The Symposium Proceedings of the 1998 Air Transport Research Group (ATRG)

Volume 2

Editors
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November 1998

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ABOUT THE EDITORS

Dr. Aisling Reynolds-Feighan received her B.A. and M.A. in Economics from University College Dublin, Ireland, and her Ph.D. from the University of Illinois in 1989 in the field of Regional Science. She has been a College Lecturer at University College Dublin in Economics since 1990, where she teaches Transport Economics and Regional Science courses. Her main research interests are in air and road transport, with particular emphasis on the links between transport and regional economic development. She has published several studies examining the impacts of airline deregulation in the US and Europe including *The Effects of Deregulation on U.S. Air Networks* (Springer-Verlag, 1992).

Dr. Brent D. Bowen is Director and Professor, Aviation Institute, University of Nebraska at Omaha. He has been appointed as a Graduate Faculty of the University of Nebraska System-wide Graduate College. Bowen attained his Doctorate in Higher Education and Aviation from Oklahoma State University and a Master of Business Administration degree from Oklahoma City University. His Federal Aviation Administration certifications include Airline Transport Pilot, Certified Flight Instructor, Advanced-Instrument Ground Instructor, Aviation Safety Counselor, and Aerospace Education Counselor. Dr. Bowen's research interests focus on aviation applications of public productivity enhancement and marketing in the areas of service quality evaluation, forecasting, and student recruitment in collegiate aviation programs. He is also well published in areas related to effective teaching. His professional affiliations include the University Aviation Association, Council on Aviation Accreditation, World Aerospace Education Organization, International Air Transportation Research Group, Aerospace Education Association, Alpha Eta Rho International Aviation Fraternity, and the Nebraska Academy of Sciences. He also serves as program director and principal investigator of the National Aeronautics and Space Administration funded Nebraska Space Grant and EPSCoR Programs.

ATRG President's Foreword

The **Air Transport Research Group** of the WCTR Society was formally launched as a special interest group at the 7th Triennial WCTR in Sydney, Australia in 1995. Since then, our membership base has expanded rapidly, and now includes over 400 active transportation researchers, policy- makers, industry executives, major corporations and research institutes from 28 countries. Our broad membership base and its strong enthusiasm have pushed the group forward, to continuously initiate new events and projects that benefit the aviation industry and research communities worldwide.

It became a tradition that the ATRG would hold an international conference at least once a year. As you know, the 1997 conference was held in Vancouver, Canada. Over 90 papers, panel discussions and invited speeches were presented. In 1998, the ATRG organized a consecutive stream of 14 aviation sessions at the 8th Triennial WCTR Conference (July 12-17: Antwerp). Again, on 19-21 July, 1998, the ATRG Symposium was organized and executed every successfully by Dr. Aisling Reynolds-Feighan of the University College of Dublin.

As in the past, the Aviation Institute at the University of Nebraska at Omaha (Dr. Brent Bowen, Director of the Institute) has kindly agreed to publish the Proceedings of the 1998 ATRG Dublin Symposium (being co-edited by Dr. Aisling Reynolds-Feighan and Professor Brent Bowen), and the Proceedings of the 1998 WCTR-ATRG Conference (being co-edited by Professors Tae H. Oum and Brent Bowen). On behalf of the ATRG members, I would like to express my sincere appreciation to Professor Brent Bowen and to the staff at the Aviation Institute of UNO for their efforts in publishing these ATRG proceedings. Also, I would like to thank and congratulate all the authors of the papers, for their fine contribution to the conferences and the Proceedings.

Finally, I would like to draw your attention to the ATRG newsletter and the ATRG website (www.commerce.ubc.ca/atrg/) which will keep you informed of the ATRG operations and forthcoming events. On behalf of the ATRG Networking Committee, I would also appreciate it very much if you would encourage others in the field, to sign up for ATRG membership. Thank you for your attention.

Tae H. Oum
President, ATRG

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The Symposium

The ATRG held its Research Symposium at University College Dublin, Ireland in July 1998, following the main WCTR meetings.

