International Transport Forum

To Allocate Slots or Not: That is the question

25

Discussion Paper 2017 • 25

Nicole Adler and
Ekaterina Yazhemsky
Hebrew University of Jerusalem, Israel

OECD

International Transport Forum

To Allocate Slots or Not:

That is the question

Discussion Paper No. 2017-25

Prepared for the Roundtable on

Capacity building through efficient use of existing airport infrastructure

9-10 March 2017, Querétaro

Nicole Adler and Ekaterina Yazhemsky
Hebrew University of Jerusalem, Israel

September 2017

OECD

The International Transport Forum

The International Transport Forum is an intergovernmental organisation with 59 member countries. It acts as a think tank for transport policy and organises the Annual Summit of transport ministers. ITF is the only global body that covers all transport modes. The ITF is politically autonomous and administratively integrated with the OECD.

The ITF works for transport policies that improve peoples' lives. Our mission is to foster a deeper understanding of the role of transport in economic growth, environmental sustainability and social inclusion and to raise the public profile of transport policy.

The ITF organises global dialogue for better transport. We act as a platform for discussion and pre-negotiation of policy issues across all transport modes. We analyse trends, share knowledge and promote exchange among transport decision-makers and civil society. The ITF's Annual Summit is the world's largest gathering of transport ministers and the leading global platform for dialogue on transport policy.

The Members of the Forum are: Albania, Armenia, Argentina, Australia, Austria, Azerbaijan, Belarus, Belgium, Bosnia and Herzegovina, Bulgaria, Canada, Chile, China (People's Republic of), Croatia, Czech Republic, Denmark, Estonia, Finland, France, Former Yugoslav Republic of Macedonia, Georgia, Germany, Greece, Hungary, Iceland, India, Ireland, Israel, Italy, Japan, Kazakhstan, Korea, Latvia, Liechtenstein, Lithuania, Luxembourg, Malta, Mexico, Republic of Moldova, Montenegro, Morocco, the Netherlands, New Zealand, Norway, Poland, Portugal, Romania, Russian Federation, Serbia, Slovak Republic, Slovenia, Spain, Sweden, Switzerland, Turkey, Ukraine, the United Arab Emirates, the United Kingdom and the United States.

International Transport Forum

2 rue André Pascal

F-75775 Paris Cedex 16

contact@itf-oecd.org

www.itf-oecd.org

ITF Discussion Papers

Abstract

Based on a non-parametric, structural equation modelling framework, this paper compares a set of highly congested US and European airports in order to assess the impact of approaches on overall social welfare, considering airline and airport surplus and passenger welfare. This paper discusses the data collected in order to estimate the impact of administrative changes with respect to slots on the most congested airports in Europe and the potential impact of introducing such a system in the United States.

Table of contents

Figures

Tables

Slot policies at all congested European airports follow regulations that restrict aircraft movements to declared runway capacity parameters. In the United States, movements are accommodated on a first come–first served basis, except for three airports restricted according to High Density Rules. The trade-off between these two approaches lies in maximising airport infrastructure utilisation versus minimising the creation of delays at hub airports. Based on a non-parametric, structural equation modelling framework, we compare a set of highly congested US and European airports in order to assess the impact of these approaches on overall social welfare, considering airline and airport surplus and passenger welfare. We find that delays in Europe are significantly lower than their US counterparts, which suggests that regulation in Europe could be relaxed. An increase in declared capacity of one slot per peak hour would lead to a higher number of aircraft movements and relatively minor increases in delays hence significantly higher overall social welfare in the region of USD 68 million at an average congested airport annually. We also find that the introduction of slots in the US (or reduction in slot caps allocated at the currently constrained airports) would decrease overall social welfare in the region of USD 18 million annually at the average congested airport. In conclusion, European slot cap regulation prevents the optimal use of current infrastructure whereas the US system is better able to capitalise on existing airport infrastructure.

Introduction

Air traffic congestion is caused by excess demand with respect to limited airport infrastructure. This phenomenon mostly pertains to shortages of runway capacity although terminal capacities may also create bottlenecks. It occurs more frequently at hub airports, although not exclusively, where airlines utilise banks of flights to maximise potential connections and minimise passenger-waiting times between flights in a hub-and-spoke system. The large number of incoming flights followed by outgoing flights in two to three banks over a day causes congestion that could be solved theoretically by encouraging a uniform number of flights spread over the day. However, this would reduce the benefits of the hub-and-spoke systems that enable more cities to be served more frequently than would occur in a fully connected network (Brueckner and Zhang,2001; Adler, 2005). As suggested by Mayer and Sinai (2003), such delays are necessary or even desirable hence congestion taxes are unlikely to affect the market characteristics. If infrastructure expansion is not possible, the introduction of slot controls simply passes scarcity rents from the airport to the airlines (Gillen and Starkie, 2016).

In order to accommodate the growth in demand for aviation over the decades, existing infrastructure has been reconfigured and expanded and new infrastructure such as airports, air traffic control towers, aprons and ground transportation facilities have been created. Furthermore, both the US and the EU have invested in research and development of air traffic control technologies. The aim is to increase existing runway and en-route capacities, with the intention of reducing congestion levels that reached high peaks in 1999 and again in 2007. Investment in technology is considered a preferable solution because it does not require physically expanding the airport size and may reduce aircraft fuel consumption and other negative externalities. Nonetheless, these new technologies are rather expensive with the projected costs of the European Single European Skies Initiative estimated to be approximately EUR 30 billion according to the European ATM Master Plan (SESAR, 2012). The American equivalent, NextGen, is estimated to cost USD 37 billion through the year 2030 (FAA, 2012). However, it should be noted that full implementation of these technologies is likely to take at least ten years, if not more, and will only mitigate but not completely eliminate the problem of limited capacity (Adler et al., 2014).

One of the main consequences of the existing gap between supply and demand in the aviation industry is the congestion that causes delays in particular during peak hours in the summer season. According to Ball et al. (2010), the overall cost of US air transportation delays for 2007 amounted to USD 28.9 billion, out of which USD 8.3 billion were direct costs to airlines and USD 16.7 billion were attributed to passengers. According to a report prepared by Cook and Tanner (2011), the cost of delays caused by European air traffic flow management was approximately EUR 1.25 billion in 2009. In summation, the cost of congestion and delays is clearly substantial and it is worthwhile investigating potential solutions, particularly if they are administrative, hence relatively less complicated to apply as compared to expanding infrastructure.

Different approaches have been discussed in the literature in order to assist in mitigating the complexity of managing excess demand, such as peak pricing and (secondary) market auctions. Peak pricing was first suggested by Levine in 1969. However, this approach has been implemented at only three airports in the UK to date, and airlines in Europe are heavily lobbying against the idea (Forsyth, 2007). Levine (2008) proposes a blind auction in which slots are chosen at random and made available to all bidders including the previous owner. In order to avoid potentially substantial revenues being earned by the Federal Aviation Authority (FAA) or relevant airport, Levine proposes that the proceeds of the auction are passed to the airline with grandfather rights on the slot and that the amount of both the winning and second-highest bid (but not the identity of the second-highest bidder) be made public. This in turn means that the airport has no monetary incentive to create scarcity. These ideas have rarely been attempted, except for LaGuardia for a short period and at London Heathrow in a secondary market. Once again, the airlines are rather opposed (Sentance, 2003). This may be due in part to the fact that there are considerable complexities in designing auctions for sets of slots and the strong possibility of creating further market distortions by unfairly favouring incumbent airlines (Czerny et al., 2008).

