Flight Delays on US Airlines: The Impact of Congestion Externalities in Hub and Spoke Networks

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Abstract

This paper examines the impact of hub and spoke congestion on flight times and departure delays in the US airline market. It measures the change in flight times resulting from infrastructure-constant changes in passenger demand. In addition, it quantifies the difference in flight times between airlines with large and small networks. Results indicate that delays rise with the ratio of demand to fixed airport infrastructure, decreasing average flight times by close to seven minutes after the sharp decrease in demand in the fall of 2001. Flight time differences between the airlines in the sample are small, though the larger United had shorter average flight times in the winter quarter than America West, the smaller airline in the data sample. While these results are a step toward quantifying and understanding the complex externalities of hub and spoke systems, further study on the degree of interdependence of flights within networks would help to better explain the distribution of congestion delays across airline networks.

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1. Introduction

Hub and spoke networks changed the face of airline competition in the 1980s, creating a network industry far different from what regulators envisioned before deregulation. Since then, the cost advantages of hub and spoke systems have been well documented. Resulting changes in the price and frequency of flights have also been the subject of detailed economic analysis. The impact of hub and spoke systems on flight delays, however, has received less attention, despite the high cost of delays to time-sensitive business travelers. This study seeks to add to the growing body of literature on airline competition by analyzing the effects of congestion and airline size on the length and variation of flight times in hub and spoke systems.

Especially in during the extended economic boom of the 1990s, airline demand increases outpaced growth in airport infrastructure, contributing to system overcrowding. The lack of infrastructure improvements can be attributed to a variety of factors, including financing problems, environmental concerns and a history of large fluctuations in consumer demand for air travel. While demand decreased substantially in 2001, the problem of congestion is unlikely to disappear in the near future, especially as the economy expands. Investments in new airport facilities and improved air traffic control technology will help to lessen the effects of congestion on flight times. Quantifying the costs and benefits of these investments requires a measurement of the delay impact of changes in the ratio of passenger demand to infrastructure.

The sharp decline in demand for air travel in late 2001 provides a unique opportunity to analyze the effects of changes in demand on the travel time while keeping fixed-capital airline infrastructure relatively constant. The econometric model in this study uses data from the period January 2000 through February 2002 and analyzes changes in flight times and variation in flight times as they relate to changes in Revenue Passenger Miles (RPM) per month for the entire domestic airline industry.

Quantifying the change in flight times also required comparison to other factors that impact flight times, such as snow at the hub airport and winter weather on the network as a whole. Measurements of flight time differentials across several sample destination airports also help to quantify the level of airport infrastructure capital necessary to provide a constant level of service with different levels of demand. Different weather patterns at the sample destinations mean that the most accurate comparisons between airports will be in metropolitan areas with more than one airport.

Overall system congestion and choice of airport, while important determinants of airline flight length, are often impossible for travelers to avoid. On the other hand, customers generally have more flexibility in choice of airline than in selecting a destination or time of year to travel. This study also tests the hypothesis that there are systematic differences between flight time on airlines of different sizes, as measured by the number of destinations served.

It is theorized that larger airlines should have increased exposure to delays from weather when they serve more destinations, because every destination served is connected to the nationwide network. More destinations mean more potential delays to be spread throughout the system. Countering this effect is the benefit of increased network size with regard to variance in the number of expected delay events. Because they have more flights, larger airlines can more accurately predict the likelihood of crew sickness or mechanical failure. This enables them to keep a smaller percentage of their resources in reserve than smaller carriers, while maintaining the same on-time performance.

Delay data on both large- and medium-sized national carriers allows comparison of the effects of congestion and weather delays on airlines with different network characteristics. Holding overall system congestion constant, flight times on United Airlines and America West Airlines were compared over the course of the year to test the impact network size on delays. In addition, analysis of variation in flight time as it differs between airlines provides further information on the differentiation of service across carriers. Information on the variance of flight times would be most useful for time-sensitive consumers concerned about the probability of unusually long flight delays. High variance increases the risk that any one flight will have a flight time far different from expected. Lower variation in flight time reduces the chance of being delayed for several hours.

Differentiation in airline service speed over time and across carriers is an important factor to be included in complete models of the airline industry. Quantitative estimates of the benefits to improved infrastructure will help communities and regulators to weigh the costs and benefits of airport expansion investments. Measures of returns to scale in flight time will aid regulators in evaluating merger proposals and airline competition in general.

The next section provides background on the development of the airline industry from deregulation through the present day. The literature review in Section 3 outlines some of the key studies on airline competition and hub and spoke systems that have shaped economic thought on the industry over the past several decades. Section 4 provides specifications on the data sample used in this study. A model for analysis of congestion effects and the impact of network size on flight times and delays is described in Section 5, while the results of the regression model can be found in Section 6. Section 7 includes conclusions and suggests potential areas for further research.

2. Background

Until 1978, US airlines were heavily regulated. The Civil Aviation Board (CAB) required airlines to serve specific routes, and price changes had to be approved by the government. Regulation ensured that the long term investments made by large airlines were protected from low-cost competition, and it also ensured that smaller cities were able to get airline service. The CAB issued takeoff and landing slots with preference to established carriers, preventing new airlines from entering the market (Joskow 105).

The industry was plagued by inefficiency, though, and studies done in the 1970s suggested that airlines would be more efficient if pricing and routing decisions were left to the private sector (Caves 1970, Keeler 1972).[1] The argument for privatization was that airlines were now sufficiently established in a diversity of markets, and with deregulated competition would have incentives to lower prices and reign in costs. This contrasted with the regulated market, where price caps limited the incentive to innovate.

The 1978 Airline Deregulation Act gradually eliminated most of the competitive restrictions on airline service in the US, and allowed low-cost start-ups to enter the market and compete with established airlines. Thrust out into the open market, major airlines adjusted quickly to the new deregulated atmosphere. Efficiency at new entrant airlines was far greater than that of established carriers. For example, a 1987 study showed that cost per seat on a 200 mile journey on a Boeing 737 aircraft were 120% higher at United Airlines than at Southwest, a new entrant into the national market (Pryke 55). Cost savings stemmed from more efficient use of staff and lower labor costs, as well as bare-bones service catering toward users who preferred lower prices to an extra bag of peanuts. As a result of competition from new

[1] A more detailed discussion of these studies can be found in the Literature Review section.

entrants, established carriers were forced to cut costs and find ways to serve customers more efficiently.

No longer required to serve specific routes, airlines began to move away from direct service between city pairs toward networks focused around centralized hubs, through which the vast majority of passengers transferred en route to their final destinations. The adoption of these hub and spoke networks increased the ratio of seat-miles sold to seat-miles flown for airlines, known as the load factor, and led to greater efficiency in terms of the use of resources (Caves, Christensen and Tretheway 476). The greater amount of choices in travel destinations and the lower costs of long-distance travel overcame inconveniences for customers as a result of layovers. Airlines were able to fill up more seats per plane, but the cost savings from improved load factors were moderated by the fact that routes were shorter, adding to the cost per mile flown because of more takeoffs and landings (Liu and Lynk 1085).

Consumers benefited from the switch to hub and spoke networks, as airline cost savings forced flight prices lower on longer flights. While short-haul passengers saw slightly higher prices after the change, their destination options were greatly increased. Studies in the early 1980s showed that the industry was still competitive, as prices were falling and new entrants were numerous (OECD 37). Pat Hanlon (1999) notes that, "the number of carriers offering scheduled services on trunk routes rose from 36 in 1978 to over 120 by 1985; and by 1985 the top five carriers accounted for 57 per cent of the US industry's output, compared with 69 per cent in 1978" (43). All of these signs pointed to a more efficient industry as a result of deregulation and the adoption of hub and spoke networks.

While there have been substantial benefits to hub and spoke networks, the new system also created a new set of problems. The competitive balance in the airline industry has changed substantially since the mid-1980s, as airlines sought the benefits of lower marginal costs, increased density and larger scale that came with hub and spoke systems. Market dominance at major hub airports has become an issue of concern for regulators and economists, who worry that monopolistic carriers are able to raise fares and limit market supply to less than optimal levels (Berardino and Golaszewski 345).

The airlines with the largest and most densely utilized networks have gained much through acquisitions since deregulation. Some of the most controversial mergers involved airlines sharing the same hubs, such as Northwest's takeover of Republic Airlines in 1986 and TWA's buyout of hub competitor Ozark Air in the same year. The US Department of Justice opposed both mergers on the grounds that they would restrict competition between hubs in Minneapolis and St. Louis and particular cities around the country, but the US Department of Transportation (DOT) allowed the mergers to go through (Joskow 122). One reason cited by the DOT was that there was a serious possibility that Republic and Ozark might file for bankruptcy if the mergers failed, limiting flight options for customers should the airlines have to fold. As a result, Northwest gained an 80% market share in Minneapolis, and TWA took a 76% share of landing slots in St. Louis (Joskow 122).