The symposium attracted 106 delegates from 17 countries. Additionally a plenary session yielded three views on the future prospects for European air transport.

The Proceedings

Once again, on behalf of the Air Transport Research Group, the University of Nebraska at Omaha Aviation Institute has agreed to publish the Proceedings of the ATRG Symposium in a three-volume monograph set.

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The Proceedings of the 1998 ATRG Symposium are contained in a three-volume monograph set. Orders within the U.S. are $7.50 (U.S.) per monograph volume, and international orders are $10.00 (U.S.) per monograph volume to cover the costs of printing, shipping, and handling. Allow 4-6 weeks for delivery.

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Volume 1, Number 1

Opening Remarks

Opening Address at the 1998 ATRG Dublin Symposium by T. Oum, ATRG President

Plenary Session: Irish Air Transport in the New Millennium

Air Transportation in the New Millennium: Opportunities in Competitive Markets by J. Lumsden
Irish Air Transport Policy in the New Millennium by J. Burke
Irish Air Transport Policy in the New Millennium by G. Cullen

Speakers: European Air Transport in the New Millennium

Air Transportation in the New Millennium: Opportunities in Competitive Markets by D. Andrew
Reflections on the European Aviation Industry by D. Kennedy

Session 1B: Airport Management, Economics and Pricing I

Benchmark Airport Charges, 1996 by A. de Wit & N. Cohn
Duty Free Shopping: Its Importance as a Source of Revenue in Spanish Airports by R. Rendeiro Martin-Cejas
Non-Parametric Measures of Efficiency at US Airports by D. Gillen
Access to Airports: A Case Study of the San Francisco Bay Area by E. Pels, P. Nijkamp & P. Rietveld

Session 2B: Airport Management, Economics and Pricing II

Integrated Airport Pavement Management and Facility Management Using Geographical Information Systems Technology by M. McNerney
The Integrated Airport Competition Model, 1998 by J. Veldhuis, I. Essers, D. Bakker, N. Cohn & E. Kroes
Airport Competition - Myth and Reality by T. Haughey

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Globalization of Airline Networks and Airline Alliances

by

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Globalization of Airline Networks and Airline Alliances

OUTLINE

1. Background and Government Policy Towards Alliances

2. Current Status of Alliances

3. Area of joint activities

4. Reasons for alliance formation

5. Effects of Alliances on Carriers and Passengers
   - Trans-Atlantic Alliance Study
   - Asia-Pacific Codeshare Alliance Study
   - Policy Implications

6. Summary and Future Research Needs

I. Background and Government Policy Towards Alliances

Background.

- International aviation remains heavily regulated by bilateral agreements
  ⇒ Airline business restricted by these agreements.

- Consumer preference on airlines with extensive networks
  ⇒ Inducing airlines to establish global networks.

- Some major carriers have attempted **to penetrate overseas services by adding spokes** to their domestic hubs.

- Many airlines use *strategic alliances* to form global service networks.

Government Policies

(A) United States

- 1967: First domestic alliance
    Allegheny(USAir)+Commuters

- early 1980's: Trunk carriers + Regional feeders alliances

- 1986: First int'l alliance
    Air Florida + British Island on London-Amsterdam route

- 1988: US began to require govt approval for int'l codesharing alliance

- *US began to use, in bilateral negotiations, the permission to allow foreign carriers to do codeshare alliances involving US domestic routes.*
  e.g. NW+KLM, UA+LH, BA+AA, Recent Bilaterals with Asian countries (Singapore, Brunei, Malaysia, Taiwan, Philippines, Thailand, Hong Kong, Korea, Japan, China, etc.)

- US uses *Anti-trust immunities* to codesharing alliances to encourage foreign countries to sign *open skies agreements* with the U.S.
  e.g. KLM/NW (Nov, 1992), LH/UA (May, 1996)

Recent Developments in the U.S.

Northwest/Continental (March, 1998)
NW: 14% of CO's share

American Airlines/US Airways (April, 1998)
Frequent flyer program + codesharing

Delta Air Lines/United Airlines (April, 1998)
not including European flights

US Carriers' Recent Inter-continental Alliances.

