Journal of Air Transport Management 16 (2010) 36–41

Contents lists available at ScienceDirect

Journal of Air Transport Management

journal homepage: www.elsevier.com/locate/jairtraman

Pricing congestion for arriving flights at Chicago O'Hare Airport

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ABSTRACT

This paper estimates congestion fees for arriving flights at Chicago O'Hare Airport. The analysis finds that the level of congestion is only about a fifth of the magnitude of the congestion associated with departing flights. Congestion is much worse in poor weather conditions, and mitigating these weather delays is a primary objective of the current program to reconfigure the airfield. The analysis finds that the non-linearities inherent in models of congestion mean that even a very modest change in flight patterns reduces delays and congestion fees quite considerably.

1. Introduction

This paper is a companion piece to Johnson and Savage (2006). That paper calculated a set of congestion fees applicable to take offs from Chicago O'Hare International Airport. Of course, under a system of congestion charges, aircraft will be assessed two separate fees. One fee will be for the congestion caused when they land and a second fee will cover the congestion caused when they take off. This contrasts with most traditional airport pricing systems where aircraft are assessed a single fee that covers both landing and taking off.

We calculate the arrival congestion fees for the same two days that were analyzed by Johnson and Savage. One day (Wednesday, September 22, 2004) featured perfect flying weather nationwide. Even on that day the volume of traffic caused congestion. A week earlier (September 15) light rain and moderate winds from the southwest set in during the afternoon and necessitated use of a less efficient set of runways with consequent extensive delays that persisted until the late evening. While we will refer to this as a "bad weather day," it should be noted that the weather was not extreme (there were no thunderstorms, fog or snow) and operations did not have to temporarily suspended at all; a situation not uncommon in Chicago.

In the period since the publication of the original paper, there has been renewed interest in tackling airport congestion in the US using economic methods. The benefits from doing so were calculated by Morrison and Winston (2007), who estimated that charging congestion fees would generate annual net benefits of at least \$2.7 billion nationwide. O'Hare generated the most net benefits of any airport at \$0.4 billion. In a major policy shift, the US Department of Transportation announced in April and May 2007 that they intend to tackle the problem at the three largest airports in the New York City area by means of auctioning off a proportion of the daily slots. Brueckner (2008) provides background references on this new policy direction, and discusses the economic desirability of a policy of slot sales versus charging a congestion fee.

2. Measuring arrival delays

The magnitude of arrival delays is a lot harder to measure than departure delays. Departing aircraft queue up on the taxiways. In contrast, arrival delays can be manifested in many ways. Aircraft can be held on the ground at the originating airport, and aircraft en-route can be asked to slow down, take a circuitous route, or circle in a holding pattern. Finally, aircraft that have landed may experience congestion on the taxiways or in the gate areas. We found that the latter was not a significant factor. Using the wheels-on time and gate arrival time from the Bureau of Transportation Statistics (BTS) Airline On-Time Performance database, we found that the taxi-in time averaged about 7 min, but did not vary in any significant fashion with the amount of other traffic present. Therefore, our estimation of arrival delays will be solely concerned with ground holds and lengthened in-flight times.

A word of caution is necessary. The BTS database only contains information on domestic scheduled passenger flights by US flag carriers. It does not contain international passenger flights operated by either US or foreign carriers, or other operations. Not only don't we know the delays suffered by these flights, we also do not know how many of these aircraft are present in the arrival queue. However, O'Hare is primarily a domestic airport. Official traffic movement reports show that domestic scheduled passenger flights represented 86% of all aircraft movements in September 2004. International scheduled passenger flights (that include Canadian

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0969-6997/\$ – see front matter
doi:10.1016/j.jairtraman.2008.11.010

and Mexican operations) were 8.4% of aircraft movements, and the remaining 5.7% were a mixed bag of unscheduled, cargo, military and general aviation traffic.