Today, it is the slot allocation mechanism that represents the most conventional means for managing demand at airports in all regions of the world apart from the United States. The slot allocations rules are set by national airport scheduling committees, which operate according to the International Air Transport Association's (IATA) guidelines (Ulrich, 2008). The committee allocates the capacity to airlines for a period of six months based on a set of rules, notably grandfathering of slots. However, these rules are often criticised for being inefficient and leading to a decrease in welfare and competition. The removal of grandfathering rights in Europe has been discussed in the academic literature, with the intention of finding ways to increase the utilisation of existing airport capacity and encourage competition between airlines, incumbents and new entrants alike. Removing or changing the current administrative mechanism will probably prove difficult to implement, among other factors due to the likely lobbying of incumbent airlines (Schank, 2005).

Despite the fact that slot allocation is the most common administrative procedure to control demand and limit congestion levels, each region has developed its own approach to enforcement. The USA was the first country to implement the High Density Rule (HDR) in 1969 in order to handle congestion and delays at the five most congested airports at the time: the three airports in New York (JFK, LaGuardia, and Newark), Chicago O'Hare and Washington Reagan. On the other hand, the capacity at all other US airports has not been regulated, with airlines being served under the first-come first-served concept. Over the years, there have been some regulatory changes such as the termination of the HDR at Newark in 1970, at Chicago O'Hare in 2002, and at JFK and LaGuardia in 2007. However, in anticipation of severe delays, the FAA did implement airport-specific orders to limit operations at LaGuardia beginning December 2006, then at Newark and JFK in January 2008. Chicago is no longer limited in part due to the large infrastructure changes that are still undergoing construction and are expected to increase capacity by 10% according to the FAA (2014) Newark was removed in October 2016 due to improved on-time performance. In Europe, mainly due to the later liberalisation of the airline sector compared to the US, council regulation no. 95/93 on common rules for allocation of slots at community airports was enforced in January 1993, together with the implementation of the Third Package of liberalisation. Today, there are 98 fully coordinated airports and 78 schedule-coordinated airports in Europe.[1]

The direct impact of these rules is highlighted in a benchmark study comparing Newark and Frankfurt airports in 2007, a year of strong demand on both continents (Odoni et al., 2011). The two airports display similar characteristics in terms of runways layouts, regional importance and air traffic movements, however substantially different demand-to-capacity relationships. While at slot coordinated Frankfurt airport, the demand is flat throughout the day, at Newark there is substantial excess demand at peak periods. Consequently, airlines serving Newark airport suffer from significantly higher delays, poor punctuality and a lack of schedule reliability. Swaroop et al. (2012) estimate the welfare effects of slot controls in the US system and argue that more widespread use of slot controls would improve passenger welfare by taking into consideration the trade-off between the reduction in queuing delays and the increase in schedule delays. Schedule delay is defined as the difference between the time that the passenger prefers to travel and the relevant airline schedule. Swaroop et al. (2012) suggest that slot limitations at the four[2] slot-constrained US airports are insufficient hence lower ceilings should be introduced and that two-thirds of total delays could be reduced by making a broader use of slot caps at airports.

Capacity constraints have varying impacts on the main players in the aviation industry. For the high demand airports, limited capacity means loss of revenues and spill over of demand to alternative airports. Alternative airports could be those within the catchment area of the capacitated airport or an airport that also serves as a hub for a network carrier (Gelhausen, 2011). There have been claims that runway constraints at London Heathrow are already resulting in a loss of trade of GBP 1 illion per year to rival European hub airports such as Charles de Gaulle in Paris, Schiphol in Amsterdam and Frankfurt (London Assembly, Transport Committee, 2013). For the airlines, limited capacity means less competition, which might favour the incumbent airlines that may be in a position to charge higher prices as compared to new entrants that then struggle to gain market share. Furthermore, the inability of airlines to offer higher frequencies to destinations with strong demand encourages them to utilise large aircraft for short-haul routes, which results in higher than necessary operating, maintenance and depreciation costs. From the passengers' perspective, slot controls engender greater confidence in the airline schedules at the most congested airports. Nonetheless, the outcome of restricted competition is fewer options for selecting airlines, limited frequencies, higher airfares and higher schedule delay costs.

In exploring the causal relationship between airport activities, capacity and externalities, we develop a multi-stage network description that estimates the parameters of the airport service process, as first described in Adler et al. (2013). One major issue in modelling airport capacity is the fact that many processes and stakeholders are likely to influence capacity, which has consequently proven very difficult to measure directly. In an attempt to bypass this issue, we apply a structural equation model based on proxy information, which describes the runway and terminal capacities as endogenous variables. A far more detailed explanation may be found in Adler and Yazhemsky (2017).

The purpose of this research is to estimate the value of a marginal change in the capacity at congested airports from the perspective of the different stakeholders, namely airports, airlines and passengers. By mitigating the administrative controls on capacity at some of the world’s most congested airports, we study whether a marginal increase or decrease in operational capacity may influence overall social welfare. In the following section, we discuss the data collected in order to estimate the impact of administrative changes with respect to slots on the most congested airports in Europe and the potential impact of introducing such a system in the United States. In the third section, we discuss the results of the analysis and the final section draws conclusions.

Case study: Congested airports across two continents

Data was collected from the busiest airports in the USA and Europe (Annex 1 presents the list of airports and their respective IATA codes. Table 1 presents the complete list of variables and their relevant units). The data sources include the Official Airport Guide (OAG),[3] financial statements of the airports where available, the European Airport Coordinators Association (EUACA)[4] and the FAA.[5] The FAA's Aviation Systems Performance Records (ASPM[6]) and Eurocontrol's Central Office of Delay Analysis (CODA[7]) collect delay data for the USA and Europe respectively. Due to seasonality in operations, the peak season (August) and off-peak season (February) were analysed separately. Financial data was converted using purchase price parity (PPP) for purposes of comparison in 2013 standardised dollars.

Table 1. **Variable definitions and units**

Variable name	Definition	Units
For August and February:		
ADM	Average delay per movement	Minutes
Total delay	Cumulative delay	
ATM	Total air traffic movements at airport	Number
Declared capacity	Total number of slots per hour permitted at airport	
IFR/VFR movements	Aircraft movements based on instrumental flight rules or visual flight rules	
PAX	Passenger throughput	
Gates	Total number of gates including remote aprons	
Annually:		
Airports		
Commercial Revenue	Total revenues derived from non-aeronautical activities	Standardised USD
Aeronautical Revenues	Total revenues derived from airlines	
PFC	Passenger facility charges	
Total Operating Revenues	Total revenues from operations (sum of commercial and aeronautical revenues and PFC where relevant)	
Staff costs	Total labour costs	
Other costs	Total costs of operations not related to labour	
EBITDA	Earnings before interest, taxes, depreciation and amortisation	
Airlines		
RASK	Airline revenue per available seat-kilometre	
CASK	Airline operating costs per available seat-kilometre	
Load factor	Average percentage of seats filled	%
Average aircraft size	Average number of passenger seats per aircraft type	number
Average stage length	Average length of flights in kilometres	

Table 2a presents summary data collected for 16 European airports and the Tel Aviv airport, covering nine years from 2005 to 2013. However, the Spanish airports are only included from 2009 to 2012 due to a lack of disaggregated data in the other years. Table 2b presents summary data for 13 USA airports covering the years 2002-2013. Fewer USA airports were analysed because, despite the large number of annual movements, some proved to be un-capacitated given the size of the physical infrastructure in comparison to the number of movements. After an exploratory data analysis, Charlotte (from 2010), Denver (from 2005) and Houston (from 2012) were removed from the database due to an expansion of airside capacity. Detroit and Dallas Fort-Worth were removed in their entirety due to a lack of correlation between air traffic movements and average delays. In summation, 30 airports were analysed in total, creating two unbalanced datasets composed of 246 observations.