More recently, TWA itself was acquired after two bouts with Chapter 11 bankruptcy, a function of competition from airlines with even larger hub and spoke networks. American Airlines, one of the powerful national carriers to emerge from the regulated era, completed its takeover of TWA in late 2001. With TWA, American gained a new hub in centrally located St. Louis, increasing the airline’s network capacity.

While some smaller, low-cost carriers survive, they face an uphill battle against competitors who have near monopolies on landing slots at major airports. Southwest, for example, has been forced to utilize smaller airports such as Islip in Long Island and T.F. Green Airport in Providence, RI instead of the larger New York or Boston airports. This makes transfers between airlines more difficult, and limits the options for travelers. The inconvenience of the lack of network interconnection means that smaller airlines are at a competitive disadvantage over their larger, established rivals. Connections to flights around the world are limited by the relatively small capacities at the airports most heavily used by low-cost startups. In order for these smaller airlines to be profitable, they must be far more efficient than their established rivals need to be.

A good example of the need for market power in order to compete can be seen in the bankruptcy of Eastern Airlines in March 1989. At the time, Eastern shared its Atlanta hub with Delta a larger and, by some standards, more efficient airline (Liu and Lynk 1089). Other US airlines, such as Continental, Pan Am and Trans World (TWA), filed for bankruptcy within a couple of years of the Eastern filing, but only Eastern and Pan Am ceased operation as a result. The failure of these major accent the fact that even relatively large airlines were unable to compete with the vast and densely utilized networks of the biggest carriers.

A recent lawsuit brought by the US Department of Justice against American Airlines for abuse of market power at its Dallas-Fort Worth hub was an attempt to address the issue of hub dominance, but American was eventually successful in convincing the courts that it had not violated antitrust laws. American argued that it simply engaged in tough competition, and continued to price flights above marginal cost despite lowering fares to compete with smaller low-cost airlines (American Airlines 1999).

Outside of the court system, efforts to limit the market power of hub carriers have also met with little success, and the incentives to take such action have not diminished as a result of new regulations. One solution to the problem would be to expand airport capacity, a task which has proven quite difficult in the face of “Not In My Backyard” reaction to airport expansion and development proposals. In addition, incumbent airlines, which often hold significant influence in airport construction and expansion decisions, have understandably been opposed to airport expansions that could threaten their market power (Gudmundsson 46).

While fare premiums and airline competition have been topics of debate for some time, the issue of product differentiation has received less attention. Several studies from the deregulated era have sought to include measures of airline service and safety in their cost models, but a comprehensive model of the industry has yet to be developed.

3. Literature Review

Despite the lack of a complete model of economic competition in the airline industry, there is a broad economic literature on the efficiency of airlines, and hub and spoke networks in particular have been the subject of much economic analysis since the US airline industry was deregulated. In the regulated era, many studies were focused on the efficiency of airlines and the potential consequences of deregulation. Books by Richard Caves (1970) and William Jordan (1970) provide detailed analysis of the regulated industry, product differentiation, airline costs and barriers to entry. Later research from the deregulated era looks at the effects of hub and spoke networks on competition, fares, safety and service in the airline industry.

In 1972, Theodore Keeler developed a long-run airline cost function, building on the work of Caves and Jordan to examine profit margins in the airline industry. Keeler's airline efficiency measurements are normalized by the efficiency of service seen in Pacific Southwest Airlines (PSA), a California intrastate carrier run with far less regulation than national carriers. Expected delays are included in his cost function from the perspective of resource opportunity costs and the expense of operating planes for longer blocks of time as a result of delays. His results suggest that regulated airlines charged a significant fare premium, especially in high-density markets.

Caves, Christensen and Tretheway (1984) look at historical airline cost data to show that increasing returns to network density are the reason why start-up airlines are able to compete with more established carriers. Returns to density are defined as the "variation in unit costs caused by increasing transportation services within a network of a given size (472)." These differ from returns to scale, based on the number of cities served in the network. Caves, Christensen and Tretheway find constant returns to scale in the airline industry, supporting previous literature on the subject, which had provided justification for deregulation (Borenstein, 1992). The authors also show evidence that airline market power has led to price increases for passengers travelling directly to and from large hub airports, a so-called "hub premium." In many cases, this premium stems from the fact that hub-operating airlines control the vast majority of landing slots at their hub cities and are able to offer far more service options than any competitors.

Borenstein (1989) addresses the issue of concentration of market power in the airline industry, citing incumbency advantages for established carriers in certain markets. He concludes that along with the substantial benefits of improved efficiency on hub and spoke networks, there are customer welfare disadvantages to hubs, especially with regard to fares on flights to and from the hub cities where there is little competition with the hub carrier. Frequent flier programs, computerized reservation systems and travel agent bonus payments explain some of the advantage for established carriers, but Borenstein suggests that other factors, possibly monopolistic predatory tactics, enable hub carriers to dominate the market and stifle competition from new entrant airlines.

Brueckner, Dyer and Spiller (1992) link increasing returns to density with lower fares on routes through hub airports. They downplay the negative competition effects of mergers that increase market share at a hub airport, showing that the benefits of reduced fares stemming from increased density on routes through hub airports outweigh the costs of monopolistic pricing on a few shared routes. The authors conclude that the structure of an airline network has an important impact on fares, and that more concentrated hubs tend to yield lower fares for customers who pass through the hub en route from their original spoke city to their final destination.

Berry, Carnall and Spiller (1996) build upon the route density model employed by Caves, Christensen and Tretheway by allowing density to vary by route and consumer preferences to include flight restrictions as well as price. They model demand by dividing airline customers into relatively price-sensitive leisure travelers and price-insensitive business customers who react differently to changes in an unobserved variable in the model added reflect differences in service across airlines. This variable includes the restrictions placed on tickets, such as Saturday night stayovers and advance purchase requirements, but does not model these restrictions individually. The authors find that while the "hub premium" cited by Caves and Borenstein is substantial, the differentiation in service provided to business customers contributes to most of the mark-up seen at hub airports.

Liu and Lynk (1999) counter Caves, Christensen and Tretheway using a similar airline cost function but applying it to data from the deregulated airline industry over the period 1984-1991. They find evidence of increasing returns to scale, defined by the number of points served by an airline. Additionally, Liu and Lynk discern quantitative efficiency gaps between airlines, an indication of imperfect competition. These findings stand in sharp contrast to the expectations of constant returns to scale identified in previous research about the industry. Continuing study along similar lines is sure to follow from this study as more and more data becomes available. Data on fare restrictions and variation in prices between customers on the same flight, however, has proven difficult to obtain, because airlines fear that revealing such information would cut into their ability to price tickets based on willingness to pay (Berry, Carnall and Spiller 6).

While pricing and competition studies are abundant, there are other components of airline travel that affect customers on both short- and long-haul trips. Safety remains an issue that is on the mind of many consumers, but Federal Aviation Administration regulations do set a safety standard that limits the amount of variance in safety options for consumers (Rose 333, Caves 51).

Borenstein and Zimmerman (1988) look at the impact of crashes on demand for flights, both for the carrier involved and the industry as a whole. They find only a minimal impact of a crash on demand for flights, though the information that a crash provides as to the safety of air travel depends on the cause of the crash and the number of fatalities.

Nancy Rose (1998) looks at historical airline accident data from 1957-1986 and examines its correlation with profitability. She finds a strong relationship between a good safety record and profits, especially in smaller airlines seeking to establish themselves in the market. The effect is less pronounced in the medium and larger sized carriers in her sample. Adjusting for experience factors, she concludes that the positive correlation between safety and profits imply that, along with fares and service factors, safety records matter to airline customers.

There are also several studies of note on the topic of speed of travel. Carlton, Landes and Posner (1980) analyze a proposed merger between two local service carriers in terms of the time it will save customers who were required to change airlines en route to their destinations. Interestingly, the notion of changing carriers at a stopover on a domestic flight seems strange to the modern traveler, proving that the advantages of consolidation that Carlton, Landes and Posner cite in their study have had an impact on the US airline industry. Their study, however, utilizes scheduled flight times as a basis for comparison, eliminating the possibility (and these days the probability) that a substantial portion of flights will not arrive on schedule.

Mayer and Sinai (2001) examine the effects of cluster scheduling at hub airports on delays. They find delay externalities result from the grouping of incoming and outgoing flights into banks so that passengers coming from all origins have many destination options through the hub. Congestion impacts the major carrier clustering flights as well as other airlines attempting to take off and land during these time blocks. Mayer and Sinai suggest taxes on clustering as a way to mitigate this externality, but also concede that the "culprit," the major airline grouping flights close together, internalizes much of the impact of cluster delays. Efficiency issues caused by clustering at hub airports that are often highly dominated by one airline[2] are therefore minimal, and are considered to be endogenous choices for the airlines in my study.

