborne delay, and taxi-in delay.[9] Airborne delay is the difference between the actual (airborne) flight time and the time in the flight plan that an air carrier filed with the FAA. Note that the flight plan accounts for forecasted winds aloft en-route. Gate delay is the difference between the actual gate departure time and the scheduled departure time. The two taxi delay components are the difference between actual taxi time and FAA's estimate (by airport, carrier, and season) of unimpeded taxi times. Unlike published schedules, the flight plan and unimpeded taxi time components do not have any delay built in to them. During 2000, the average total delay for airports in our sample was 3.69 minutes per operation (i.e., takeoff or landing); the greatest average delay per operation, 9.44 minutes, was at Philadelphia; the smallest delay, 1.29 minutes, was at Lubbock. Because a flight includes two operations (takeoff and landing), the average delay per flight in our sample was 7.4 minutes. Finally, it is worth noting that air travel delays tend to be concentrated at the busiest airports. In our sample, 87 percent of total delay (average delay times number of air carrier operations) occurred at the top 30 airports. Average delay at those airports was 5.3 minutes (10.6 minutes per flight); average delay at the other airports

[5] It may also be argued that airport delays are affected by slot controls that are in effect at Chicago O'Hare, Washington Reagan National, and New York Kennedy and La Guardia airports. However, the effects of slot controls should be reflected in (reduced) airport operations; thus, the slot control dummy variables should not add any explanatory power given that airport operations are included in the model.

[6] We also point out that we found in exploratory estimations that alternative measures of concentration tended to be statistically insignificant or have a small effect on delays and that excluding the concentration variable had little effect on the other parameters. The reason is that concentrated airports tend to be hubs, which as noted have pronounced peaking characteristics. Thus, by controlling for peaking we are capturing a significant part of concentration. Based on their theoretical analysis, Zhang and Zhang (2006) suggest that concentration would have little impact on congestion if airports were not engaging in profit maximizing behavior.

[7] It is also appropriate to specify delay as an (increasing) function of weather and peaking and a (decreasing) function of FAA expenditures.

[8] We initially selected the 104 US airports with the most air carrier operations, but we had to reduce our sample because complete FAA expenditure data were available for 78 of these airports. FAA expenditure data were generally missing for the least congested airports in the original sample; thus, it is not likely that our final sample is misrepresentative of air travel activity that contributes to delays.

[9] These data are from the FAA's CODAS (Consolidated Operations and Delay Analysis System) database (FAA, 1997).

in our sample averaged 2.69 minutes (5.38 minutes per flight).

Although airlines are knowledgeable about the typical weather at an airport during a given time of year and set their schedules accordingly, they must still cancel or delay flights if weather conditions on a particular day result in a low ceiling or create poor visibility. We control for adverse weather by using hourly weather and traffic data in the FAA's CODAS data base to calculate for each airport the percentage of total air carrier operations under instrument flight rules conditions (that is, operations that took place when the cloud ceiling was less than 1000 feet or visibility was less than three miles). Either meteorological condition will increase total flight time by causing air traffic controllers to increase aircraft separation en route and within airspace around the airport.

A simple way to measure the volume–capacity ratio at an airport is to divide carrier operations by the number of runways. We sum air carrier operations per air carrier runway and general aviation and air taxi operations per (total) runway. An air carrier runway is defined as a runway at least 5000 feet long and 150 feet wide. Total runways are defined as the number of runways at least 2500 feet long and 60 feet wide. Operations and runways are obtained from the FAA.[10] A more accurate measure would recognize that the configuration of an airport's runways may be as important to its level of capacity as its number of runways. For example, an airport with three parallel runways may have greater capacity and, all else constant, less delay than an airport with four runways that intersect. As an alternative measure of the volume-capacity ratio, we therefore use the actual number of aircraft operations at a given airport divided by the FAA's estimate of the airport's maximum feasible operations given runway configuration and actual meteorological conditions during the year.[11] Data for this variable were available from the FAA for 49 of the 78 airports in our sample.[12] Thus, we perform estimations using the simple measure of volume-capacity for all airports in our sample, the measure based on FAA's estimate of capacity for 49 airports in our sample, and a measure where we use FAA's estimate of capacity to predict capacity for the 78 airports in our sample.