By comparing tables 2a and 2b, it becomes clear that the US airports are twice as large as their European counterparts on average with respect to aircraft movements and serve one-third more passengers, highlighting the fact that smaller aircraft were flown in the US. The average delay per movement is three to five minutes lower in the European system which, given the lower number of movements, translates into half the total delay minutes on an annual basis. On the other hand, the average gross profit (represented by EBITDA) of the USA airports is 200% lower due to their non-profit status as compared to their European counterparts which represent a mix of ownership forms (Adler and Liebert, 2014). We note that USA airports are privy to a passenger facility charge, which the airlines collect from passengers as part of the taxes and levies imposed on top of the base fare. For purposes of comparison, this charge was added to the EBITDA of the USA airports.

We collected European and US airline data for a second-stage social welfare analysis in which we estimate the impact of the change in capacity on airport, airline and passenger welfare. Data sources include the Thompson Reuter database, MIT's airline data project[8] and airline financial statements published on their websites. We chose one airline to match to the relevant airport, as shown in Tables 3 and 4. The carrier producing the highest frequency in the peak (August) and off-peak (February) at each airport was chosen based on OAG data. The airline chosen for the most part was a hub network carrier although EasyJet, Air Berlin and Southwest are also represented in the dataset.

Airline data collected includes revenues and costs per available seat kilometre (RASK and CASK) and load factors. We note that Lufthansa and Air France represent airline groups and their respective financial statements are consolidated hence we apply the same data for these airlines when necessary and include the name in brackets in Table 3. The average number of seats and average stage length were estimated per airline at each airport per narrow and wide body aircraft. Data on regional aircraft in the USA was also collected. Tables 3 and 4 present summary data collected for the European and US airlines respectively. Empty cells indicate that the specific aircraft type was not flown to the relevant airport. Comparing the two tables, it is noticeable that the US airlines achieve slightly higher load factors, particularly in the domestic markets. The US system is also cheaper to serve by approximately 50% on average. It would appear that the longer stage lengths, different fleet mix, cheaper airports and possibly lower taxes (in comparison, for example, to the French civil aviation tax, German air transport tax and Air Passenger Duty in the United Kingdom) enable US airlines to achieve lower CASK and lower variations in costs as compared to the European market. However, it would appear that competition is sufficient to ensure that revenues are approximately equal to costs such that the airlines are merely managing to break even on both continents during the investigated timeframe.

Table 2a. **European airport average**

				ATM		PAX		ADM		Total delay		
IATA code	**Years of observation**	**Slots**	**Gates**	**Feb**	**Aug**	**Feb**	**Aug**	**Feb**	**Aug**	**Feb**	**Aug**	**EBITDA**
AMS	2005-13	110	144	30 077	39 965	3 014 278	4 808 042	27	22	808 258	877 918	298 132 027
BCN	2009-12	65	102	19 728	25 711	1 945 571	3 357 260	20	25	392 974	645 974	135 449 446
BRU	2005-12	73	110	18 080	20 598	1 094 594	1 786 636	23	24	415 863	497 549	169 271 439
CDG	2005-13	114	133	38 347	46 516	3 958 950	5 765 806	26	23	983 396	1 093 384	672 393 804
CPH	2005-13	83	111	19 194	22 114	1 473 554	2 036 384	24	15	471 466	338 452	192 042 838
DUS	2005-13	46	84	15 419	19 036	1 139 937	1 820 440	19	17	293 348	327 294	152 666 115
FCO	2005-13	90	76	22 737	28 651	2 080 189	3 471 300	23	27	512 992	781 475	205 353 593
FRA	2005-13	86	175	35 418	42 168	3 523 624	5 219 587	28	18	1 005 255	764 958	429 532 567
LGW	2005-13	51	120	17 477	25 510	2 114 617	3 840 488	28	36	481 964	926162	136 764 274
LHR	2005-13	88	181	36 265	41 094	4 688 677	6 420 229	28	26	1 033 116	1 070 739	633 277 056
LIN	2005-06 2009-13	34	24	9 036	8 879	618 759	767 697	17	17	153 910	150 424	6 342 249
MAD	2009-12	100	224	31 269	35 266	3 315 231	4658 603	30	34	945 819	1 228 540	237 204 629
MUC	2005-12	90	160	30 347	34 828	2 323 429	3 123 474	26	15	769 226	526 811	221 632 334
PMI	2009-12	61	84	7 672	22 876	747 181	3 306 316	17	29	125 302	651 197	73 656 772
TLV	2005-10	21	30	4 626	8 167	578 550	1 268 400	22	30	100 625	244 892	197 547 556
VIE	2005-13	67	78	17 669	21 657	1 199 023	1 897 110	18	15	316 908	322 547	141 153 540
ZRH	2005-13	68	64	19 520	24 086	1 469 457	2 131 486	21	17	413 135	408 637	264 370 533
Grand total	**131**	**75**	**112**	**22 765**	**28 146**	**2 146 103**	**3 314 899**	**24**	**22**	**564 097**	**633 772**	**261 628 487**
Standard deviation		25	54	9 735	10 950	1 219 694	1 677 897	7	8	341 083	351 583	194 064 036

Table 2b. **US airport averages**

		Airside capacity			ATM		PAX		ADM		Total delay		
IATA code	**Years of observation**	**VFR**	**IFR**	**Gates**	**Feb**	**Aug**	**Feb**	**Aug**	**Feb**	**Aug**	**Feb**	**Aug**	**EBITDA +PFC**
ATL	2002-13	212	179	182	71 211	83 425	6 183 535	7 813 034	29	31	2 073 688	2 593 403	2 593 403
CLT	2005-09	131	110	87	38 429	43 299	2 330 400	2 785 507	29	28	1 109 726	1 216 481	1 216 481
DCA	2003-13	75	65	43	20 545	23 777	1 223 445	1 589 243	17	21	346 086	501 143	501 143
DEN	2002-04	219	162	147	39 912	47 857	2 746 136	3 711 778	24	21	959 664	1 003 596	1 003 596
EWR	2002-08	93	67	104	31 913	38 068	2 241 186	3 199 525	33	41	1 070 462	1 559 128	1 559 128
IAH	2008-11	157	122	127	39 207	45 842	2 862 518	3 579 219	25	23	1 005 783	1 037 286	1 037 286
JFK	2002-08	87	67	114	25 499	32 358	2 609 611	4 040 414	33	41	882 810	1 386 240	1 386 240
LAS	2002-13	119	75	98	40 417	47 406	3 071 642	3 677 161	22	22	912 678	1 063 371	1 063 371
LAX	2003-13	166	136	118	41 555	49 547	4 139 984	5 558 586	20	21	844 035	1 030 298	1 030 298
LGA	2002-08	85	74	73	28 995	33 176	1 677 143	2 231 135	34	36	996 389	1 211 987	1 211 987
ORD	2002-13	210	158	184	67 161	80 978	4 758 212	6 537 414	30	26	1 986 902	2 097 322	2 097 322
PHL	2002-13	121	92	116	35 177	41 513	2 021 032	2 818 187	32	32	1 118 630	1 344 214	1 344 214
PHX	2002-13	149	114	106	39 517	42 271	2 997 754	3 339 678	23	20	931 536	862 908	862 908
Grand total	**115**	**141**	**110**	**117**	**41 725**	**48 890**	**3 168 868**	**4 126 340**	**27**	**27**	**1 134 530**	**1 345 429**	**1 345 429**
Standard deviation		49	40	42	15 901	18 864	1 466 371	1 902 043	9	9	623 076	690 858	690 858