Suzuki, Tyworth and Novack (2001) study the delays within the context of a broad investigation of the relationship between service quality and market shares. Using a weighted service quality function calibrated based on a 1988 Fortune magazine study of air traveler preferences, these authors conclude that there is a strong negative response to declines in service quality, but not much positive response to above-average service. The authors admit, however, that their generalized model of the industry does not allow for variation in service quality on specific routes and that the survey-based model does not account for differences in consumer preference over time or across different types of customers.

Thengvall, Yu and Bard (2001) examine the ways in which airlines respond to delay-causing events, specifically hub closures. Their analysis focuses on the resources—airplanes and crew—that need to be shifted in order to get passengers and cargo to their destinations as

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[2] DOT Data in 1999 showed that US Air controlled over 80% of the gates in Charlotte and 67% of the gates in Pittsburgh; Delta controlled 74% of the gates in Cincinnati; and Northwest controlled 77% of Minneapolis gates and 64% of gates in Detroit (GAO 1999, Table 4.3).

quickly as possible. More options in such a scenario, such as a larger fleet of interchangeable planes, give carriers more flexibility in responding to weather delays or mechanical failures. This operations research literature within the airline industry is an expanding field with models being put to direct use by airlines seeking to optimize their resource allocation under dynamic pressures from exogenous delay-causing events.

4. The Data

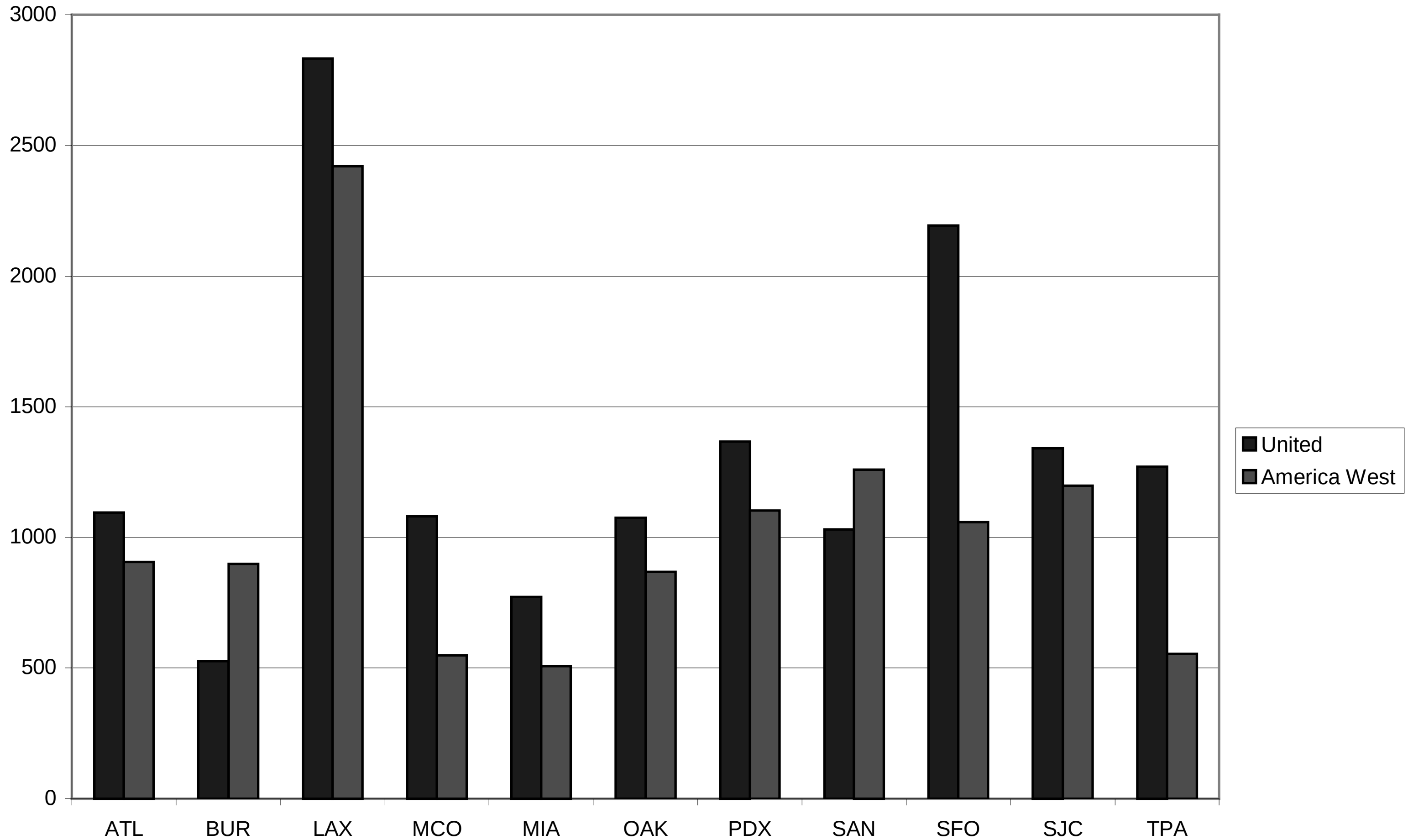
The US Department of Transportation's Bureau of Transportation Statistics (BTS) collects detailed information on both domestic and international flights by US airlines. For this study, sample data of actual elapsed time (AET) of flights from takeoff to landing was combined with departure delay (DD) data to form total elapsed flight time (TET) data, a measure of the time from scheduled departure to actual arrival.

Measuring TET captures the time needed to get from point A to point B, the portion of network delays assumed to be of most interest to the consumer. If a flight takes off late, but is able to make up time in the air, then the service value of the flight to the consumer is assumed to be equivalent to an on-time takeoff with a delayed landing. Departure delays were also included as a dependent variable in a separate regression for comparison with TET results.

The data interpreted in this study was for United Airlines flights out of its Denver hub to 11 different US cities, and for America West flights out of the airline's Phoenix hub to those same 11 cities. Destination cities were chosen based on the specification that they be served by both United and America West from these respective hub locations and also be in warm weather areas to minimize weather delay effects at destination airports. The destination airports sampled for this model, with airport codes in parenthesis, were Atlanta (ATL), Burbank (BUR), Los Angeles (LAX), Orlando (MCO), Miami (MIA), Oakland (OAK), Portland (PDX), San Diego (SAN), San Francisco (SFO), San Jose (SJC), and Tampa (TPA).

Of the over 108,000 departing flights from January 1, 2000 through February 28, 2002 that meet these criteria, a subsample of 25,906 flights was taken. A comparison of the distribution of destinations in the sample for each airline can be found in Figure 1. The sample

Figure 1: Destinations Airports by Carrier
Sample Data



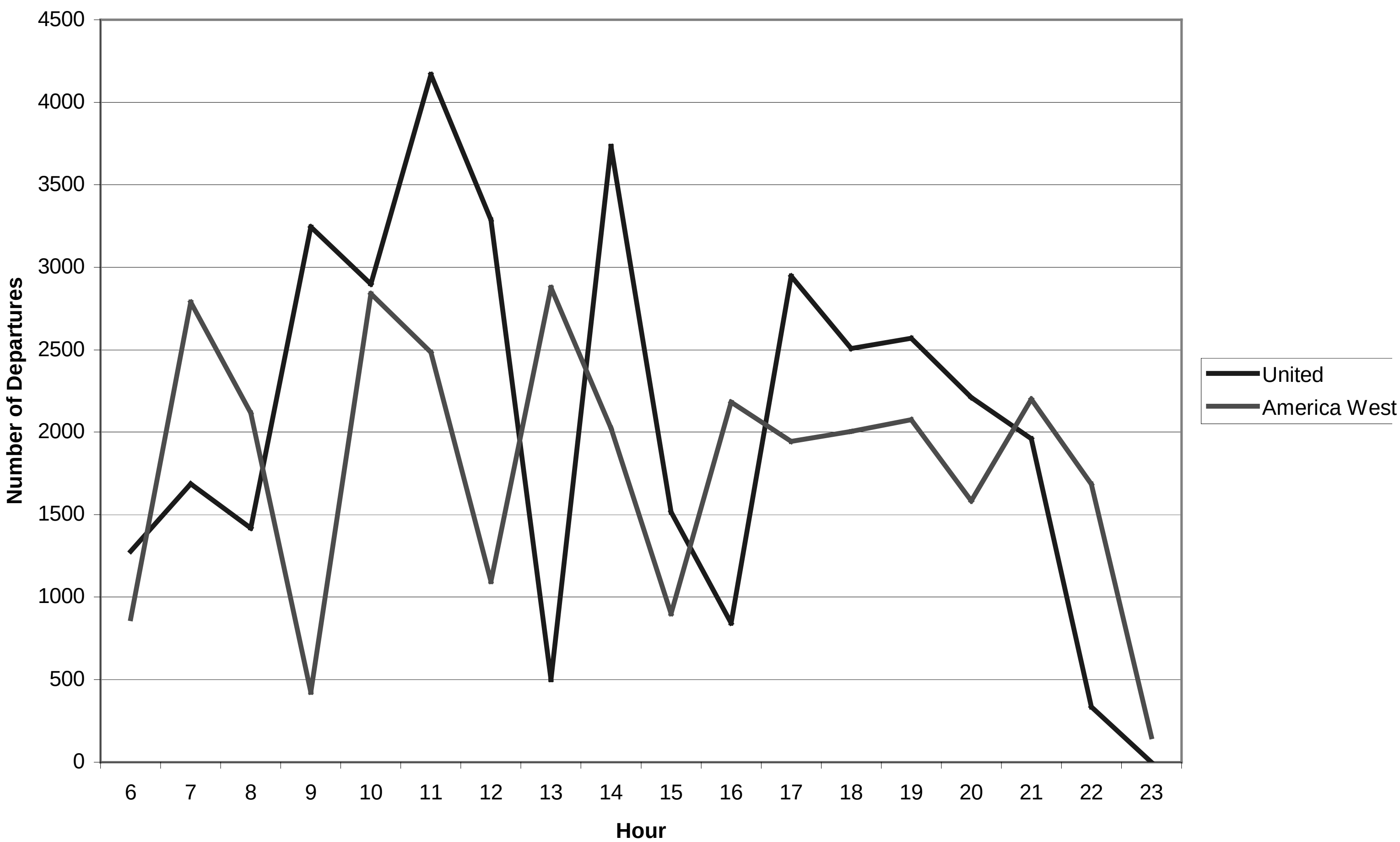
consists of all 14,584 United flights and 11,322 America West flights departing between the hours of 10am and 3pm on weekdays over the sample period.