The calculation of arrival delays is a two-step process. The first step is to calculate the time at which each of the 1000 daily domestic flights would have touched down under ideal circumstances and the absence of congestion. We will refer to this as the inflow time to an imaginary arrival "queue" at the perimeter of O'Hare. The inflow time is calculated by taking the actual observed wheel-on time and subtracting actual ground holds and calculated in-flight delays. The BTS database reports the magnitude and causation of ground holds. We are only concerned with subtracting air traffic control ("National Aviation System") delays and weather delays. Other ground delays are not adjusted for as, for example, an aircraft that is held at the gate at the origin due to a mechanical problem would be arriving late at O'Hare regardless of the congestion that is present.

Estimation of in-flight delays is more problematic. The actual in-flight time (from wheels-off to wheels-on) can be calculated from the BTS database. Of course, congestion is not the sole cause of variation in in-flight time between individual flights on a specific route. Other factors include the strength of the prevailing winds aloft, detours to avoid storms, the altitude chosen, and an aircraft's maximum speed and loaded weight. The methodology we chose was to take in-flight data for the 20 busiest routes into O'Hare, each of which had at least fifteen flights a day. For each flight we calculated the excess in-flight time compared with the minimum time achieved on that route on that day (this calculation is in the spirit of the measure used by Mayer and Sinai (2003)). We found that air times differed by as much as 23 min on some routes, and these large differences were not limited to long cross-country flights. Several relatively short routes (Boston, Philadelphia, Washington D.C. and Pittsburgh) had air times that varied by more than 20 min.

Flights on these busy routes represented almost half of all flights (461 of 1002 flights on the good weather day). We generalized the delay to all flights by calculating the average in-flight delays on the busy routes for each 15-min period of day. To do this, flights were grouped by their actual wheels-on time. This average in-flight delay was then applied to all flights arriving in that 15-min period. The rationale for using this average is that in congested conditions, all incoming flights will be subject to slowing down and vectoring as they line up to land.

The second step of the process is to construct a simulation model of this imaginary arrival queue. We used a model because we wanted to calculate the congestion-producing effects of a marginal flight. Our modeling is simplified because O'Hare operates with separate runways for arrivals and departures. The model assumes first-in-first-out. The maximum discharge rate from the queue is assumed to be 80 landings per hour on the good weather day. This is based on the official capacity of O'Hare in 2004 of 88 arrivals per hour, adjusted for the approximately 10% of flights that come from international origins.

Fig. 1 shows a plot of the *average* simulated delay experienced in each 15-min period from 5am until midnight on the good weather day. Flights are classified by their inflow time. The average simulated delay is shown as the dark line with the squares. The delays are generally quite small, averaging less than 5 min, and only rise above 5 min in the evening peak between 6pm and 8pm.

Also shown in Fig. 1 is an indication of the length of the imaginary queue, shown as the gray line with the triangles. For the purposes of this figure, the queue length is a combination of the number of flights with inflow times in each 15-min period, and the number of flights that our simulation model indicated could not be served in earlier period(s) and were held over to the current period. Significant congestion occurs when the queue exceeds the maximum discharge rate (of 20 aircraft every 15-min). Between 5am and 5pm, there are six periods when the queue exceeds the maximum discharge rate. However, on each of these occasions the excess demand only occurs for a short period, and the localized peaks are followed by a period of considerably lower inflow which allows the queue to dissipate. However, between 5:30pm and 8:15pm capacity is exceeded almost continuously, with only a brief respite around 7pm. After 8:30pm, the number of arriving flights falls to a very low level.

A test of how well the simulation model fits the observed delays can be found by comparing *average* simulated delays against the *average* difference between the inflow time and the actual wheels-on time for flights in each 15-min window. The latter is shown as the thin line with the diamonds in Fig. 1. In general the two lines