Overflights are the number of aircraft that are under the control of the tower or TRACON at the airport but that do not land at that airport. Seconds are the number of aircraft that take off and land at airports that are under the control of a TRACON that is not located at these airports. Both types of aircraft activity could increase airport delays. Data for these variables were obtained from the FAA web site http://www.api.faa.gov.

The technological relationship between capital and labor at air traffic control facilities is appropriately characterized by fixed-factor proportions (i.e., machines require a certain number of people to operate them); thus, we did not specify separate variables for FAA capital and labor expenditures. We constructed annual FAA expenditures as the sum of labor expenses during the year at each airport's tower and TRACON and, to account for interest and depreciation, 5 percent of the tower and TRACON's capital stock (estimated by the FAA) at the end of the year.[13] We expect that an increase in FAA expenditures will reduce travel delays by improving the quality of air traffic control. It is unlikely that an increase in expenditures would result in additional operations that increase average delays.[14]

As indicated by our earlier discussion, it is reasonable to treat FAA expenditures as exogenous in a model of airport delay because such expenditures are broadly influenced by air traffic controllers' safety considera-

[10] Operations data are from FAA web sites http://www.api.faa.gov and http://www.apo.data.faa.gov. Runways and their dimensions are provided by the FAA's National Flight Data Center.

[11] These data are from the FAA's Aviation System Performance Metrics (ASPM) database.

[12] FAA's estimates of an airport's maximum feasible operations given runway configuration and meteorological conditions were available for 39 airports in 2000 and an additional 10 airports in 2006. We found that including the 2006 data for airports where 2000 data were not available improved the precision of our estimates but did not have much affect on the parameter estimates.

[13] Strictly speaking we are measuring FAA costs rather than expenditures, but we shall maintain our terminology for the remainder of the paper. We obtained data on FAA expenditures at towers and TRACONs as part of a special data collection effort by the FAA. With our guidance, the FAA Office of Financial Services collected information on expenditures at towers and TRACONs that affected travel delays. No assumptions were made about allocating a TRACON's expenditures to the various airports that use it. The Office of Management and Budget uses a social discount rate of 7 percent. Assuming a depreciation rate of 3 percent yields an estimate of 10 percent to determine FAA's cost of capital. FAA officials, however, thought that figure was too high and indicated that 5 percent was a more reasonable value. We explored the sensitivity of our findings within a range of 3 to 10 percent and found that our parameter estimates were not materially affected by alternative assumptions; thus, we use 5 percent for the estimations reported here.

[14] FAA expenditures on air traffic control do not include spending on runway capacity; thus, it is not appropriate to test whether the FAA expenditures coefficient would be affected if we allowed the volume–capacity ratio to vary by omitting it from the model. When we examined how the FAA expenditures coefficient would be affected if we allowed only volume (airport operations) to vary, the bias from omitting this critical variable strongly contaminated the estimates of all the coefficients in the model.

tions, not by congestion at a particular airport. To be sure, the FAA's stated goals on their website include increasing airspace capacity in major metropolitan regions that most affect system delay. However, in practice, the FAA's ability to respond to greater traffic is severely constrained by the time it takes to procure equipment and certify new controllers. Indeed, in 2006 the FAA had roughly 1000 fewer controllers than it had in 2003 while air traffic has steadily grown. Towers and radar facilities in California, Chicago, New York, Dallas, and other high volume locations are moving planes with as few as 60 percent of the number of controllers that the FAA and National Air Traffic Controllers Association agreed constituted full staffing in 2003.[15]

We measure airport peaking characteristics by calculating the standard deviation of air carrier operations based on hourly arrival and departure counts during the year. We also experimented with measuring peaking by the percentage of flights in the upper percentiles of hourly time slots and the difference between, say, the 80th percentile and 50th percentile arrival and departure counts, but the alternative measures did not lead to any material changes in our findings. Finally, data on gates are not available at all airports. However, we were able to obtain data on gates at 41 large and mid-size airports from a survey conducted by the *Air Transport Association.* We specified gates for airports that serve as a hub for at least one carrier because additional gates are likely to have the greatest impact on reducing delays at such airports.