The 10-3 timeframe captures two large banks of connecting flights for each airline. Banks of flights, periods of relatively frequent arrivals followed by frequent departures, are typically scheduled several times a day at hub airports to maximize connection opportunities for customers changing planes on cross-country flights. See Figure 2 for a graph of daily departure times for each airline for all weekday flights out of the sample hubs, including those flights departing outside of the selected sample hours.

Arrival banks are scheduled roughly an hour before departure banks so that there is a short turnaround time for passengers, crew and airplanes. Problems with arriving planes during the arrival bank can quickly translate into departure delays at the hub, as departing flights must often wait for delayed passengers, crew and planes. For this reason, the sample of flights departing during hub banks indirectly captures delays on arriving flights in addition to any delays associated with the destination airport or the hub itself.

United Airlines and America West Airlines were chosen for comparison because each airline serves cross-country flights through a major hub city where it holds a vast majority of landing slots. United's 2001 domestic market share of 19.7% made it a good candidate for comparison with America West, a much smaller airline with a 2.9% market share in 2001 (US Business Reporter 2002). In March 2000, United, along with its regional affiliate United Express, served 224 domestic cities and 43 destinations outside of the United States (US GAO 2000). America West and its regional affiliate America West Express currently serve 134 destinations in the US, Mexico and Canada (America West Airlines 2002).

Figure 2: Weekday Flight Schedules
All Flights Jan. 2000-Feb. 2002



Data availability constraints also played a role in selecting airlines, as America West was one of the smallest airlines with flight information available in the BTS online database. American Airlines could have been chosen as the large airline in the sample, but the airline's merger with Trans World Airlines in 2001 would have complicated the model. United had a slightly larger market share than Delta, the other large carrier considered for the study.

As for the smaller carrier, options included America West, Southwest and USAir. Though data on Southwest Airlines was available, the airline lacks a typical hub and spoke network, serving customers through several smaller hubs instead. USAir's concentration on eastern seaboard flights would likely have biased the data, while America West seemed to fit the specifications of the model quite well.

America West's Phoenix hub was chosen because it is the airline's largest major hub with nationwide destination availability. Denver was then selected over United's other mid-country hub in Chicago because it is closer to Phoenix and had a similar set and number of available connections to spoke city destinations. Ideally for this model, the hubs for these carriers would have been at the same airport, but limited landing slot availability make circumstances of large- and medium-sized carriers coexisting in the same hub quite rare.[3]

Sampling flights from the short period from January 2000 through February 2002 enabled study of large changes in consumer demand with relatively constant airline infrastructure. While large-scale layoffs and a decrease in flight frequency did occur in the fall of 2001, airlines' fixed capital infrastructure, including runways, airport terminals and air traffic control technology could not adapt to the decrease in demand that resulted from the

[3] The 1986 Northwest-Republic, and TWA-Ozark mergers, and the 1989 collapse of Eastern airlines cited above, are examples of the difficulty of major airlines to coexist at the same hub. See OECD (1988) and Brueckner, Dyer and Spiller (1992) for more detailed information on the subject.

terrorist attacks in September 2001. As much of this fixed capital is often taxpayer funded, measuring the marginal benefit to expanded fixed capital relative to demand will help the public to make informed decisions on the need for new runways, terminals and airports.

5. The Model

The econometric model developed in this section seeks to estimate one component of the marginal benefit of airport infrastructure by quantifying the impact of changes in customer demand on travel time with a fixed level of airport infrastructure. In addition, the model looks at the impact of the size of an air carrier's network on length and variation of travel time.

Given a constant level of fixed airline capital, increases in passenger demand for air travel should translate into longer average flight times across all carriers. Additional customers mean that airport terminals and runways are more congested, planes take longer to load with passengers and baggage, and resources such as planes and crews must be used more frequently in order to cope with demand. These factors make it more difficult for an airline to run an on-time flight, an effect that is magnified by hub and spoke systems highly dependent on network connections to funnel passengers to their destinations. These networks force airlines to wait for passengers, crew and airplanes that are delayed on arrival into the hub city before a flight can depart on the next leg of the journey.

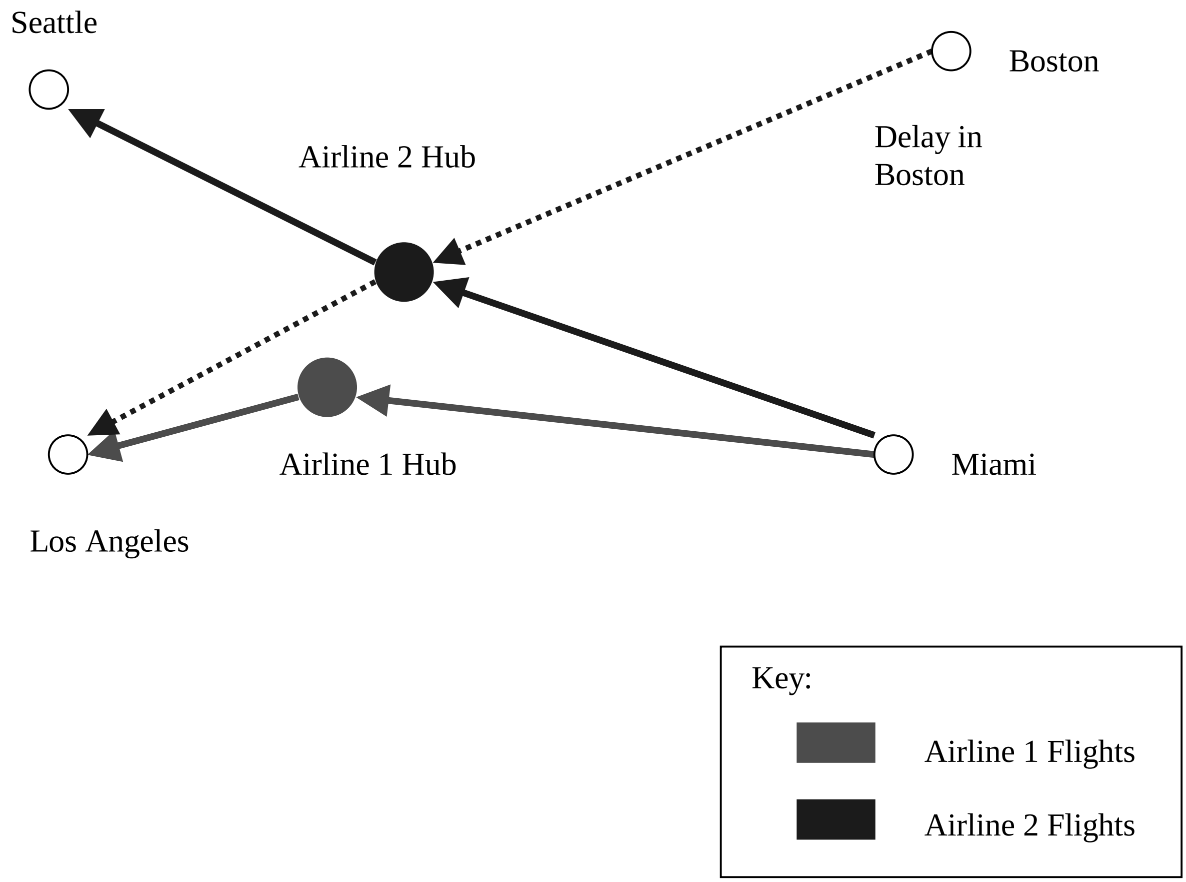
In addition to the cross-carrier effects of congestion, the model also attempts to quantify the impact of the size of an airline network on delays. Two opposing factors are theorized to be at work as airline networks expand. First, the more cities an airline serves, the more vulnerable it becomes to flight delays from weather, congestion or mechanical delay events. Closely integrated hub and spoke systems accentuate this effect, since passengers connecting at the hub must wait for planes, crew and other passengers arriving on delayed flights before they can depart on their connecting flights. On the other hand, large networks may make it easier to deal with delays, as larger airlines can keep fewer aircraft and crew as a percentage of the total fleet in reserve positions, thanks to a decreased variance in the likelihood of mechanical failure, crew sickness and other delay-causing events.