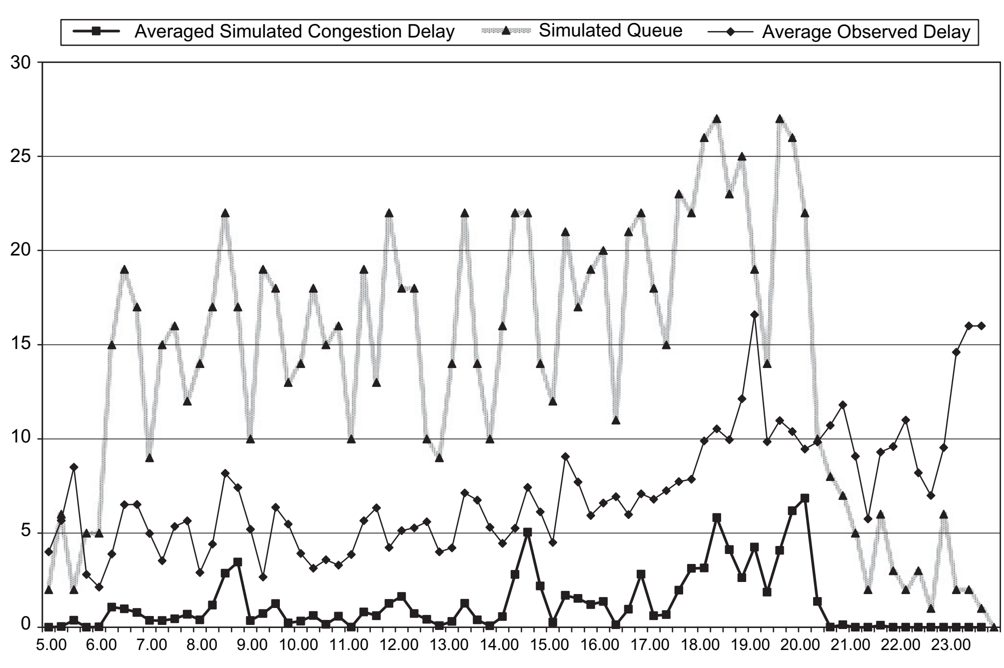

Fig. 1. Simulated versus observed congestion delays on September 22, 2004.

track each other very well, with average observed delay exceeding the average simulated delay by about 4 min for most of the day. In comparing the two lines, one should remember that the simulation model produces an estimate of congestion delays in perfect conditions. That is to say, we inherently assume that controllers have perfect foresight as to when an individual flight will arrive at the perimeter of O'Hare, and are able to practice perfect queue management with aircraft neatly spaced. In reality the length of ground holds may be too aggressive, and excessive gaps can occur between aircraft on their final approach.

In addition, the simulation solely models congestion-related delays, whereas the observed delays may include delays totally unrelated to O'Hare such as airspace congestion at the origin, changes in prevailing winds, or the use of slower aircraft. For example, the greatest divergence between observed and simulated delays occurs after 9pm when O'Hare operates in free-flow conditions. The explanation appears to be that there were some large delays experienced by a few flights originating from New York's La Guardia airport, and lengthened in-flight times for incoming flights from the West Coast, perhaps indicating less strong tail winds compared with earlier in the day.

3. Calculation of atomistic congestion prices on a good weather day

The standard steady-state bottleneck model of congestion requires that a marginal aircraft is assessed a congestion fee equivalent to the marginal additional congestion externality imposed on other flights. We estimate a set of fees for each 15-min period, based on the congestion caused by the median arriving flight in each time period. For the purposes of the calculations in this section of the paper, flights were ordered and classified into time periods based on the wheels-on time that is predicted by the simulation model. There is no inherent reason why this methodology would be preferred to, say, basing it on the inflow time to the imaginary queue.

To ensure comparability with the departure fees calculated by Johnson and Savage, the same value of delay time is used of $92.97 per aircraft min. This value includes the capital and operating cost of the aircraft and crew, and a value of time to the passengers, and is based on standard values recommended by the Federal Aviation Administration. The resulting congestion fees are shown in Fig. 2. These figures are for an atomistic airline, such as Alaska Airlines that only operates a few flights a day. For this airline, all of the congestion externality they create is imposed on other airlines.

For half of the time between 5am and midnight (38 of 72 quarter-hour periods) there is either no congestion fee payable, or a minimal fee of less than $100. The atomistic fee exceeds $1000 between 8:15am–8:45am, 2:15pm–2:45pm, 3:15pm–3:30pm, 4:30pm–4:45pm, 5:30pm–6:30pm, and 6:45pm–8:00pm. The maximum atomistic fee is $3000 in the morning and $6000 in the early evening. While these figures may seem high, they are quite small compared with the departure fees calculated by Johnson and Savage. Atomistic departure fees on the good weather day reached a maximum of $17,000 in mid-afternoon.