American Airlines/Asiana (Oct. 1997)
Codesharing

American Airlines/China Eastern Airlines (Feb. 1998)
Codesharing

American Airlines/ Japan Airlines (Feb. 1998)
Codesharing

United Airlines/ All Nippon Airways (March, 1998)
Marketing

American Airlines/TACA (May, 1998)
Codesharing + frequent flyer program

American Airlines/Iberia (May, 1998)
Codesharing + frequent flyer program

Northwest/Air China (May, 1998)
Operational and Marketing

Delta Air Lines/Air France (June, 1998)
Codesharing

(B) European Union

- EU carriers do not require gov't approval for alliances among themselves involving intra-EU routes

- Individual EU states have different perspectives on codesharing with Non-EU carriers:
    - UK and Netherlands: supportive.
    - Italy: restrictive

- EU requires *disclosure of identity of the operating carrier* of a codeshared flight, and limits the number of times a codeshared flight is displayed on CRS display to *twice.*

II. Current Status of Alliances

SEE TABLE 1:

- More than 380 alliances by 171 int'l carriers as of 1996

- 16% of the alliances involve equity investment.

- More than 50 new alliances have emerged every year since 1994.

TABLE 1 Current Status of Alliances

	'98	'96	'95	'94	change(98/94)
number of alliances	502	389	324	280	79.3%
number of airlines	195	171	153	136	43.4%
with equity stakes	56	62	58	58	-3.4%
without equity	446	327	266	222	100.9%
new alliances	121	71	50	n/a	

(Source) Airline Business (1994-98)

SEE TABLE 2:

- European carriers tend to have more equity alliances than North American or Asian carriers.

- Large carriers tend to invest in smaller carrier: for closer coordination of operations, exercise of control, durability of relation???

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TABLE 2. Equity Investment Alliances

Investor Airlines(a)	Invested Airlines	Equity Holdings July,96	1998
Air Canada(Canada)	Continental Airlines(USA)	27.5	0.0
Air France(France)	Austrian Airlines(Austria)	1.5	1.5
Air France(France)	Middle East Airlines(Lebanon)	28.5	0.9
Air India(India)	Air Mauritius(Mauritius)	8.5	8.8
Air New Zealand	Air Pacific(Fiji)	2.0	2.0
Alitalia(Italy)	Malev Airlines(Hungary)	30.0	0.0
All Nippon Airways	Austrian Airlines(Austria)	9.0	9.0
American Airlines	Canadian Airlines(Canada)	33.3	33.3
British Airways(UK)	Air Mauritius(Mauitius)	12.8	12.8
British Airways(UK)	Deutsche BA(Germany)	49.0	100.0
British Airways(UK)	Qantas Airways(Australia)	25.0	25.0
British Airways(UK)	USAir(USA)	24.6	0.0
Delta Air(USA)	Singapore Airlines(Singapore)	5.0	2.7
Delta Air(USA)	Swissair(Switzerland)	4.5	4.5
Iberia(Spain)	Aerolineas Argentinas	5.0	10.0
Iberia(Spain)	Ladeco Chilean(Chile)	25.0	0.0
Japan Airlines(Japan)	Hawaiian Airlines(USA)	8.5	0.0
KLM (Netherlands)	Braathens		30.0
KLM(Netherlands)	Kenya Airways(Kenya)	26.0	26.0
KLM(Netherlands)	Northwest Airlines(USA)	49.0	0.0
Lufthansa(Germany)	Lauda Air(Austria)	39.7	20.0
Malaysia Airlines	World Airways(USA)	25.0	n/a
Northwest	Continental		14.0
Qantas(Australia)	Air New Zealand	19.4	0.0
SAS(Sweden)	British Midland(UK)	40.0	40.0
Singapore(Singapore)	Delta Air(USA)	5.0	3.0
Singapore(Singapore)	Swissair(Switzerland)	2.7	2.7
Swissair	Austrian Airlines(Austria)	10.0	10.0
Swissair	Delta Air(USA)	5.0	3.0
Swissair	Sabena(Belgium)	49.5	49.5
Swissair	Singapore Airlines(Singapore)	0.6	0.6

(Sources) Airline Business (1995-98), Flight International (1996)
(Note) Investor airlines in North American, European, Asian continents only

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SEE TABLE 3:

- TABLE 3 shows changes in the number of the world's top-30 airlines' alliances during the past three years.