4. Empirical findings

We found in preliminary estimations that seconds and airport gates had small and statistically insignificant effects on average delay and that their exclusion did not affect the other parameters in the model; thus, we did not include these variables in our final estimation.[16] Table 1 presents parameter estimates for the determinants of delay for three specifications that differ in their measurement of airport capacity.

The first specification uses a simple measure of airport capacity, number of runways, and forms the variable operations per runway. The second measures an airport's capacity with FAA's estimate of an airport's maximum feasible operations given its runway configuration and actual meteorological conditions during the year and forms the variable actual operations divided by maximum feasible operations. Estimation is performed for the 49 airports for which this variable is available. The third specification uses a predicted value of an airport's maximum feasible operations given its runway configuration and actual meteorological conditions to form the variable actual operations divided by maximum feasible operations. The predicted variable is obtained by running a linear regression (with a constant) of an airport's maximum feasible operations on the number of air carrier runways interacted with the percent of operations during instrument meteorological conditions, the number of air carrier runways interacted with the percent of operations during visual meteorological conditions, air carrier operations, air taxi operations, and general aviation operations for the airports that report their maximum feasible operations. We then use the estimated regression to predict maximum feasible operations for the 78 airports in our sample given their operations, number of runways, and meteorological conditions.

For all the specifications, we find that airports with greater peaking in their traffic experience longer delays. Given Morrison and Winston (in press) find that a modest amount of delay is internalized at US airports, this finding illustrates the importance of congestion pricing, which would smooth the traffic flow throughout the day by setting higher takeoff and landing charges for aircraft that operate during peak periods. We also find that adverse weather and overflights have positive and statistically significant effects on average delay, although the coefficient for adverse weather falls in the second and third specifications because their measure of capacity partly controls for this effect.

In the first specification operations per runway has a positive significant effect on average delays while annual FAA expenditures have a negative marginally significant effect.[17] The second and third specifications in-

[15] James R. Carroll and Nicole Gaudiano, "Fewer Air Controllers Could Lead to More Mistakes, Union Says," *USA Today*, December 17, 2006.

[16] We attempted to control for congestion caused by interactions among nearby airports by using a dummy variable that indicated whether an airport was located in a metropolitan area served by multiple airports (e.g., Washington, DC is served by Reagan National and Dulles airports). But we found that this variable was statistically insignificant. We also did not find that FAA expenditures at a given airport affected delays at other airports.

[17] Based on a one-tailed test, the coefficient for FAA expenditures approaches the 5 percent significance level. A one-tailed test is appropriate because as noted it is highly unlikely that annual FAA expenditures at airports would bear a positive relationship to average delay. In addition to the specification of FAA expenditures shown in Model 1 of Table 1, we estimated a model that explicitly captured its contribution to capacity by forming the volume–capacity variable

Table 1
Coefficient estimates of the determinants of delay at airports in 2000

Explanatory variable	Coefficient*		
	Model 1	Model 2	Model 3
Peaking at the airport: standard deviation of air carrier operations	0.017 (0.004)	0.024 (0.002)	0.018 (0.004)
Weather: percentage of air carrier operations at the airport when the ceiling was less than 1000 feet or the visibility was less than three miles	6.609 (0.780)	4.359 (1.041)	4.389 (0.881)
Overflights: the number of aircraft that are under the control of the tower or TRACON but that do not land at the airport	$1.49E-6$ $(6.11E-7)$	$1.31E-6$ $(4.93E-7)$	$1.21E-6$ $(4.25E-7)$
Volume/Capacity: Operations per runway	$5.11E-6$ $(1.02E-6)$		
Volume/Capacity: Operations divided by maximum feasible operations**		1.487 (0.179)	2.020 (0.340)
Expenditures: FAA annual capital and labor expenditures at the airport's tower and TRACON	$-4.33E-9$ $(2.71E-9)$	$-5.84E-9$ $(1.42E-9)$	$-5.89E-9$ $(2.58E-9)$
Number of observations	78	49	78
R-squared	0.438	0.621	0.628