Table 3. **European airline averages (2005-13)**

Airport	Airline	Load factor	RASK	CASK	Narrow-body		Wide-body	
					Seats	Distance	Seats	Distance
AMS	KLM (Air France)	0.81	0.12	0.12	122	1 166	291	7 709
BCN	Iberia	0.80	0.10	0.10	153	1 097	-	-
CDG	Air France	0.81	0.12	0.12	156	844	264	7 264
CPH	SAS Scandinavian Airlines	0.74	0.14	0.14	146	942	259	7 159
DUS	Lufthansa	0.77	0.16	0.16	157	590	322	3 877
FCO	Alitalia (Air France)	0.81	0.12	0.12	139	937	291	7 211
FRA	Lufthansa	0.77	0.16	0.16	157	855	322	6 052
LGW	EasyJet/British Airways	0.85	0.06	0.05	156	997	290	4 111
LHR	British Airways	0.77	0.08	0.07	135	1 068	290	6 488
LIN	Alitalia (Air France)	0.81	0.12	0.12	139	600	-	-
MAD	Iberia	0.80	0.10	0.10	153	1 108	266	5 637
MUC	Lufthansa	0.77	0.16	0.16	157	805	337	5 801
PMI	Air Berlin/Iberia	0.77	0.07	0.07	181	1 025	-	-
TLV	El Al Airlines	0.82	0.09	0.09	143	3 014	326	5 357
VIE	Austrian Airlines (Lufthansa)	0.77	0.16	0.16	99	1 113	235	6 753
ZRH	Swissair (Lufthansa)	0.77	0.16	0.16	161	843	231	6 279
Grand total		**0.79**	**0.12**	**0.12**	**147**	**1 063**	**284**	**4 981**

Table 4. **US airline averages (2002-13)**

		Load factor				Regional		Narrow-body		Wide-body	
Airport	**Airline**	**Domestic**	**Intl.**	**RASK**	**CASK**	**Seats**	**Distance**	**Seats**	**Distance**	**Seats**	**Distance**
ATL	Delta	0.82	0.80	0.08	0.08	64	947	155	1 336	217	5 903
CLT	US Airways	0.82	0.79	0.08	0.08	74	901	141	1 083	276	5 259
DCA	US Airways	0.82	0.79	0.08	0.08	59	655	122	846	-	-
DEN	United	0.83	0.81	0.08	0.08	61	1 413	170	1 509	269	3 998
DTW	Delta	0.82	0.80	0.08	0.08	61	883	158	1 440	298	6 553
EWR	Continental	0.84	0.80	0.08	0.08	50	1 124	142	2 945	284	6 679
IAH	Continental	0.84	0.80	0.08	0.08	50	1 117	154	1 817	276	8 109
JFK	Delta	0.82	0.80	0.08	0.08	57	789	182	3 840	229	6 266
LAS	Southwest	0.75	-	0.07	0.06	-	-	137	818	-	-
LAX	United	0.83	0.81	0.08	0.08	57	938	177	2 376	257	5 745
LGA	US Airways	0.82	0.79	0.08	0.08	39	307	137	750	-	-
ORD	United	0.83	0.81	0.08	0.08	68	947	132	1 453	247	5 532
PHL	US Airways	0.82	0.79	0.08	0.08	51	658	158	1 721	263	5 649
PHX	US Airways	0.82	0.79	0.08	0.08	76	670	149	2 225	-	-
Grand total		**0.82**	**0.80**	**0.08**	**0.08**	**59**	**878**	**151**	**1 738**	**258**	**5 993**

Results of the European and USA case study

In this section, we first present the structural equation modelling outcomes graphically and then discuss the generalised numerical estimates. Finally, we discuss the second stage social welfare computation per continent, considering an additional slot in the peak hour in Europe and the reduction of a unit of capacity in the US, with respect to airports, airlines and passengers.

Structural equation modelling

The airport system is first defined by (1) the airside capacities, represented by declared capacity in Europe and IFR movements in the US, and (2) terminal capacities, represented by the number of gates available. Airside capacity enables airside activities, represented by the number of aircraft movements and negative externalities, defined by total delay. Terminal capacity serves the terminal side activities, represented by passenger throughput. We also assume that airside activities enable terminal side activities and create a directed path in the network model accordingly. Financial activities, represented by earnings before interest, taxes, depreciation and amortisation (EBITDA), draw from both airside and terminal side activities. The airlines pay airport charges per landing and per departing passenger. The passengers may purchase services and goods at the terminal, which translates into additional revenues for the airport. Furthermore, the US passenger facility charge was added to the EBITDA value for purposes of comparison. The airside activities also affect negative externalities, namely delays, which may in turn influence costs to the airports hence financial activities. We note that many undesirable externalities caused by aviation activities may be incorporated into the analysis, including delays, noise and local air pollution (Scotti et al., 2014). For the purpose of this research question, delays are included in order to estimate the impact of a marginal change in capacity. The results of these analyses,[9] covering Europe and the USA separately in the peak and off-peak season, are presented in Figures 1-4.

Within the circles in Figures 1-4, we present the coefficients of determination (R^2). In general, an R^2 above 0.67 is considered significant, however for model structures consisting of one or two endogenous variables, a more moderate R^2 above 0.33 is also deemed acceptable (Chin, 1998). The interpretation of the standardised path coefficients (which are located near the relevant arrows) is relative to each other, i.e. if one path coefficient value is higher than the other, its effect on the endogenous variable is greater. As can be seen in Figures 1-4, the path coefficient of the link *Terminal activities→Profit* is much higher than the path coefficients of *Airside activities→Profit* and *Delay→Profit* in all four cases. This suggests that the operational profit of airports is significantly positively influenced by the number of passengers and slightly by the number of aircraft movements and delay generated. Furthermore, the number of passengers is substantially influenced by the number of aircraft movements and weakly by terminal capacity. Delays are influenced more by the number of aircraft movements than by airside capacity. All these conclusions are significant and independent of the continent analysed or the season of operations.