A good example to illustrate the way in which network size can increase delays in hub and spoke systems uses two airlines and very simple route structures. The product to be examined is a flight from Miami to Los Angeles, connecting in the middle of the country at a hub airport. Airline 1 serves only Miami and Los Angeles from its hub. Airline 2 serves Boston and Seattle in addition to Miami and Los Angeles from its hub (Figure 3). When the network is running smoothly, all flights are on time and the utility each customer obtains from an on-time flight to the same city on either airline is the same.

What happens if it snows in Boston? Both airlines' flights from Miami to their hubs arrive on time. The Airline 1 flight from its hub to Los Angeles is also on time; however, Airline 2's flight from its hub to Los Angeles is delayed, since the plane that was scheduled to fly this route is stuck in Boston. Passengers travelling to Los Angeles on Airline 2 must wait for the plane from Boston to arrive at the hub before they can proceed with the second segment of their trip. Thus snow in Boston has no effect on Airline 1's customers on the Miami to LA route, while Airline 2's passengers on the Miami to LA route are delayed.

The theory behind positive externalities applies the Law of Large Numbers to the probability of delay-causing events, such as crew illness. According to my elementary statistics book, the Law of Large Numbers is defined as follows: "If a situation, trial, or experiment is repeated again and again, the proportion of successes will tend to approach the probability that any one outcome will be a success" (Freund and Simon, 124). Taking a cue from inventory optimization models created during the 1920s, William Baumol first applied this theory to the economics problem of cash reserves in 1952, showing that optimal cash

Figure 3


Seattle
Boston
Airline 2 Hub
Delay in
Boston
Airline 1 Hub
Miami
Los Angeles
Key:
Airline 1 Flights
Airline 2 Flights

balances “vary with the square root of the volume of transactions” (548). James Tobin later elaborated on Baumol’s work (1956). Here the theory is applied to airlines’ reserve resources.

An example should help clarify the theory of reserves and the Law of Large Numbers as it applies to airline networks. Assume that Airline 1 has 100 flights daily, while Airline 2 has 1000 flights daily. Each airline also has the same 10% probability of a delay on a given flight caused by an uncontrollable event, such as mechanical failure, crew sickness or airport closure. In order to be sure that at least 95% of its flights are on time, each airline must keep a certain number of planes and crews in reserve, ready to enter service on the network to keep flights on time. The equation for the lower boundary on the 95% confidence interval of 100% of flights departing on time is as follows:

$$p - 1.96 * \sqrt{p(1-p)/n} \, .$$

For Airline 1, this equates to:

$$.9 - 1.96 * \sqrt{.9(.1)/100} = .84.$$

This means that the airline must have 100/.84 –100 = 19 planes and crews in reserve to meet the 95% threshold. Airline 2’s 95% threshold percentage would be:

$$.9 - 1.96 * \sqrt{.9(.1)/1000} = .88,$$

which means that the airline must have 1000/.88 – 1000 = 135 planes in reserve. The percentage reserve requirement for Airline 1 is 19%, while the percentage reserve requirement for Airline 2 is 13.5%. Assuming both airlines have the same percentage of reserves, then Airline 2 will have more on-time flights than Airline 1, all other things equal. This is the result of a decrease in the variance in number of delay events as the number of flights increases.

Regardless of positive or negative delay externalities, adding a new destination to the network has its benefits. Serving a new city is an opportunity to add customers and earn more revenue. The effects of network size increases are magnified by the hub and spoke system, because the addition of one destination from the hub means that passengers from all cities connected to the hub can now connect to the new destination (Hanlon 84-85, Button and Stough 47-48). In the first example above, an Airline 2 customer could take a flight from Miami to Seattle, while a customer on Airline 1 would only be able to go to Los Angeles.

Economically, the flight from Miami to Los Angeles on Airline 1 is different from the flight from Miami to Los Angeles on Airline 2 if the expected flight time or the variance in flight time differs. Knowledgeable customers paying equal fares in a competitive market would always prefer to fly on the airline that meets their needs best by having either faster flight times, lower variance in flight times, or both.

This study examines how the theories outlined in the examples above actually apply to the US airline market. It quantifies the flight time effects of network congestion, given constant infrastructure, and tests to see if airline networks exhibit increasing, constant or decreasing returns to scale in flight time. The sheer size of the data set available from the BTS, which includes detailed delay and flight time information for all flights on major airlines from 1995 through the present, enabled use of specific city data to keep the model as simple as possible. Eventually, biases in the data forced the creation of a larger regression model than originally anticipated. This expanded model should make it easier to apply to different data sets in the future.

Total elapsed time (TET) from scheduled takeoff to actual arrival time and departure delay (DD) from scheduled to actual departure for each flight are regressed on an AIRLINE dummy variable and on industry-wide monthly domestic revenue passenger miles (RPM) flown, a measure of the demand for air travel. As described above, sample characteristics kept airline capital infrastructure fixed, so that changes in RPM over time represent fixed capital increases in demand. Table 1 shows historical RPM data by month for the sample period. Comparison of flight delays during these periods of shifting RPM will show the impact of the number of passengers flying in the domestic market on speed of travel.

Between airlines, the coefficient for the AIRLINE dummy variable should explain the difference in TET or DD caused by the size of the particular carrier, or any other differences between airlines not accounted for in the model. Means and standard deviations of these dependent variables, as well as the independent variables in the regression can be found in Table 2.

Several regressors were added to the model to measure the effects of specific variables on flight times and to account for certain characteristics of the data set that may differ from the industry as a whole. First, a snow dummy, SNOW, with a value of one if there is any recorded snowfall in the departure hub on the day of the flight, keeps the impact of bad weather in hub cities constant. A measure of the miles flown on each flight, DISTANCE, is included so that flights of different lengths could be compared on a per-mile basis. The combined variable UADIST is the product of the UA dummy variable and the DISTANCE variable, measuring the per-mile flight time of United flights. This variable accounts for the sample difference in total miles flown by United and America West, since longer flights tend to take less time per mile (Liu and Lynk 1085).

Table 1

Domestic Revenue Passenger Miles

	2000 RPM	Change Y/Y	2001 RPM	Change Y/Y	2002 RPM	Change Y/Y
January	33,372,731	1.40%	35,040,439	5.00%	30,550,124	-12.80%
February	34,465,901	8.50%	33,608,437	-2.50%	30,137,148	-10.30%
March	41,852,797	6.80%	41,477,627	-0.90%		
April	40,042,819	5.90%	39,836,640	-0.50%		
May	40,967,302	8.70%	39,960,902	-2.50%		
June	43,590,027	7.60%	42,664,756	-2.10%		
July	45,045,450	3.90%	45,136,951	0.20%		
August	44,196,852	3.90%	45,534,380	3.00%		
September	36,303,141	2.90%	24,505,451	-32.50%		
October	39,294,150	1.40%	31,020,363	-21.10%		
November	38,181,090	2.90%	31,419,755	-17.70%		
December	37,296,633	2.20%	32,362,608	-13.20%		
Total	474,608,893	4.70%	442,568,309	-6.80%		

Table 2

Means and Standard Deviations of Regression Variables

Number of Observations:	25906			
	Mean	Std Dev	Minimum	Maximum
TET	164.68417	57.90741	48	622
DD	15.1419	33.44866	-15	432
AET	149.54227	46.87483	52	354
RPM	3.81270D+07	5251451.859	2.45055D+07	4.55344D+07
DISTANCE	957.12047	443.96841	298	1981
UADIST	604.74226	573.01902	0	1720
UA	0.56296	0.49603	0	1
QUARTER1	0.3063	0.46096	0	1
QUARTER2	0.2472	0.43139	0	1
QUARTER3	0.2328	0.42263	0	1
QUARTER4	0.2137	0.40992	0	1
UAQ1	0.17208	0.37746	0	1
UAQ2	0.14321	0.35029	0	1
UAQ3	0.1307	0.33708	0	1
UAQ4	0.11696	0.32138	0	1
SNOW	0.065931	0.24817	0	1

Dummies are added for quarter of the year, Q1, Q3 and Q4, to see if bad winter weather and congestion in areas of the network outside of the sample destinations actually impact flight times. These dummies are also interacted with the UA dummy variable in the regressors UAQ1, UAQ3 and UAQ4 to indicate whether flight time differences between airlines vary with the seasons. In all cases, second quarter flight regressors are omitted to avoid singularity. Flight times during this base quarter are measured in the coefficients B0 and BUA.