Dependent variable: ln average delay (minutes).
* White heteroskedasticity-consistent standard errors in parentheses.
** Model 2 specifies actual maximum feasible operations for each airport. Model 3 specifies predicted maximum feasible operations for each airport.

dicate that the precision of the estimated coefficient of FAA expenditures improves when we use a more accurate measure of airport capacity. We find in both specifications that aircraft operations divided by maximum feasible operations has a positive and significant effect on average delays and that FAA expenditures have a negative and significant effect. Because it uses all the airports in our sample, makes use of our preferred measure of airport capacity, and has a statistically significant coefficient for FAA expenditures, we use the third specification as our base case model in the simulations and use the first and second specifications for sensitivity analysis.

We argued that it was reasonable to treat FAA expenditures as exogenous in a model of airport delays. We tested this assumption with a Hausman specification test where our instruments were ten distinct categories of per-capita state-level federal highway expenditures in 2000. Given that state-level highway and airport expenditures are allocated to a certain extent by formulas that implicitly account for a state's population among other characteristics, it is reasonable to expect that these expenditures would be correlated. At the same time, it is highly unlikely that state highway expenditures have a measurable effect on air travel delays. We found for all the specifications that we could not reject the null hypothesis that FAA expenditures are exogenous at high levels of confidence.

as: Operations/(Runways + β FAA Expenditures), where β is an estimable parameter. But we found that the nonlinear model did not fit the data as well as the semilogarithmic model.

Effect of Current FAA Expenditures. We first use the base case delay equation (the third specification) to calculate the average effect that FAA expenditures of $0.86 billion in the year 2000 at towers and TRACONs have on the cost of delays to travelers and aircraft operators.[18] To do so, we predict travel delays at each of our sample airports with current FAA expenditures and multiply the predicted delays (in minutes) by the cost that each airport user (commercial carrier, commuter, and general aviation) attaches to a minute of delay times the annual volume of users in each category. We then predict travel delays at each of our sample airports without current FAA expenditures and perform the same multiplications to estimate the annual savings in delay costs that are attributable to FAA expenditures. Finally, the sample estimate is inflated to a national estimate and divided by $0.86 billion.

The cost of delaying a flight is composed of aircraft operating costs and the value of passengers' time costs. Pilot costs are included in data on aircraft operating costs but flight attendant costs are not included. Aircraft operating costs and flight attendant costs depend on the type and size of aircraft. At each airport, we model the "average" flight; that is, we use the average number of

[18] Annual FAA expenditures at towers and TRACONs based on our sample are $0.64 billion. To obtain a national estimate of annual expenditures, we assume that expenditures are proportional to operations and inflate this figure by 1.34, which is the ratio of total air carrier operations in 104 airports (accounting for nearly all carrier operations in the United States) to the total air carrier operations in our sample of 78 airports.

seats and passengers per flight that actually operated to and from a given airport in 2000. These averages were obtained from data contained in the US Department of Transportation's Data Banks 28DS, Domestic Segment data and 28-IS, International Segment data.

Given that we are modeling the average flight at each airport, we need to express aircraft operating costs as a function of aircraft size (seats). Thus, we estimated average aircraft operating cost using data on aircraft operating cost per block hour for major and national carriers that are contained in the US Department of Transportation's Form 41 (from Data Base Products).[19] Specifically, (the logarithm) of aircraft operating costs per block hour for each aircraft type operated by each airline was regressed on (the logarithm of) each airline's average number of seats for the corresponding aircraft type. With 146 observations (and an R^2 of 0.735), the coefficient of (log) seats [0.8101] has the correct positive sign and is statistically significantly less than one (standard error = 0.0405), reflecting economies of aircraft size (that is, aircraft costs rise less than proportionately with the number of seats). The estimated equation is used to predict average aircraft operating costs for each airport. Using this equation, aircraft operating costs per block hour ranged from $1177 (at South Bend) to $3356 (at Honolulu) with a median of $2439. Flight attendant costs per seat-hour in 2000 were calculated for major carriers using the US Department of Transportation's Form 41 Data Base (from Data Base Products), resulting in a value of $2.52.