4. Atomistic versus Cournot congestion prices

American and United Airlines, and their regional affiliates, dominate O'Hare with market shares of domestic flights on the good weather day of 48.8% and 40.5% respectively. Brueckner (2002) argues that these airlines should be assessed congestion fees equivalent to the atomistic fee multiplied by unity minus their market share. This is because these airlines are already bearing some of the externality as their own aircraft form a significant proportion of the flights that are backed up behind the marginal flight. The most recent literature refers to this price as a "Cournot congestion fee," because of the assumed nature of the oligopolistic competition between the major airlines.

However, this argument has been controversial. Daniel and Harback (2008) argue that a dominant airline would not be able to internalize any congestion gains from removing a marginal flight if a competitor that was viewed by passengers as a perfect substitute immediately stepped in to occupy the vacated slot. In these circumstances, even a dominant airline should be assessed an atomistic congestion fee. Brueckner and Van Dender (2008) present a unifying theoretical model, and argue that, in practice, the

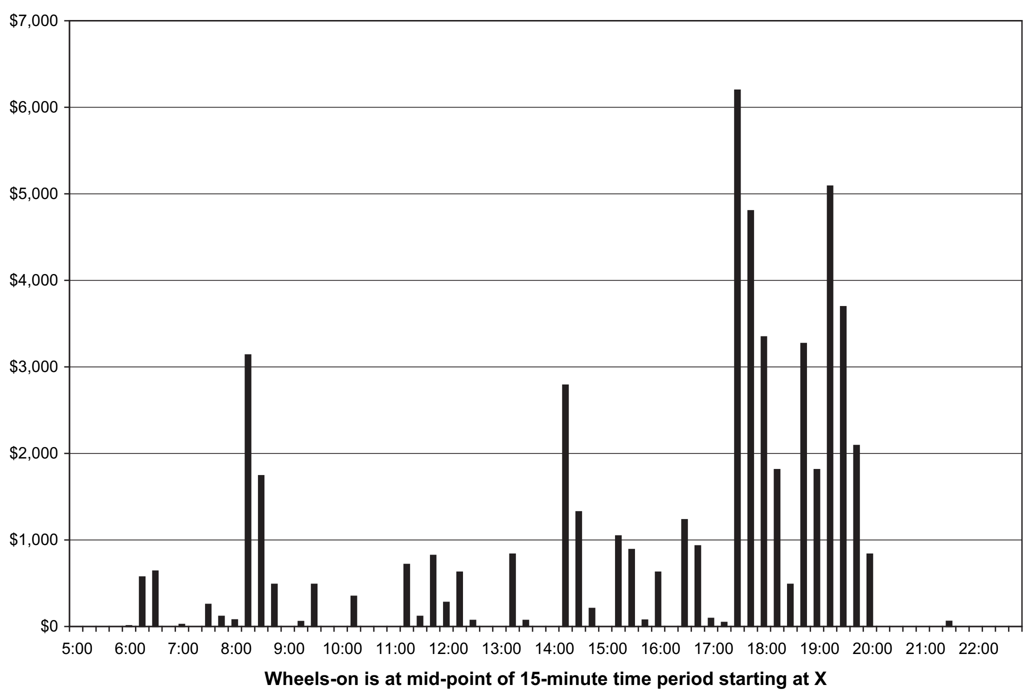

Fig. 2. Arrival congestion fees for an atomistic airline assuming current traffic levels on September 22, 2004.

appropriate congestion fee will depend on the existence of a "competitive fringe" of airlines, and whether passengers view the fringe as a perfect or imperfect substitute for the dominant carrier(s).