Figure 1. **European off-season**

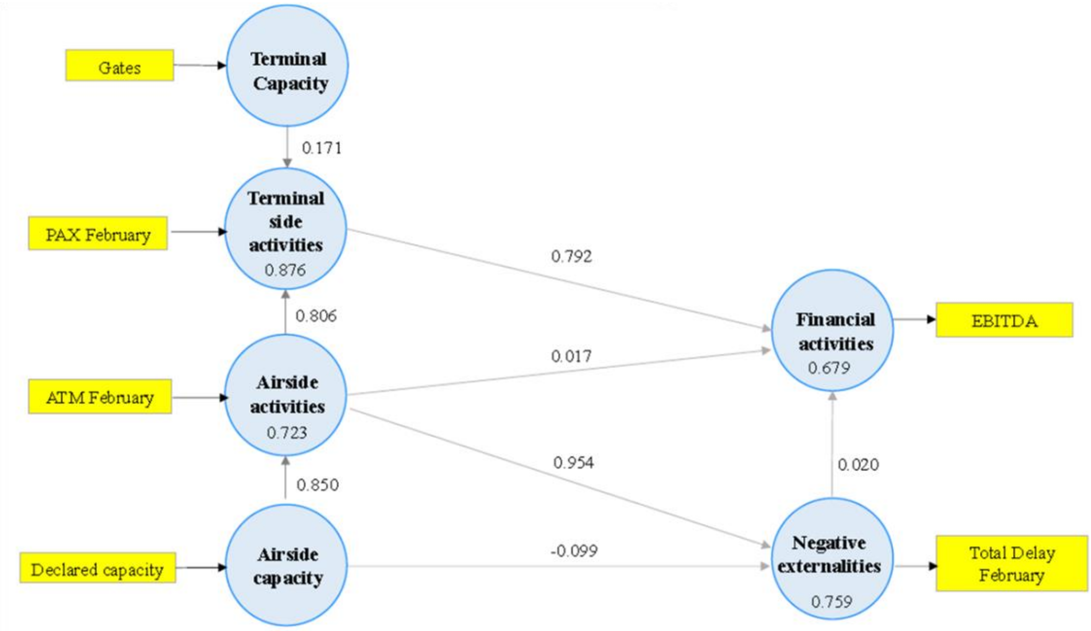


Figure 2. **European peak season**

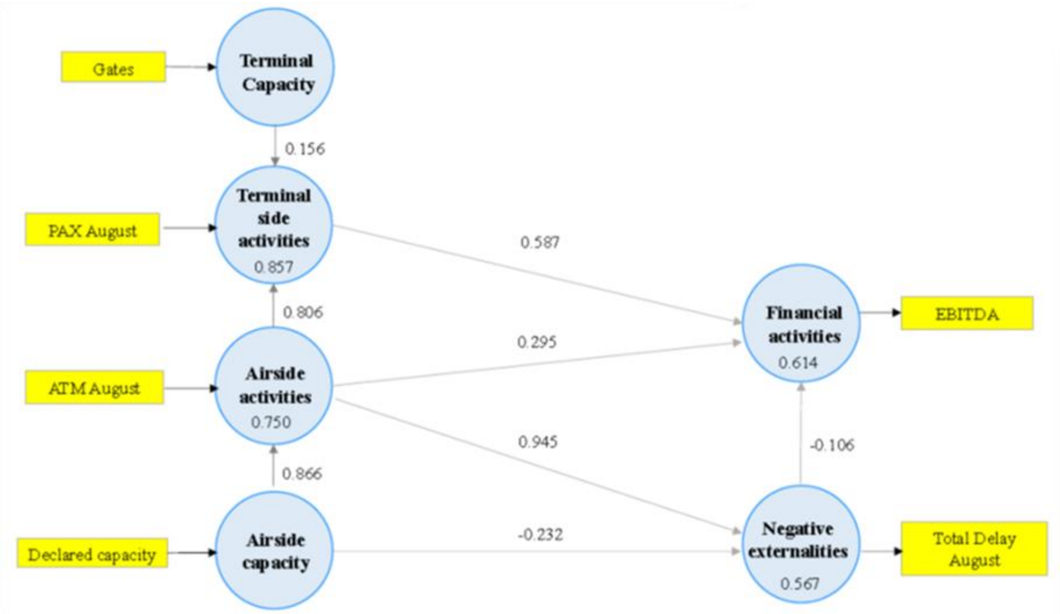


Figure 3. **USA off-season**

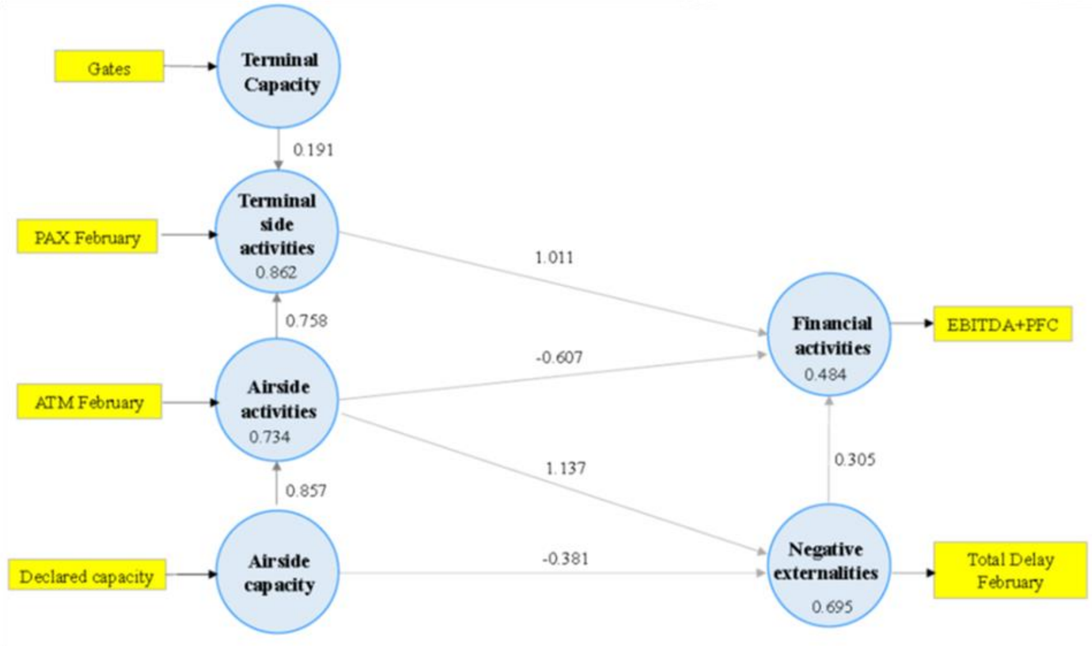
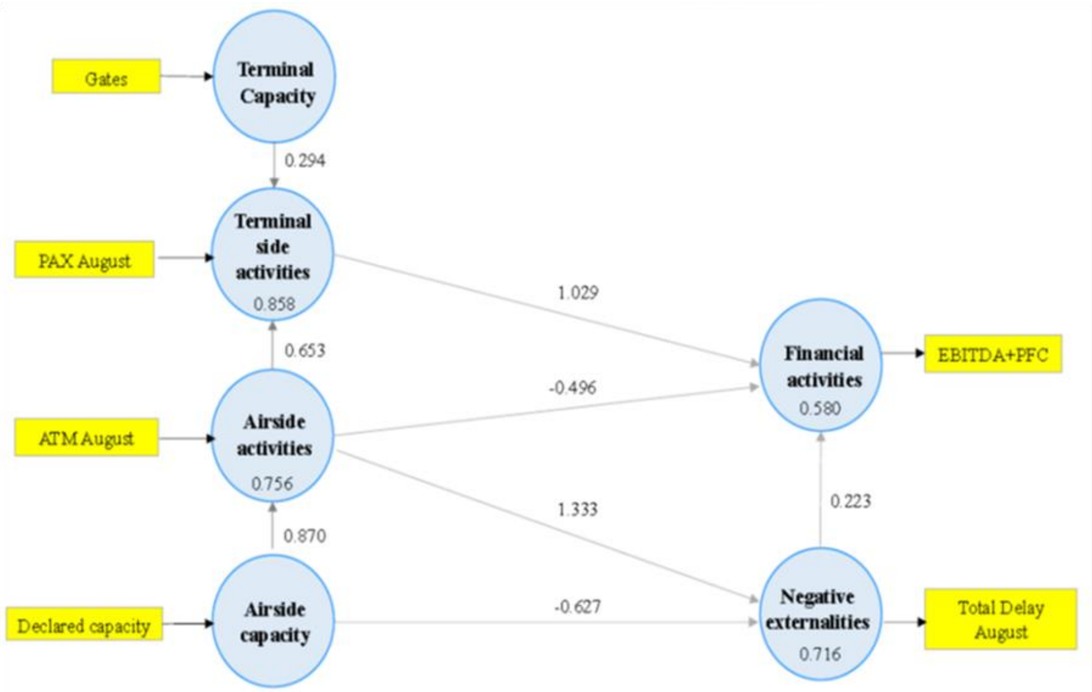