Finally, dummy variables are included for each destination city to reflect differences in congestion and weather at the destination airports in the sample. The coefficients for these variables are BATL, BBUR, BLAX, BMCO, BMIA, BOAK, BPDX, BSAN, BSFO and BSJC. The basis destination is TPA, which is excluded. Just as the Q2 flights are included in the coefficients B0 and BUA, flight times and delays to TPA are also measured in these base coefficients.

In order to capture the effect of network size on both the length and variation of flight times, a variance components model was added to the regression. By breaking down variance terms into their component parts, the model is able to show what portion of the variation in flight length stems from demand to infrastructure ratio changes and differences in the size of the airline. Measurement of variation of flight times has not been studied in previous research, but represents an important characteristic of flight service for time-conscious business travelers, to whom long delays have high costs.

The variance model includes many of the same independent variables and regressors as the equation designed to estimate means. The model measures the contribution to variance of RPM, AIRLINE, DISTANCE, UADIST, QUARTER (Q1, Q3 and Q4) and combined AIRLINE*QUARTER (UAQ1, UAQ3 and UAQ4).

The model function was estimated using maximum likelihood with a log-linear form:

logl = log(sigi) + lnorm((TET-xb)*sigi))

Where TET is total elapsed time and "xb" is an equation with the variables described above:

xb = B0+ BUA*UA+ BRPM*RPM + BSnow*Snow
+ BDist*Distance + BUADist*UA*Distance
+ BQ1*Quarter1 + BQ3*Quarter3 + BQ4*Quarter4
+ BUAQ1*UA*Quarter1 + BUAQ3*UA*Quarter3 + BUAQ4*UA*Quarter4
+ BATL*City1 +BBUR*City2 + BLAX*City3 + BMCO*City4 + BMIA*City5
+ BOAK*City6 + BPDX*City7 + BSAN*City8 + BSFO*City9 + BSJC*City10.

The "sigi" term is ($1/\sigma$), the inverse of the standard deviation of TET, broken down into its component parts and several cross effect variables:

sigi = G0 + GUA*UA + GRPM*RPM
+ GQ1*Quarter1 + GQ3*Quarter3 + GQ4*Quarter4
+ GUAQ1*UA*Quarter1 + GUAQ3*UA*Quarter3 + GUAQ4*UA*Quarter4.

In order to interpret the effects of the G coefficients, a conversion can be performed to compare the contributions of each term to total variance in the regression. This can be done through the following transformation:

$$\text{Variance} = 1/(G0)^2 + 1/(GUA*\overline{UA})^2 + 1/(GRPM*\overline{RPM})^2 + \ldots,$$

with barred variables representing the means. Table 3 explains the interpretation of all of the coefficients included in the model.

The model was also run on data for departure delays (DD) to see the extent to which changes in total elapsed time can be explained by departure delays, as opposed to in-flight variables. Results were expected to be quite similar to those for the TET regression.

Table 3: Parameters and Interpretations

Parameter	Interpretation
B0	Average delay for an America West flight in the fourth quarter, holding dummy variables at zero and other regressors at their means
BUA	Difference in average delay for UA flights over America West flights
BRPM	Difference in average delay resulting from a log change in the Revenue Passenger Miles flown by domestic airlines in the month of the flight
BSNOW	Difference in average delay explained by at least a trace of snow at the hub of departure on the day of the flight
BDIST	Difference in average delay caused by a one mile increase in the length of the flight
BUADIST	Difference in average delay per mile flown for United versus America West
BQ1	Difference in average delay in the first quarter of the year relative to the second quarter.
BQ3	Difference in average delay in the third quarter of the year relative to the second quarter.
BQ4	Difference in average delay in the fourth quarter of the year relative to the second quarter.
BUAQ1	Difference in average delay for UA's Q1 flights over America West's Q1 flights
BUAQ3	Difference in average delay for UA's Q3 flights over America West's Q3 flights
BUAQ4	Difference in average delay for UA's Q4 flights over America West's Q4 flights
BATL→BSJC	Difference in average delay caused by effects particular to the destination airport
G0	Average variance in delay for an America West flight in the fourth quarter, holding dummy variables at zero and other regressors at their means
GUA	Difference in variance in delay for United flights over America West flights
GRPM	Difference in variance in delay resulting from a log change in the Revenue Passenger Miles flown by domestic airlines in the month of the flight
GDIST	Difference in variance in delay per mile flown on a given flight
GUADIST	Difference in variance in delay per mile flown for United versus America West
GQ1	Difference in variance in delay for flights in the first quarter over flights in the second quarter
GQ3	Difference in variance in delay for flights in the third quarter over flights in Q2
GQ4	Difference in variance in delay for flights in the fourth quarter over flights in Q2
GUAQ1	Difference in variance in delay for United flights over America West flights, holding the quarter constant at Q1
GUAQ3	Difference in variance in delay for United flights over America West flights, holding the quarter constant at Q3
GUAQ4	Difference in variance in delay for United flights over America West flights, holding the quarter constant at Q4

6. Results

The results of the regressions are summarized in Tables 4 and 5. Table 4 shows coefficient estimates, standard errors and t-statistics for the Total Elapsed Time regression, and Table 5 shows the same information for the Departure Delay regression.

Economic interpretation of the coefficients reveals some expected results as well as some surprises. As expected, average flight times and delays rise with domestic Revenue Passenger Miles. The impact of the 21.1% (-8,273,787) decrease in RPM from October 2000 to October 2001 was a reduction in average TET of 6 minutes, 51 seconds. This change represents approximately 4% of average total flight time for the base period in the sample. Contributing to this improvement was a decrease in departure delay of 5:47. A one-percent increase in revenue passenger miles flown relative to the mean RPM of 38,127,000 for the sample period translates into an increase in flight time of 0.02%.

In addition to the positive correlation between average flight time and infrastructure-constant increases in demand, variance in flight times also rises with RPM. The GRPM coefficients, which are inversely related to variance, are negative in both TET and DD regressions. The decrease in RPM from October 2000 to October 2001 was accompanied by a reduction in the variance of flight times of over 30% for both airlines in the sample. A one-percent rise in RPM at the mean translates into an increase in variance of flight time of about 2% for both airlines.

The increase in flight time on snowy days in the departure hub, BSNOW, was estimated to be slightly under 6 minutes (5:57), with 5:33 of this difference occurring as longer departure delay. It is of note that, during the sample period, there was never any snow at the America West hub in Phoenix, meaning that the effects of snow at the hub in this

Table 4

Total Elapsed Time

Parameter	Estimate	Standard Error	t-statistic	P-value
G0	0.065482	6.96E-04	9.41E+01	[.000]
GUA	-3.87E-03	4.69E-04	-8.25752	[.000]
GRPM	-7.97E-10	1.54E-11	-51.7594	[.000]
GDIST	-2.96E-06	2.08E-07	-14.222	[.000]
GUADIST	-5.1E-07	3.68E-07	-1.39772	[.162]
GQ1	-0.00431	2.93E-04	-14.7207	[.000]
GQ3	0.003644	3.31E-04	10.9993	[.000]
GQ4	0.000605	3.54E-04	1.70829	[.088]
GUAQ1	0.00554	3.41E-04	16.2382	[.000]
GUAQ3	-0.00384	4.03E-04	-9.54381	[.000]
GUAQ4	0.0014	4.32E-04	3.24E+00	[.001]
B0	21.7279	5.87E+00	3.70E+00	[.000]
BUA	1.49E+01	4.75E+00	3.14E+00	[.002]
BRPM	8.29E-07	5.74E-08	1.44E+01	[.000]
BSNOW	5.96211	8.65E-01	6.89E+00	[.000]
BDIST	0.108036	2.86E-03	3.78E+01	[.000]
BUADIST	-0.01548	3.90E-03	-3.97E+00	[.000]
BQ1	6.67576	1.32E+00	5.06153	[.000]
BQ3	0.661737	1.26E+00	5.24E-01	[.600]
BQ4	2.04115	1.34E+00	1.53E+00	[.126]
BUAQ1	-8.41029	1.79E+00	-4.69E+00	[.000]
BUAQ3	1.59746	1.91E+00	8.37E-01	[.402]
BUAQ4	-2.68411	1.88E+00	-1.43E+00	[.154]
BATL	2.15618	1.86E+00	1.16031	[.246]
BBUR	0.95599	4.35E+00	2.20E-01	[.826]
BLAX	6.49832	4.22E+00	1.54E+00	[.124]
BMCO	3.02499	1.34E+00	2.25E+00	[.024]
BMIA	6.9745	1.74E+00	4.01E+00	[.000]
BOAK	8.88198	3.59E+00	2.47E+00	[.013]
BPDX	11.1442	3.09E+00	3.60171	[.000]
BSAN	-2.6606	4.36E+00	-6.10E-01	[.542]
BSFO	21.4905	3.46E+00	6.20E+00	[.000]
BSJC	11.0981	3.65947	3.03271	[.002]