The value of passengers' time costs depends on passengers' value of travel time, which varies by trip purpose, and the number of passengers on each flight. For each of the airports in our sample, we used the US Department of Transportation, Bureau of Transportation Statistics, *American Travel Survey, 1995* to calculate the percentage of trips whose purpose was business and the percentage whose purpose was pleasure and the average household income for business and pleasure travelers.[20] Consistent with the US Department of Transportation's (1997) guidelines, we value business travelers' travel time at 100 percent of the wage and pleasure travelers' travel time at 70 percent of the wage. Passengers' average value of time per hour, updated to 2000 dollars, ranged from $27.08 (at Fairbanks) to $72.76 (at Dallas) with a median of $40.16.

The cost of flight delays is obtained by summing average aircraft operating costs per block hour, flight attendant costs per block hour (i.e., costs per seat hour times the average number of seats per flight), and the aggregate value of passengers' average time costs per hour. The estimates, expressed on a per-minute basis, ranged from $35.09 (at South Bend) to $165.82 (at Tampa) with a median of $98.94.

Unfortunately, data do not exist to calculate airport-specific flight costs for general aviation. Data available from the US Department of Transportation Bureau of Transportation Statistics[21] allow the calculation of average operating cost per hour for general aviation aircraft in 2000, $254/hour, and the average number of passengers per aircraft in 1997 (the most recent year with such data), 3.22. Using data in the US Department of Transportation, Bureau of Transportation Statistics, *American Travel Survey, 1995* we estimated the mix of general aviation air travelers whose trip purpose was business and whose trip purpose was pleasure. We also estimated the average income of these travelers. As before, we used the US Department of Transportation's guidelines and valued business travel at 100 percent of the wage and pleasure travel at 70 percent of the wage, which, when updated to 2000 dollars, resulted in a composite value of time of $55.77 per hour. Thus, accounting for aircraft operating costs and the value of passengers' time, the cost of a one-minute delay to general aviation aircraft was estimated to be $7.23.

Based on the preceding estimates of the costs of delay to commercial airlines, commuters, and general aviation and the predictions of delays with and without FAA expenditures, we find that one dollar of current spending reduces the cost of delay to airport users $2.13.[22] By reducing flight times, ATC expenditures are clearly providing a benefit to the traveling public (note, we have not yet accounted for any benefits from ATC in improved safety). This is an important finding giving concerns about the efficacy of FAA expenditures in addressing air travel delays. [23] At the same time, such

[19] A block hour is the standard measure of the duration of an aircraft operation. A block hour begins when the aircraft pushes back from the gate (wheel blocks out) and ends when the aircraft parks at the gate (wheel blocks in).

[20] The calculations were based on the Metropolitan Statistical Area (MSA) where the airport was located. If an airport was not located in an MSA or if the MSA was not identified due to its small size, data were calculated for the state in which the airport was located, which was the case for Fairbanks and Lubbock.

[21] General Aviation Profile available at http://www.bts.gov/publications/national_transportation_statistics/2005/html/table_general_aviation_profile.html.

[22] The estimates based on the first and second specifications of average delay are $1.59 and $2.48.

[23] FAA spending at Air Route Traffic Control Centers (ARTCCs), which handle traffic to and from multiple airports and are important in maintaining an orderly traffic flow, may also provide notable benefits.

concerns motivate interest in whether the benefits from FAA spending could be larger.