Figure 4. **USA peak season**



In Table 5, we present the complete set of results of the structural equation modelling approach. The top section of Table 5 includes the direct path coefficients (as shown in Figures 1-4) and the bottom section of the table specifies the combined effects that incorporate all the routes of the path modelling approach defining the airport structure. For example, airside capacity directly influences delays and indirectly via aircraft movements, hence the total effect is a summation of the direct coefficient (*Airside capacity→Neg. Externality)* and a multiplication of two coefficients *Airside capacity→Airside activity* and *Airside activity→Neg. Externality*. The direct path coefficient shows that an increase in capacity would decrease delays however, given that these are highly congested airports with strong demand, there is a greater than 0.85 probability[10] that the slot will be filled which in turn increases likely delay. The total effect is significantly positive for both continents, increasing average delays by 7 500 to 10 000 minutes annually per unit of declared capacity.

Table 5. **Path coefficients and total effects across continents**

	Europe			**United States**		
	Std. coefficient	**t-statistic**	**Nominal coefficient**	**Std. coefficient**	**t-statistic**	**Nominal coefficient**
Path coefficients						
			February			
Airside activity → Neg. externality	0.95	13.25	33	1.14	12.75	45
Airside activity → Terminal activity	0.81	28.00	101	0.76	12.09	70
Airside activity → Finance	0.02	0.10	-	-0.61	2.52	-2 667
Neg. externality → Finance	0.02	0.17	-	0.31	2.46	40
Terminal activity → Finance	0.79	4.90	126	1.01	5.69	57
Airside capacity → Airside activity	0.85	41.22	335	0.86	29.01	279
Airside capacity → Neg. externality	-0.10	1.16	-	-0.38	3.67	-4 985
Terminal capacity → Terminal activity	0.17	5.26	8 596	0.19	2.91	6 618
			August			
Airside activity → Neg. externality	0.95	8.45	30	1.33	14.51	49
Airside activity → Terminal activity	0.81	23.69	123	0.65	9.31	66
Airside activity → Finance	0.30	1.87	5 352	-0.50	2.77	-2 667
Neg. externality → Finance	-0.11	1.14	-	0.22	1.82	27
Terminal activity → Finance	0.59	3.39	67	1.03	7.44	46
Airside capacity → Airside activity	0.87	40.96	384	0.87	32.35	335
Airside capacity → Neg. externality	-0.23	1.88	-3 332	-0.63	6.14	-9,081
Terminal capacity → Terminal activity	0.16	4.01	10 806	0.29	4.13	13,308
Total effects						
			February			
Airside capacity → Neg. externality	0.71	17.77	9 905	0.59	10.45	7 567
Airside capacity → Terminal activity	0.69	22.26	33 790	0.65	11.73	19 483
Airside activity → Finance	0.67	13.78	11 874	0.51	5.15	2 688
Airside capacity → Finance	0.57	13.81	4 480 267	0.32	3.03	548 856
Terminal capacity → Finance	0.14	4.16	486 233	0.19	2.17	394 549
			August			
Airside capacity → Neg. externality	0.59	10.11	8 109	0.53	8.14	7 445
Airside capacity → Terminal activity	0.70	20.44	47 300	0.57	9.31	22 011
Airside activity → Finance	0.67	11.71	13 296	0.47	3.75	2 114
Airside capacity → Finance	0.60	14.14	4 731 791	0.27	2.42	450 785
Terminal capacity → Finance	0.09	2.67	328 922	0.30	3.19	615 980

According to the nominal path coefficients presented in the top half of Table 5, the direct influence of airside activity on negative externalities is significantly higher in the USA than in Europe, keeping all other factors equal. Airside capacity is negatively correlated to delays and the relationship is stronger in August than February in both systems, but the absolute value of the direct path coefficient is significantly higher in the USA than in Europe. The relative importance of terminal capacity in explaining passenger volume is higher in August than in February due to peak-season demand, especially in the USA.

According to the lower half of Table 5, the total effect of airside capacity on delays is higher in February than in August, which is attributed to poor weather conditions. On the other hand, the total effect of aircraft movements on operational profitability is almost independent of the season in both Europe and the USA. There are large differences between the two systems with respect to *airside capacity→finances, airside activities→finances* and *airside capacity→terminal activities*, all of which are significantly lower in the USA than in Europe due to ownership effects, which impact profitability goals and the size of aircraft flown on the two continents.

Second stage social welfare analysis of marginal capacity changes

In the subsequent social welfare analysis, we estimate the impact of adding or subtracting marginal capacity on the three main stakeholders. We assume that the change in capacity due to an expansion or retraction will be executed during the peak hours assuming twelve capacitated hours per day and 30 working days per month, leading to a change of 4 320 movements annually. Based on the analysis, this amounts to an additional 483 840 passengers per year on average at a representative congested European airport (≈1.5% annual change) and 293 760 fewer passengers per year at an average congested US airport (≈0.7% annual change).

In order to estimate the value of a marginal change on the airlines, financial data was converted to 2013 PPP standardised US dollars (USD). The operational profit per carrier was calculated using each of the airline's revenues and costs per available seat kilometre (RASK and CASK), which was then multiplied by the relevant load factor, average seat number and average distance given the current fleet mix per airline-airport combination. For the US market, we included regional aircraft in the computation. In order to create confidence intervals, lower and upper bounds were then estimated, which were based on the assumption that any change could be exclusively of one aircraft type. The results for Europe and the USA are presented in Tables 6 and 7 respectively.