Table 5

Departure Delay

Parameter	Estimate	Standard Error	t-statistic	P-value
G0	0.067404	7.44E-04	9.07E+01	[.000]
GUA	-2.88E-03	4.95E-04	-5.81107	[.000]
GRPM	-8.24E-10	1.67E-11	-49.2474	[.000]
GDIST	-2.86E-06	2.12E-07	-13.471	[.000]
GUADIST	-1.1E-06	4.00E-07	-2.82267	[.005]
GQ1	-0.00375	2.96E-04	-12.6511	[.000]
GQ3	0.004072	3.47E-04	11.7437	[.000]
GQ4	0.002315	3.75E-04	6.17084	[.000]
GUAQ1	0.006293	3.51E-04	17.9538	[.000]
GUAQ3	-0.00407	4.32E-04	-9.411	[.000]
GUAQ4	0.000336	4.56E-04	7.37E-01	[.461]
B0	8.42302	5.80E+00	1.45E+00	[.147]
BUA	1.50E+01	4.72E+00	3.18E+00	[.001]
BRPM	6.99E-07	6.12E-08	1.14E+01	[.000]
BSNOW	5.55802	7.92E-01	7.01E+00	[.000]
BDIST	-0.01216	2.76E-03	-4.40E+00	[.000]
BUADIST	-0.0119	3.91E-03	-3.04E+00	[.002]
BQ1	4.66278	1.36E+00	3.42543	[.001]
BQ3	0.888601	1.33E+00	6.69E-01	[.504]
BQ4	0.840814	1.39E+00	6.04E-01	[.546]
BUAQ1	-6.43209	1.86E+00	-3.46E+00	[.001]
BUAQ3	2.40902	2.02E+00	1.19E+00	[.232]
BUAQ4	-0.65505	1.97E+00	-3.32E-01	[.740]
BATL	-4.18389	1.80E+00	-2.3251	[.020]
BBUR	-23.8806	4.18E+00	-5.71E+00	[.000]
BLAX	-17.3941	4.06E+00	-4.29E+00	[.000]
BMCO	1.63507	1.26E+00	1.30E+00	[.194]
BMIA	3.8749	1.65E+00	2.35E+00	[.019]
BOAK	-16.3549	3.45E+00	-4.73E+00	[.000]
BPDX	-12.1148	2.99E+00	-4.05348	[.000]
BSAN	-19.8512	4.18E+00	-4.75006	[.000]
BSFO	-2.83663	3.33E+00	-8.52E-01	[.394]
BSJC	-15.8298	3.51E+00	-4.51E+00	[.000]

sample fell solely on United flights. While adding in the effects of hub snow to flight time estimates may bias the model against United slightly, the choice of hub location is an important one for airlines, and cannot be ignored by travelers when choosing flights.

The effect of hub weather on flight times can be estimated roughly by calculating the portion of BSNOW that can impact flights on a given day. In Denver during the sample period, it snowed on 24% of flight days in the winter quarter, 16% of flight days in the fall quarter, 6% of days in the spring quarter and less than 1% of days in the summer quarter. Assuming constant probability of snowfall and constant number of flights per day during a given quarter, rough estimates of the impact of snow suggest adding 3:00 to average UA Q1 flight times, 2:00 to UA Q4 flight times and 0:45 to UA Q2 flight times.

Network-wide winter weather also was shown to increase flight times and delays. The coefficient for the Q1 dummy variable was positive in the TET regression, with first quarter flights lasting an average of 6:40 longer than flights in the second quarter. The increase was also seen in departure delays, with Q1 flights departing an average of 4:40 later than flights in the second quarter. At the 5% significance level, total elapsed times and delays in the third and fourth quarters were not shown to be statistically different from those of second quarter flights.

Between airlines, the expected value of total elapsed time is almost exactly equal for the large and medium-sized carrier in the base second quarter. Table 6 provides a quarterly breakdown of TET means, variances and standard deviations. In the spring basis quarter, a flight of average distance on United landing in Tampa would take:

B0 + BUA + BRPM*(Mean RPM) + (BDIST + BUADIST)*(Mean Distance) =

21.7 + 14.9 + 8.29E-7*(38,127,000) +(0.108 -0.0155)*(957) = 157 Minutes,

Table 6

Predicted Total Elapsed Time (Minutes) by Airline and Season

Excluding hub snow

	United		America West	
	Mean	Std. Dev.	Mean	Std. Dev.
Q1	123	16.8	132	17.1
Q2	125	17.2	125	15.9
Q3	127	17.2	126	15.1
Q4	124	16.6	127	15.8

Including hub snow

	United		America West	
	Mean	Std. Dev.	Mean	Std. Dev.
Q1	126	17.0	132	17.1
Q2	126	17.2	125	15.9
Q3	127	17.2	126	15.1
Q4	126	16.8	127	15.8

assuming no snow at the hub airport. Under the same restrictions, a flight of the same distance on America West would have a total elapsed time of:

B0 + BRPM*(Mean RPM) + BDIST*(Mean Distance) =

21.7 + 8.29E-7*(38,127,000) + 0.108*(957) = 157 Minutes

Adjusting for flights of different distances, shorter flights are faster on America West than United, while longer distance flights take slightly longer on America West.

Looking at the variance in flight times, however, flights of equal distance on United and America West are slightly different. At the sample mean distance of 957 miles, a United flight has an expected variance in total elapsed time of:

$1/ [G0 + GUA + GRPM*(Mean RPM) + (GDIST + GUADIST)*(Mean Distance)]^{2} =$

1/[0.0655 – .00387 – 7.97E-10*(38,127,000) + (-2.96E-6 – 5.1E-7)*(957)]^2 =

$1/[.0279]^{2}$ = 1282 Minutes.

An America West flight of the same distance has an expected variance of:

$1/[G0 + GRPM*(Mean RPM) + GDIST*(Mean Distance)]^{2} =$

$1/[0.0655 – 7.97E-10*(38,127,000) – 2.96E-6*(957)]^{2} =$

$1/[0.0323]^{2}$ = 960 Minutes.

These equate to standard deviations of 35:48 for United flights and 30:59 for America West. Overall, the standard deviation of United's flight times on flights of average distance for the sample is 16 percent higher than that of America West flights in the base quarter. With flights of different distances, the gap between the airlines in terms of variance stays roughly the same.

As for the effect of winter weather across route networks, America West has a disadvantage versus the larger United. Holding distance flown constant, America West flights took 8:25 longer than United flights in the winter quarter. When likelihood of snow at the hub is factored in, America West flights still come in roughly 5:25 later than United flights. Negligible differences were found in flight times during the spring, summer and fall. Delays followed a similar pattern. Spring, summer and fall delays were not statistically different between the airlines at the 5% significance level.

After accounting for snow at the hub, flights on United had relatively constant variance throughout the year. America West had roughly the same variance in flight times as United in the winter, but lower variances in flight times than United in the spring, summer and fall. The largest difference in variances between the airlines was in the summer quarter, when United had a variance 30% higher than America West. Even still, the actual difference in flight times amounts to very little, as America West's summer advantage translated into a difference in standard deviation of only 2:06, a difference of just 1.3% of average flight time.

To summarize, America West and United flights take the same amount of time in the spring, summer and fall, while United has slightly better flight times than America West in the winter. Overall variation in flight times is smaller on America West, except in the winter, when variances are the same on both airlines. Quantitatively, though, the difference in flight time variance between airlines is small relative to total flight time.

These results show that the interaction of network size effects changes over the course of the year. United's advantage in reduced reserve requirements is most clearly evident in the winter, as average flight times remain pretty much constant for United despite the effects of winter weather. America West enjoys less variance in flight times than United for the rest of the year, but is less equipped to deal with delay problems in the winter quarter, leading to an increase in flight times. Thus there are both service advantages and disadvantages to having a larger hub and spoke network. Measurement of consumer preferences for speed versus variability in flight time would allow regulators to quantify these returns to scale.

Just as congestion, season, hub airport location and airline play important roles in determining flight length, the destination airports in the sample may also be of interest to regulators and some customers, especially those flying into areas with more than one airport. The highest total elapsed times in the sample can be found at San Francisco International Airport, with flights into San Francisco taking 21:30 longer than equal distance flights to other airports.