The empirical evidence at O'Hare is mixed. There has been longstanding evidence that American and United have engaged in Cournot competition at this airport (Brander and Zhang, 1990). On the other hand, Daniel and Harback's position is supported by events in the summer of 2004. The Federal Aviation Administration had brokered a deal with American and United to reduce congestion by rescheduling 37 flights a day away from peak hours. Almost immediately these slots were filled by fringe airlines, most notably Northwest Airlines and newcomer Independence Air. While this behavior would argue for charging atomistic fees to all airlines, one would be hard pressed to argue that the fringe were in any way perfect substitutes for the two dominant carriers. The liquidation of Independence Air eighteen months later would seem to support the contention that they were unable to gain market share. Brueckner and Van Dender would therefore argue that the appropriate fee to charge American and United will fall somewhere between the Cournot fee and the full atomistic fee.

5. The effects of bad weather

O'Hare is currently in the midst of an expansion program that intends to substitute a set of parallel runways for the current configuration. The present configuration is very vulnerable to a southwest wind, which is quite common in Chicago. Light rain and moderate winds of less than 20 knots set in by mid-afternoon on September 15, 2004 and resulted in extensive delays starting about 2pm and persisted until 11pm. At the peak of the congestion, our simulation model predicted that every flight was suffering a congestion-related delay of more than one hour.

Calculation of congestion prices on the bad weather day was conducted in the same manner as on the good weather day. The main difference is a lower queue discharge rate. While we do not know the formal discharge rate, it can be inferred from observing the actual rate of landings, and by comparing the delays predicted by the simulation model with the actual delays experienced. Ultimately the best fit was obtained when the maximum queue discharge rate was restricted to 60 landings an hour starting at 9am, with further restrictions to 56 an hour starting at 3pm, and 50 per hour from 6pm.

The calculated congestion fees for an atomistic airline are shown in Fig. 3. The highest fee is \$44,000 at 2pm. This is when the most severe congestion starts. The fee then declines until the congestion dissipates, which is not until 11pm. Again, while the fee may seem extreme, it is much more moderate that the maximum atomistic departure fee calculated by Johnson and Savage on this day, which was a staggering \$1.3 million.

The purpose of making this calculation is to raise an important question: Should congestion fees be calculated based on operations in ideal conditions, or based on a weighted average of the actual weather conditions experienced over a year? (Presumably, one would exclude from this calculation days when conditions lead to operations being temporarily or completely suspended, but such a calculation would represent the typical traveler experience.)

6. Combining arrival and departure fees

By matching aircraft registration numbers from the BTS database, we were able to determine that the median time from an aircraft's wheels-on time to pushing back from the gate for its next flight is 71 min (aircraft that stay overnight were excluded from this calculation). Therefore, we were able to combine together the arrival fees calculated here and the departure fees calculated by Johnson and Savage by assuming that an aircraft that had a simulated wheel-on time at the median point of a 15-min period would pushed back exactly at the quarter-hour approximately 67.5 min later.

The sum of the atomistic fees on the good weather day is shown in Fig. 4. The time shown on the horizontal axis is the starting point of the 15-min period in which the aircraft landed. The combined fee is broken down into the arrival fee, the departure congestion caused to aircraft that are in the queue at the same time as the departing aircraft, and (if appropriate) any congestion delays suffered by later departures when congestion is persistent. For aircraft arriving in the morning and midday hours, and in the mid to late evening, the total