Table 6. **European airline second stage analysis**

Years	**Airline profit (current fleet mix)**	**Lower bound (narrow-body)**	**Upper bound (wide-body)**	**PAX (current fleet mix)**	**Upper bound (narrow-body)**	**Upper bound (wide-body)**
2005	1 779 218	877 945	9 790 831	106 440 161	58 848 898	294 069 040
2006	2 349 405	1 441 295	14 029 043	111 371 706	75 354 926	309 076 589
2007	4 331 555	2 240 490	24 036 106	107 975 844	61 951 873	299 612 645
2008	2795 079	979 329	16 174 741	110 016 979	64 966 556	292 070 581
2009	-3 848 075	-2 638 892	-22 672 086	99 058 621	58 298 726	290 813 083
2010	-950 533	-569 940	-8 714 010	97 664 859	58 419 866	274 237 541
2011	51 348	-145, 458	292 145	98 951 438	59 128 025	285 457 737
Average	**929 714**	**312 110**	**4 705 253**	**104 497 087**	**62 424 124**	**292 191 031**

Table 7. **USA airline second stage analysis**

Years	Airline profit (current fleet mix)	Lower bound (regional)	Middle bound (narrow-body)	Upper bound (wide-body)	PAX (current fleet mix)	Lower bound (regional)	Middle bound (narrow-body)	Upper bound (wide-body)
2005	-788 844	-168 805	-1 017 207	-5 397 470	33 624 277	15 583 953	28 858 531	96 045 634
2006	1 171 969	346 333	1 706 863	7 767 377	35 862 439	16 087 665	31 811 980	105 909 196
2007	2 436 282	719 865	3 257 459	20 994 525	37 974 751	17 262 382	30 508 158	115 514341
2008	-2 779 011	-820 459	-4 264 279	-30 156 572	41 209 566	18 592 049	36 196 317	130 680 782
2009	304 226	63 101	487 452	4 753 780	34 681 480	15 629 639	31 877 818	113 407 368
2010	3 407 920	1 048 882	5 701 117	30 557 367	41 231 687	17 499 695	38 153 068	120 377 239
2011	2 227 981	738 581	3 663 098	23 941 794	44 604 910	18 804 222	39 893 532	138 530 528
Average	**854 361**	**279 550**	**1 452 875**	**8 620 700**	**38 455 587**	**17 065 658**	**33 899 915**	**11 209 298**

The European airlines could thus expect an average increase in profitability of around USD 1 million annually from an additional peak slot and would be in a position to carry an additional 105 million passengers annually. Clearly, airline profits are very low particularly due to the inclusion of financial years 2009 and 2010. The US airlines would carry an average of 38 million fewer passengers but could expect their profits to increase due to the reduction in delays lowering their costs. Consequently, the airline carriers in Europe would prefer an increase in slots and the airlines in the US would be better off with the marginal reduction. However, the impact on profits is marginal in both regions.

Finally, we estimate the impact of the marginal change in capacity on passenger surplus. The estimation assumes that the current aircraft fleet mix and load factors are fixed according to the data collected at the relevant capacitated airports. The European passenger consumer surplus is based on an average RASK of USD 0.13 and an average stage length of 1 652 km, which suggests an average airfare of USD 215 one way. According to the results of the analysis, the expected delay per air traffic movement increases from 23.5 to 23.6 minutes because of the additional slots. Assuming a value of delay per passenger of USD 37 per hour (Ball et al., 2010; ITA, 2000), the benefits from the additional flights outweighs the cost of the increase in delays for European passengers, as shown in Table 8. For the US passenger market, we apply an average RASK of USD 0.08, average stage length of 2 020 km and expected decrease in delay from 27.4 to 27.2 minutes. The results suggest that the US passengers would suffer from a decrease in welfare because the loss in benefits outweighs the delay cost savings.

Table 8. **Overall annual social welfare changes**

	Europe			**USA**		
	Expected	**Lower bound (barrow-body)**	**Upper bound (wide-body)**	**Expected**	**Lower bound (regional)**	**Upper bound (wide-body)**
Airports:						
Expected profit/loss	54 367 012			-10 371 621		
Airline:						
Expected profit/loss	929 714	312 110	4 705 253	-854 361	-279 550	-8 620 700
Delay	-14 807 451			21 903 873		
Passengers:						
Consumer surplus	38 233 307			-38 806 079		
Delay	-11 124 931			10 089 832		
Total	**67 597 651**			**-18 038 356**		

Table 8 presents the overall social welfare from the perspective of the three stakeholders, summarising the value of the marginal change in capacity during the peak hours on an annual basis. According to the results of the model, we estimate the value of this change from the airport managers' point-of-view. The expected total effect of changes in air traffic movements on airport profitability was multiplied by 4 320 movements in order to estimate an annual value. The effect of delay on the airport profitability was not statistically significant, therefore we did not separate the delay from the total effect. This suggests that airport operational profits are less likely to be impacted by the change in delays as compared to airlines and passengers. As shown in Table 8, adding slots in Europe is worthwhile from the airport perspective because it yields on average USD 54 million annually in additional operating profits at a representative airport. This is not the case for the marginal reduction in capacity in the US, which would lead to an average USD 10 million loss in annual operating profit for a representative, congested airport. Reducing peak hour capacity has a two-sided effect; on the one hand, fewer staff may be required to manage the reduced number of air traffic movements and passenger flows but on the other hand, commercial revenues may be reduced in the terminal facility. Moreover, we note that the not-for-profit approach in the US is likely to lead to higher charges for the remaining air traffic flows in this case in order to cover the loss, which will be passed on to the airlines directly and passengers indirectly.

For the European airlines, the additional slots will produce slight profits as compared to the negative impact of additional delay. The potential revenues from the additional traffic would be dependent on the aircraft type hence number of additional passengers that could be carried. Several published papers have attempted to estimate the cost of delay to the airlines including Nombela et al. (2002) who estimated EUR 83.3 per minute and Cook and Tanner (2011) who estimated EUR 81 per minute for short delays. Based on these parameters, the benefits from a reduction in air traffic movements in the US are worth approximately USD 22 million annually as compared to the relatively small losses caused by the removal of flights. However, due to the competitive environment, an airline would not willingly reduce its timetable due to the fear that another carrier would simply enter the market. Consequently, the reduction in air traffic movements would probably require the introduction of high density rules at many more airports than is currently the case. Finally, we note that these results are robust to a change in the fleet mix.

From the passengers’ perspective, the additional slots in the European system will increase consumer welfare by approximately USD 38 million annually, a sum that substantially exceeds the effects of additional delays which is in the region of USD 11 million. These results proved robust and the value of delay to a passenger would need to triple for the overall results to change. The results for the US consumer are the opposite, in other words the loss in benefits outweighs the decrease in delay costs. This would suggest that from a consumer perspective, the US regulator should not restrict airports that do not currently have high density rules and the existing restrictions at the three constrained US airports should not be further restricted.

Conclusions

In this research, we analysed the impact of capacity limitations on airport throughput from the passengers’, airlines’ and airport managements’ perspectives. Given that airport capacity is rather difficult to define due to its multi-faceted and dynamic nature, we assess the value of airport capacity using a structural equation modelling approach that permits capacities to be defined as endogenous variables. The results of the non-parametric regressions suggest that at congested airports, there is a significant probability that an increase in capacity will lead to higher air traffic movements, an increase in passengers and an equivalent increase in delays.

Taking into account the impact of delays on all stakeholders, the results suggest that the total social welfare is positive from adding an additional slot per peak hour in the European system. The expected increase in overall social welfare is worth around USD 68 million annually at an average congested airport and would be preferable for both the airport management and passenger welfare but less from the airline perspective. On the other hand, overall social welfare is negative from removing a peak hour unit of capacity in the US system. The expected reduction in overall welfare is approximately USD 18 million annually and although acceptable from the airline perspective, it would reduce passenger welfare and airport surplus.

These results may indicate why the US regulatory authorities have not expanded the high density rule restrictions despite the delay levels experienced to date. The results are in line with the findings of Billette de Villemeur et al. (2015): the welfare losses that follow from sub-optimal scheduling are relatively small as compared to the potential benefits of a decrease in ticket prices. However, this is in direct contradiction to Ball et al. (2010) and Swaroop et al. (2012) who have argued for the need to introduce or strengthen slot restrictions in the US aviation market. Based on an assessment of overall social welfare, it would appear that European slot restrictions are excessive and increased utilisation of the existing infrastructure could be achieved as occurs in the US currently. It may also be reasonable to consider an increase in slot caps on specific days of the week or times of the year, such as Christmas holidays or the month of August. Finally, the impact of additional connectivity for passengers has not been considered directly and would likely further increase the value of additional slots were new destinations to be served for example.