Effect of Optimal FAA Expenditures. Congestion varies significantly among US airports, but the allocation of FAA expenditures is not closely aligned with these variations. It is therefore likely that FAA spending would be more effective in reducing the costs of travel delays to airport users if it were explicitly directed toward towers and TRACONs serving the most congested airports. We estimated how much the cost of air travel delays would be reduced if FAA funds were allocated to airports to minimize total airport costs, *TC*, composed of commercial carriers', commuters', and general aviation's delay costs at each airport i in our sample and current annual FAA spending, s_i, at each airport, subject to the current level of FAA spending. Formally, the problem can be expressed as:

$$\begin{aligned} \min TC = \sum_i & v_{ic} * Q_{ic} * Average\ Delay_i(s_i) \\ & + v_{it} * Q_{it} * Average\ Delay_i(s_i) \\ & + v_{ig} * Q_{ig} * Average\ Delay_i(s_i) + s_i, \\ & \text{s.t.} \quad \sum_i s_i = S, \end{aligned} \tag{2}$$

where the subscripts c, t, and g denote commercial carrier, commuter, and general aviation operations, respectively, v is the value (in \$/minute) of delay costs, Q is the number of annual operations, the *Average Delay* function is based on the coefficients of the third specification in Table 1, and S is the current level of FAA spending in our sample airports (all appropriate variables are in 2000 dollars).

We find that airport users would save \$2.2 billion in delay costs (and that one dollar of current spending now reduces the cost of delay \$4.67) if FAA expenditures were allocated among airports to minimize total airport costs.[24] This represents an 18 percent reduction (from \$12.3 billion to \$10.1 billion) in delay costs to the nation's air travelers and operators. That the total improvement exceeds FAA's annual spending on towers and TRACONs indicates that the FAA is allocating this component of its air traffic control resources inefficiently.

It can be argued, however, that although the FAA is concerned with delays, its primary mission is to ensure safety. Because air traffic control serves this dual function at airports, it is important to introduce a constraint in our cost-minimization model to prevent spending from falling to a level that could compromise safety at any airport.[25] (We begin by assuming that current spending is sufficient to ensure an adequate level of air travel safety.) In the model, we assumed that each airport was allocated enough funds to place it in at least the 20th percentile of observed spending per operation, thereby ensuring that it achieves a level of safety above that being achieved by some airports in our sample—with all airports already being funded at an adequate level of safety. Minimizing *TC* subject to this constraint and the current level of spending enables airport users to save \$0.54 billion, with one dollar of spending reducing the cost of delays \$2.75.[26] The potential delay savings from an efficient reallocation of FAA expenditures are not at variance with maintaining air carrier safety, which

We are not able to measure these benefits here because the effect of spending at ARTCCs cannot be traced back to a single airport.

[24] We obtain an estimate of national savings using the inflator, 1.34, described in footnote 18. Because our analysis holds output (operations) constant, benefits from optimal FAA spending are accrued in lower delay costs. Alternatively, optimal FAA spending could lead to more air carrier operations with no increase in current delay costs. Based on the first and second specifications, one dollar of current spending reduces the cost of delay \$4.03 and \$4.87, respectively, if expenditures were allocated among airports to minimize total airport costs.

[25] We verified that total FAA spending improves air carrier safety by using annual time series data from 1978 to 2001 to estimate a logistic regression where the dependent variable was the natural log of the odds of a fatal accident occurring to (Part 121) air carriers and (Part 135) commuter airlines. The independent variables were total real FAA spending (\$ millions), scheduled airlines' lagged operating profit margin (see Rose, 1990), and total operations. Accident data are from the National Transportation Safety Board, FAA spending and total operations are from the FAA, and operating profit margins are from the Air Transport Association. Initial estimations indicated that serial correlation was not present. Our final parameter estimates with standard errors in parentheses are:

$$\begin{aligned} \ln\left[\frac{\Pr(\text{fatal acc.})_t}{1-\Pr(\text{fatal acc.})_t}\right] = & \underset{(2.10)}{-16.63} - \underset{(0.0001)}{0.0004}\ \text{FAA spending}_t \\ & - \underset{(4.27)}{7.74}\ \text{Profit margin}_{t-1} \\ & + \underset{(3.88\text{E}-08)}{7.92E-08}\ \text{Operations}_t, \end{aligned}$$

R-squared $= 0.47$.