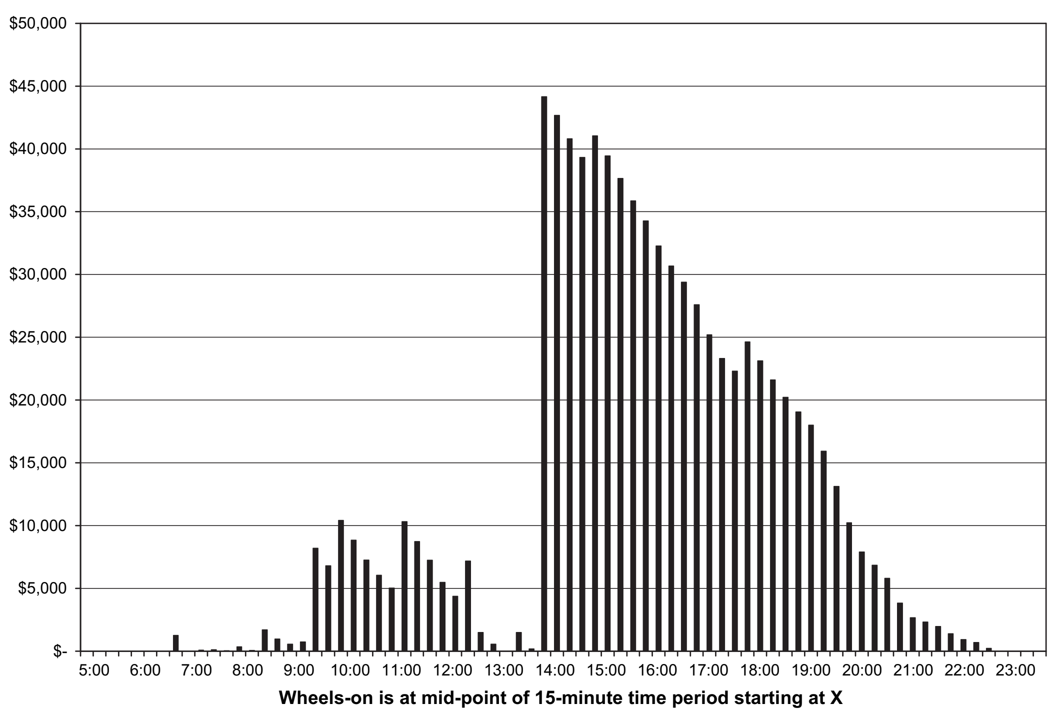

Fig. 3. Arrival congestion fees for an atomistic airline assuming current traffic levels on September 15, 2004.

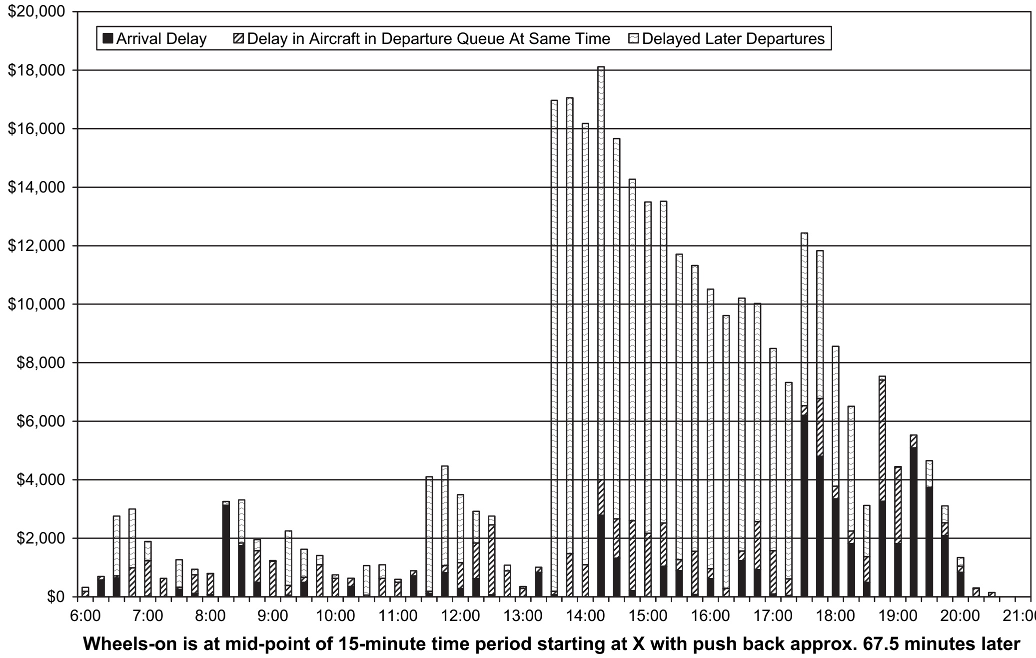

Fig. 4. Combined arrival and departure congestion fees for an atomistic airline assuming current traffic levels on September 22, 2004.

atomistic fee is less than $5000. The persistent congestion in the mid and late afternoon and early evening results in atomistic fees of greater than $10,000 with the maximum fee of $18,000 for a landing that occurs between 2:15pm and 2:30pm, with a subsequent push back from the gate at 3:30pm. Across the entire day, the average combined arrival and departure fee is $5650 for an atomistic airline. By way of comparison, the weight-based fee payable in 2004 was $520 for a Boeing 757-200 and $120 for a Canadair CRJ200.