References

Adler, N. (2005), “Hub-spoke network choice under competition with an application to Western Europe”. *Transportation Science,* Vol. 39/1,pp. 58-72.

Adler, N., E. Hanany, and S. Proost (2014), Managing European air traffic control provision. SESAR Innovation Days 2014. http://www.sesarinnovationdays.eu/sites/default/files/media/SIDs/SID%202014-09.pdf

Adler, N. and V. Liebert (2014), “Joint impact of competition, ownership form and economic regulation on airport performance and pricing”. *Transportation Research part A*, Vol. 64, pp. 92-109.

Adler, N., V. Liebert, and E. Yazhemsky (2013), “Benchmarking airports from a managerial perspective”. *Omega – International Journal of Management Science*. Vol. 41/2, pp. 442-458.

Adler, N. and E. Yazhemsky (forthcoming), “The value of a marginal change in capacity at congested airports”. *Transportation Research part A.*

Ball, M., C. Barnhart, M. Dresner, M. Hansen, K. Neels, A. Odoni, E. Peterson, L. Sherry, A. Trani, B. Zou and R. Britto (2010), Total delay impact study. In NEXTOR Research Symposium, Washington DC. http://www.nextor.org/.

Billette de Villemeur, E., M. Ivaldi, E. Quinet and M. Urdanoz (2015), “The Social Cost of Air Traffic Delays”. *CEPR Discussion Paper,* No. DP10386. http://ssrn.com/abstract=2559327.

Brueckner, J.K. and Y. Zhang (2001), “A model of scheduling in airline networks: how a hub-and-spoke system affects flight frequency, fares and welfare”. *Journal of Transport Economics and Policy*. Vol. 35/2, pp. 195-222.

Chin, W.W. (1998), “The partial least squares approach to structural equation modelling”. In G.A. Marcoulides (Ed.), *Modern Methods for Business Research* (pp. 295–358). Lawrence Erlbaum Associates, Mahwah, NJ.

Cook, A. and G. Tanner (2011), European airline delay cost reference values: Final report for Performance Review Unit, EUROCONTROL.

Czerny, A.I., P. Forsyth, D. Gillen and H-M. Niemeier (eds.) (2008), *Airport slots: international experiences and options for reform*. Ashgate Publishing, Ltd.

Federal Aviation Authority (FAA) (2014), ORD Airport Capacity Profile https://www.faa.gov/airports/planning_capacity/profiles/media/ord-airport-capacity-profile-2014.pdf

Federal Aviation Authority (FAA) (2012), NextGen: The business case for the Next Generation air transportation systems.

Forsyth, P. (2007), "The impacts of emerging aviation trends on airport infrastructure". *Journal of Air Transport Management*, Vol. 13/1, pp. 45-52.

Gelhausen, M.C. (2011), "Modelling the effects of capacity constraints on air travellers' airport choice". *Journal of Air Transport Management*, Vol. 17/2, pp. 116-119.

Gillen, D., and D. Starkie (2016), "EU slot policy at congested hubs, and incentives to add capacity". *Journal of Transport Economics and Policy*, Vol. 50/2,pp. 151-163.

Levine, M.E. (1969), "Landing fees and the airport congestion problem". *The Journal of Law and Economics*, Vol. 12/1, pp. 79-108.

Levine, M.E. (2008), "Airport congestion: when theory meets reality". *Yale Journal of Regulation*, Vol. 26/1.

London Assembly, Transport Committee (2013), Airport Capacity in London.

Mayer, C. and T. Sinai (2003), "Network effects, congestion externalities, and air traffic delays: Or why not all delays are evil". *The American Economic Review*, Vol. 93/4, pp. 1194-1215.

Odoni, A., T. Morisset, W. Drotleff and A. Zock (2011), Benchmarking airport airside performance: FRA vs. EWR. Proceedings of the Ninth USA/EUROPE Air Traffic Management Research & Development Seminar, Berlin.

Ringle, C.M., S. Wende, J-M. Becker (2014), Smartpls 3. Hamburg: SmartPLS. http://www.smartpls.com

Schank, J.L. (2005), "Solving airside airport congestion: Why peak runway pricing is not working". *Journal of Air Transport Management*, Vol. 11/6, pp.417-425.

Scotti, D., M. Dresner, G. Martini and C. Yu (2014), "Incorporating negative externalities into productivity assessments of US airports". *Transportation Research Part A*, Vol. 62, pp. 39–53.

Sentance, A. (2003), "Airport slot auctions: desirable or feasible?" *Utilities Policy*, Vol. 11/1, pp. 53-57.

SESAR (2012), The roadmap for sustainable air traffic management: European Masterplan, Edition 2.

Swaroop, P., B. Zou, M.O. Ball and M. Hansen (2012), "Do more US airports need slot controls? A welfare based approach to determine slot levels". *Transportation Research part B*, Vol. 46, pp. 1239-1259.

Ulrich, C. (2008), "How the present (IATA) slot allocation works". In: Czerny, A.I., P. Forsyth, D. Gillen and H-M. Niemeier (eds.), *Airport slots: international experiences and options for reform*. Ashgate Publishing, Ltd.

Annex 1. Airport codes in dataset

IATA Code	Airport in Europe		IATA Code	Airport in USA
AMS	Amsterdam		ATL	Atlanta
BCN	Barcelona		CLT	Charlotte
BRU	Brussels		DCA	Washington National Reagan
CDG	Paris (Charles de Gaulle)		DEN	Denver
CPH	Copenhagen		DFW	Dallas Fort Worth
DUS	Dusseldorf		DTW	Detroit
FCO	Rome Fiumicino		EWR	New York (Newark)
FRA	Frankfurt		IAH	Houston
LGW	London Gatwick		JFK	New York (John F. Kennedy)
LHR	London Heathrow		LAS	Las Vegas
LIN	Milan Linate		LAX	Los Angeles
MAD	Madrid Barajas		LGA	New York (LaGuardia)
MUC	Munich		ORD	Chicago O'Hare
PMI	Palma de-Mallorca		PHL	Philadelphia
TLV	Tel Aviv		PHX	Phoenix
VIE	Vienna			
ZRH	Zurich			

Notes

[1] http://www.iata.org/publications/airlines-international/august-2010/Pages/06.aspx

[2] Since October 2016, only three US airports are slot restricted, namely John F. Kennedy and LaGuardia in New York and Ronald Reagan Washington National. https://www.faa.gov/about/office_org/headquarters_offices/ato/service_units/systemops/surface/slot_administration/schedule_facilitation/. Swaroop et al. (2012) also included Newark in their estimations as relevant at the time of the analysis.

[3] http://www.oag.com/

[4] http://www.euaca.org/

[5] http://www.faa.gov/

[6] https://aspm.faa.gov/

[7] https://www.eurocontrol.int/articles/central-office-delay-analysis-coda

[8] http://web.mit.edu/airlinedata/www/default.html

[9] The Smartpls software created the results displayed here (Ringle et al., 2014).

[10] This parameter draws from the arc connecting airside capacity to airside activities.

International Transport Forum

International Transport Forum
2 rue André Pascal
F-75775 Paris Cedex 16
contact@itf-oecd.org
www.itf-oecd.org