The difference in flight length to San Francisco cannot be attributed to delays, as flights departing for SFO leave the hub an average of 2:50 before flights to TPA, the basis airport. Weather delays from rain and fog are almost definitely to blame, as planes are often put into holding patterns due to runway congestion during times of low-visibility. Proposed runway construction would likely reduce SFO's disadvantage relative to other airports in terms of delays. For now, Bay Area customers appear to be better off flying into Oakland as opposed to San Francisco or San Jose, though flights into the Bay Area all take longer on average than flights to other destinations in the sample. Customers flying into the Los Angeles area typically will have faster flights into Burbank than LAX, while flights into San Diego see the lowest average flight times in the sample.

7. Conclusions

The regression results described above restate quantitatively what airline customers have known for a long time: flight times go up when more travelers are added into a fixed-capacity airline infrastructure system. Delay sensitive customers are better off flying at times of low demand and good weather, especially in departure and arrival cities, but also on the entire hub and spoke network. There are few instances of these optimal flying conditions in the domestic market over the course of a given year, especially in years of high demand or particularly bad weather.

As for flight time disparity between airlines, there was little difference between United Airlines and the smaller America West Airlines. United's slight advantage in average flight times in the winter months was countered by lower variation in flight times for America West through most of the year. This difference between the airlines is evidence that the effect of greater vulnerability to network delays on larger airline networks is offset by the ability of larger airlines to make up for delays with lower levels of reserve resources.

Industry-wide congestion is shown to increase flight times, as can be seen in the levels of the BRPM coefficients in both total elapsed time and departure delay regressions. The increases in flight time due to congestion are small on an incremental level, but large demand decreases within the sample period reveal a sizeable impact on flight times. The positive relationship between revenue passenger miles and flight times is evidence of decreasing returns to scale for the industry as a whole, at a fixed level of infrastructure. More passengers in the system translate into decreased service quality for all passengers at current levels of capital. This decrease in service quality comes mainly in the form of longer flights, much of which can be explained by longer departure delays. In addition, flight times have a higher variance as the ratio of travelers to infrastructure rises.

Rapid demand decreases as a result of terrorist attacks during the fall of 2001 allowed the opportunity to compare airline delays as the number of passengers change over time, even within the 26-month dataset utilized in this study. The small time period of the study ensured that the basic infrastructure of the airline industry remained in tact for the duration of the sample. Heightened airport security in the fall of 2001 may have added to flight times, though the effects of increased security measures seem difficult to quantify separately from the decrease in demand, given the constraints of the sample. As a result, the impact of the change in demand on flight times may be understated by the estimates in the regression.

While the sharp decrease in demand has lessened public worries about the effects of congestion on flight times, it is likely that these concerns will return once the industry recovers from the residual effects of the September 11, 2001 terrorist attacks. The results of the model regressions provide some insight into the manner in which congestion affects different size carriers, revealing that winter weather delays seemed to impact the smaller America West more than United. The consistently lower variation in flight times for America West flights indicates that, while average delays may be equal on both airlines, United's customers are more likely to suffer a very long delay than America West customers are.

Despite the fact that larger network size was not found to have a sizeable impact on the on-time performance of the airlines in this study, interpretation of the interaction between the scale effects of increased delay risk and decreased reserve ratio requirements yields some interesting results. Seasonal differences between the airlines imply that the reduced reserve ratio advantages for United are strongest in the winter, the time when the network is most vulnerable to delay causing events. For the rest of the year, the fact that America West flights have a lower variance in flight time than United flights implies that there are at least slight disadvantages to having a larger network. These may come from increased exposure to delay-causing events. While United generally manages to make up for this potentially negative effect on flight times, the airline was unable to avoid a few unusually long delays during the sample period, adding to flight time variance. America West, with fewer exposure points, could more effectively keep flight times within a smaller band of variation from the mean.

A look at the effects of snow at a hub airport helps to put the magnitude of delays from seasonal congestion, network spoke weather and airline size into perspective. Not surprisingly, bad weather at the hub airport was shown to delay flights significantly, adding roughly 5:58 to the average flight time on snowy days in Denver. Thus snow at the hub contributes to flight delays more than an incremental change in any other variable in the model. Airlines such as United with relatively high vulnerability to snow at their hub airports have sought ways to limit the impact of hub snow on their hub and spoke networks, sometimes shifting passenger traffic to other hubs during times of high potential for bad weather. Further study could compare the weather advantages of southern hubs in relation to the centrality of location on connecting cross-country flights between cities, and would help airlines to determine optimal hub locations.

American Airlines' acquisition of TWA, with a hub in St. Louis, was at least in part motivated by the opportunity to gain a hub in a centrally located area with better weather than Chicago, one of American's main cross-country hubs. A study of the competitive advantages to this purchase would shed light on the structure of the industry and help both consumers and regulators to ensure that airlines remain competitive in the face of mergers, partnerships and alliances between carriers.

The maximum likelihood regression employed in this study is by no means a complete model of the airline industry, but instead focuses on the specific components of competition that relate to delays. Increasing returns to scale when looking at airline costs may be larger than the delay effects of increased scale, but the differentiation in service that stems from the service speed changes must be included in a complete model of the airline industry. A more comprehensive economic evaluation of airline competition could incorporate the results of this study with measures of differences in fares, efficiency and input costs across airlines.

Network characteristics, such as the degree of interconnection of routes, and the distribution of airplanes on the network over time may further explain the impact of hub and spoke networks on flight service. If planes flying in from delay-prone airports fly only to and from the problem airport and the hub, then the delays are not magnified across the network as they would be if these planes were scheduled to fly on many different routes on a given day. Flight schedules that incorporate the likelihood of delay from a particular spoke airport may help to mitigate the negative effects of adding such destinations to the route network. A model of delays that incorporated such scheduling factors would be beneficial for both researchers and airlines seeking to optimize their resources.

In addition to the limitations of the model in analyzing the source of delays, data sample constraints restricted the economic interpretations that could be made from the study. A clear next step would be to include more airlines in the study, and to study those carriers for a longer period of time. A larger distribution of airline sizes would have produced a more complete picture of flight times across the industry. The inclusion of a wider variety of destination cities could also prove informative, as would restricting the sample to a particular route with measurable weather or congestion effects that vary over time.

The congestion externalities of increased passenger demand reveal the need for better management of passengers on hub and spoke networks, and may provide justification for infrastructure expansion. Customer and airline awareness of the costs and benefits of network size characteristics and resource distribution will lead to greater efficiency in choosing and pricing flights. Time-sensitive business travelers are particularly eager to ensure that their flights are as fast as possible on a consistent basis, and the results of this study cast some light on the network factors that can impact delays and flight time variation. Recognition of the impact of total flight time differentials over time and across airlines will hopefully allow for researchers, regulators and consumers to gain a better understanding of the complex competitive markets in the airline industry.

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What have the airline reports on the causes of delay shown about flight delays? Is it true that weather causes only 4 percent of flight delays? How many flights were really delayed by weather?Â In 2020, there are 10 marketing carrier networks. Additionally, operating carriers that have 0.5% of total domestic scheduled-service passenger revenue report on-time data and the causes of delay. In 2020, there are 17 carriers reporting these numbers, including one (ExpressJet Airlines) that is reporting voluntarily. Do the airlines report the exact cause of the delay?Â Air Carrier: The cause of the cancellation or delay was due to circumstances within the airline's control (e.g. maintenance or crew problems, aircraft cleaning, baggage loading, fueling, etc.). As we frame the problem, we should note that we are living in the safest period in aviation history and we are constantly striving to make it safer still. In the past 10 years, the commercial fatal accident rate has dropped 57%. In the past three years, the United States averaged approximately two fatal accidents per year and 28 deaths per year; while any loss of life is tragic, this statistic is remarkable, given that there are well over 100,000 aircraft operations per day.Â The Future Airport Capacity Task (FACT) 2, an FAA study which was recently released, considered the impact of growth in air travel through 2025. Demand and operational capacity at 291 airports spanning 223 metropolitan areas across the country was evaluated. Non hub flights at hub airports operate with minimal additional travel time by avoiding the congested peak connecting times of the hub carrier. These results suggest that an optimal congestion tax would have a relatively small impact on air traffic delays since hub carriers already internalize most of the costs of hubbing and a tax that did not take the network benefits of hubbing into account could reduce social welfare. Acknowledgements and Disclosures. Cook and Goodwin: Airline Networks: A Comparison of Hub-and-Spoke and Point-to-Poin Airline Networks. Airline networks: a comparison of hub-and-spoke and point-to-point systems. Gerald N. Cook and Jeremy Goodwin. Abstract.Â This indiscriminate terminology obscures the fact that most US LCCs do not employ point-to-point route architectures. Certainly the prototypical LCC Southwest Airlines is an example of a predominately point-to-point airline; but AirTran and Frontier, for example, operate classic hub-and-spoke (H&S) route systems.Â A delay on one or a few inbound flights can spread as outbound flights are held for connecting passengers.