7. Demand responsiveness

All of the calculations up to this point have assumed that demand is completely inelastic at the current levels of traffic. This is clearly not realistic. One would imagine that if passenger fares were raised at peak times, then some passengers would not fly and others would reschedule their trips to off-peak, cheaper, times. Airlines might be encouraged to consolidate departures on busy routes and use larger aircraft, or reallocate some spoke routes to an alternative hub (Denver in the case of United, and St Louis for American). When demand is shifted in time, one would expect the fee to fall in the periods where flights are removed from, and to rise in the periods that the flights are shifted to. At least in theory, the congestion fees will iterate to equilibrium.

Complicating the calculation of the ultimate equilibrium fees is uncertainty as to whether the revenue obtained from the congestion fees will result in a reduction or elimination of other airport fees and federal taxes. In 2004, operating revenues for O'Hare were $1.2 million a day, of which about half came from landing fees and terminal usage fees, and the balance from rents and concessions (City of Chicago, 2004). Even if the congestion fees were determined based on operations on the good weather day, they would generate daily revenues of between $3.3 million (based on a Cournot fee) and $5.6 million (if every airline pays the atomistic fee). There would clearly be sufficient extra revenue available to offset some or all of the federal taxes and fees (see Karlsson et al., 2004). Of course, all current fees and taxes do not vary by time of day, and moving to congestion pricing will provide incentives to reschedule flights.

A further complication is that any moves to allow O'Hare to price congestion would probably occur subsequent to, or in conjunction with, similar initiatives at other notoriously congested airports, especially those in the New York City area. Consequently calculation of the ultimate equilibrium fees would have to be based on a network simulation model, with knowledge of cross-price elasticities across times of day, rather than a comparative statics model of an individual airport.

Table 1
Demand responsiveness example on good weather day, September 22, 2004.

Wheels-on in quarter-hour starting at	Current domestic arrivals	Initial combined arrival and departure atomistic congestion fee	Flights canceled	Flights shifted out	Flights shifted in
12:30	10	$2759			1
12:45	9	$1082			1
13:00	14	$351			2
13:15	22	$1012			1
13:30	12	$16,966		−1	
13:45	10	$17,054		−1	
14:00	16	$16,177		−2	
14:15	22	$18,103	−1	−1	
14:30	20	$15,655	−2		
14:45	12	$14,271	−1		
15:00	12	$13,493	−1		
15:15	21	$13,518	−2		
15:30	16	$11,709			
15:45	19	$11,322		−1	
16:00	20	$10,510		−1	
16:15	11	$9613			2
16:30	21	$10,202	−1		
16:45	21	$10,024	−1		
17:00	16	$8488			
17:15	15	$7326			2
17:30	23	$12,419		−2	
17:45	19	$11,815	−1		
18:00	24	$8552			
18:15	21	$6503		−1	
18:30	16	$3120			2
18:45	22	$7526		−1	
19:00	14	$4439			
19:15	14	$5512			
19:30	27	$4640		−3	
19:45	19	$3105		−1	
20:00	16	$1341			
20:15	8	$304			4