The coefficients for the independent variables have the expected signs and reasonable statistical reliability. The coefficient for FAA spending indicates that an additional \$1 billion of spending reduces the chance of a fatal accident per million departures by 0.13, which is approximately one third of the fitted value of the dependent variable in the sample for 2001.

[26] Based on the first and second specifications, one dollar of spending reduces the cost of delays \$2.17 and \$3.00, respectively, subject to the safety constraint. As an alternative safety constraint, we minimized *TC* subject to each airport's spending per operation being greater than or equal to its current spending per operation. Setting this constraint had little effect on our findings.

suggests that the current misallocation is primarily attributable to political pressure applied by members of Congress and other air transport interests to maintain spending at their airports.[27]

Given that the benefits to airport users from current spending exceed its costs, it is also worth exploring whether FAA expenditures should be increased. Because the production function for air traffic control is likely to exhibit some form of diminishing returns eventually, which is not captured in our delay equations, it would be inappropriate to add capital and labor to the system without any bound. We therefore determine the effect of optimizing FAA spending among airports subject to the previous safety constraint and a constraint that total spending cannot increase more than \$1 billion dollars.

We find that the spending constraint is binding under optimal spending at each airport and that the \$1 billion increase in spending at the sample airports improves airport users' welfare \$3 billion for a net welfare gain of \$2 billion.[28] Of course, by more than doubling current spending, it is possible that some form of diminishing returns may have been encountered. In any case, it is likely that large benefits exist from increasing spending at towers and TRACONs, especially if expenditures are optimized across airports.

Additional Ways the FAA Could Reduce Delay Costs. It is widely believed that the FAA has failed to produce potential benefits in travel time savings and enhanced safety from the timely implementation of recently developed technologies that could effectively expand airspace around airports and en route.[29] A rigorous analysis of this issue is beyond the scope of this paper, but the following back-of-the-envelope calculation is illustrative. According to our three specifications of air travel delay, if capacity at all airports were expanded 10 percent, the reduction in delay costs to the nation would be roughly \$1 billion. Savings of at least this magnitude could be achieved if the FAA expanded runway capacity by spurring the implementation of technology that, without compromising safety, would facilitate additional operations on parallel runways and reduce the separation between aircraft when they take off and when they land. Cost savings could also result if pilots were allowed by the FAA to use new technology that enables them to choose the most efficient altitude, routing, and speed for their trip (so-called Free Flight) instead of being forced to follow fixed air lanes based on FAA ground navigational systems.

[27] Oster and Strong (2006) point out that when the Air Traffic Organization proposed in February 2005 to close control towers between midnight and 5:00 a.m. at 48 lightly used airports, US representatives from the airports' districts strongly opposed the action without even considering whether the tower services were needed or even used.

[28] Using the first and second specifications, the net welfare gains are \$1.8 billion and \$1.9 billion.

[29] The FAA has had a long history of failing to adopt technological improvements in a timely fashion. Its Advanced Automated System was initiated in the early 1980s, but the system is more than a decade behind schedule and still not completed. Worse, the technology is no longer state-of-the art. Satellite-based systems are the next generation of air traffic control technology. But it is expected that it will take more than 25 years for such a system to become fully operational in the United States.

5. Final comments

The introduction of air traffic control over US skies more than 50 years ago has clearly made flying safer and reduced travel delays. But given that expenditures on the system are the primary tool that the FAA has used to combat congestion, it is essential for FAA spending to be efficient. We have found that the FAA could produce substantial benefits in travel delay savings to airport users by increasing the overall level of spending on towers and TRACONs and by optimizing expenditures across airports to minimize total airport costs.

Unfortunately, when travel delays have reached dramatic proportions, policymakers have not considered whether ATC spending is as efficient as possible. Instead, they have instituted arbitrary controls such as take off and landing slots and have allowed carriers to coordinate their schedules. Economists have strongly made the case that by ignoring economic incentives to reduce delay, Congress and the FAA have failed to provide a long-term solution to congestion. By failing to optimize ATC expenditures, Congress and the FAA have compromised their short-term solution to congestion.

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