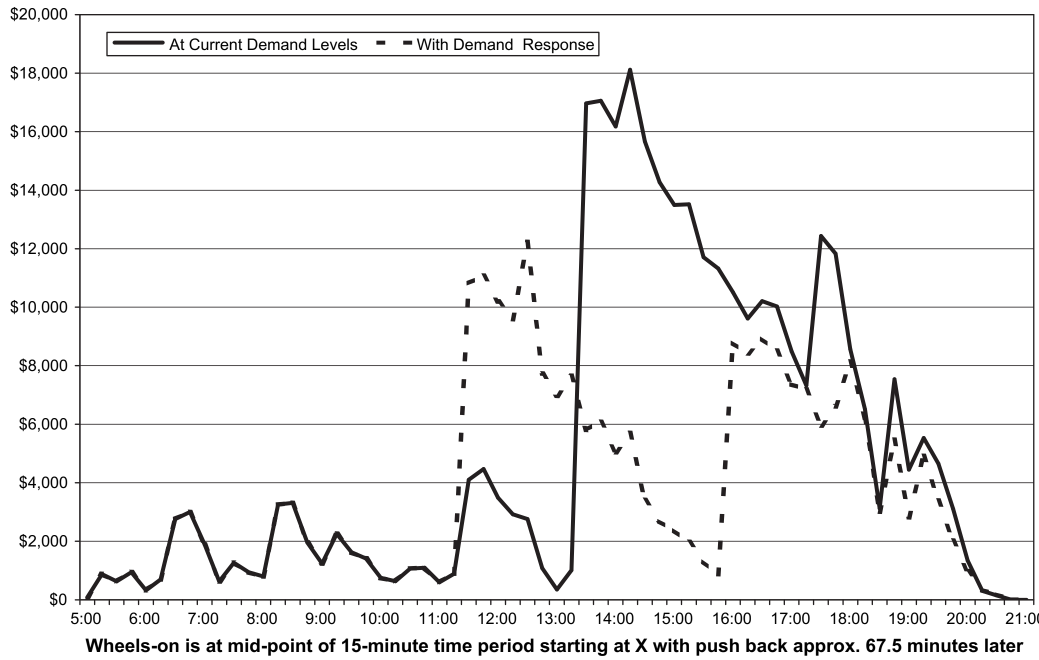

Fig. 5. Effect on combined arrival and departure congestion fees for an atomistic airline from changes in demand on September 22, 2004.

While we are unable to calculate the ultimate set of congestion prices, our model can be used to investigate non-linearities in the price schedule. A standard observation in the highway congestion literature is that even removing a very small amount of traffic has a grossly disproportionate effect on reducing congestion and the consequent congestion fee (see Small and Verhoef, 2007, Chapters 3.3 and 3.4). To this end, we modeled the effect of canceling ten flights and rescheduling a further fifteen flights in the afternoon and early evening hours. These flights, which are detailed in Table 1, represented only 5% of the 463 flights that arrive between 1:30pm and 8pm. Flights move away from the highest priced times. Consistent with Salop's (1979) "circle model" of product variety, we assume that if there is a proximate lower-priced time available, a flight is rescheduled. However, when high fees persist over an extended period, flights are canceled.

Revised congestion prices were obtained by rerunning both the arrival simulation model developed for this paper and Johnson and Savage's departure queue model. A comparison of the combined atomistic fees for arrivals and departures is shown in Fig. 5. The solid line indicates the fees based on assuming current traffic levels and the dashed line indicates the fees after there has been a demand response. There are a number of notable features. First, the rescheduling of some early afternoon flights to slightly earlier times results in large price increases in these earlier time periods as the congested period has now been lengthened. It is a standard result in the highway congestion literature that people who travel at the start of the congested period pay high prices as the "knock-on" effect of the congestion they cause persists for longer.

Second, despite the broadening of the peak, prices in general fall. The maximum atomistic congestion fee falls from $18,000 to $12,000. The non-linearities inherent in congestion models are readily apparent. Canceling just 2% of afternoon and early evening flights, and rescheduling a further 3% reduces the average total atomistic congestion fee paid by aircraft that arrive between 11:30am and 9pm from $8100 to $5800, a drop of almost 30%.

8. Summary

This paper estimates arrival congestion fees at Chicago O'Hare Airport, and finds that they are only about a fifth of the size of the departure congestion fees estimated in an earlier paper (Johnson and Savage, 2006). This is due to the fact that arrivals make more efficient use of available air and runway space, and unlike departures tend not to be concentrated at the top of each hour (37% of departing flights push back from the gate in the 15-min period between 10 min to the hour and 5 min after the hour). Congestion builds rapidly in poor weather conditions, and mitigating these delays is a primary objective of the current program to reconfigure the airfield. Finally, non-linearities inherent in models of congestion mean that even a very modest change in flight patterns resulting from congestion pricing reduces delays and congestion prices quite considerably. Alterations to just 5% of flights in the afternoon and early evening hours are found to reduce congestion fees by almost 30%.

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