- AF has formed the largest number of alliances among the top-30 carriers.

- Alliances involving the 30 top airlines account for more than 90 per cent of the total alliances as of 1996.

- *Forming strategic alliances is not just a fad or passing phenomenon.* The alliance race will likely continue until bilateral air treaties are liberalized completely or restrictions on foreign ownership of airlines disappear.

TABLE 3 Top Airlines' Alliance Race

	'98	'96	'95	'94
Air France	27 (7)	31 (13)	34 (13)	25 (12)
Lufthansa	14 (1)	26 (4)	25 (3)	25 (5)
Malaysia Airlines	24 (1)	19 (1)	19 (1)	17 (1)
KLM	21 (3)	18 (4)	14 (3)	10 (4)
Singapore Airlines	15 (1)	17 (3)	8 (3)	5 (3)
Air New Zealand	12 (2)	17 (2)	8 (2)	7 (2)
Swissair	24 (4)	16 (4)	9 (4)	9 (4)
Delta Airlines	18 (2)	15 (2)	13 (2)	14 (4)
Korean Air	18 (0)	15 (0)	14 (0)	12 (0)
Japan Airlines	20 (1)	14 (3)	10 (3)	9 (3)
British Airways	16 (3)	13 (5)	8 (5)	11 (5)
United Airlines	18 (0)	13 (0)	14 (0)	12 (0)
Air Canada	12 (0)	12 (2)	9 (1)	9 (1)
American Airlines	26 (2)	12 (1)	8 (1)	6 (1)
Cathay Pacific	10 (2)	11 (2)	8 (2)	10 (1)
SAS	14 (2)	11 (0)	9 (2)	9 (2)
Alitalia	18 (1)	10 (1)	7 (1)	9 (1)
Varig	7 (0)	10 (0)	12 (0)	11 (0)
Continental	13 (2)	9 (2)	5 (2)	6 (1)
Canadian Airlines	9 (1)	9 (1)	8 (1)	5 (1)
Northwest Airlines	13 (1)	9 (1)	6 (1)	4 (1)
Qantas	16 (2)	8 (3)	7 (3)	7 (3)
Saudia	5 (0)	8 (0)	7 (0)	1 (0)
Philippine Air	10 (0)	7 (1)	6 (0)	6 (0)
Sabena	12 (2)	6 (1)	2 (1)	3 (1)
Virgin Atlantic	5 (0)	6 (0)	5 (0)	3 (0)
USAir	1 (0)	5 (3)	7 (1)	5 (0)
All Nippon Air	5 (1)	5 (2)	5 (2)	4 (2)
Thai Air	10 (0)	4 (0)	5 (0)	3 (0)
Aeroflot	7 (1)	4 (0)	4 (0)	4 (0)
TOTAL	420 (42)	360 (60)	296 (57)	261 (55)

(Source) Airline Business (1994-98)
(Note) The number of equity investment alliances is shown in the parentheses.

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III. Joint Activities Among Alliance Carriers

Based on the analysis of 46 alliances between the top-30 airlines, areas of coordination are identified as:

. *Coordination of ground handling*

. *Joint use of ground facilities*

. *FFP Linkage*

. *Codesharing operation*

. *Block space sales*

. *Coordination of flight schedule*

. *Exchange of flight attendants*

. *Joint development of systems*

. *Joint advertising and promotion*

. *Joint maintenance*

. *Joint purchase of aircraft/fuel*

Types of Alliances.

TYPE 1: Simple route-by-route alliance (28 cases)

. Involves lower level of coordination on a few routes.

. KLM-JAL on Tokyo-Amsterdam-Zurich route ('93.1)

. Air Canada - Korean Air on Vancouver-Seoul route ('94)

TYPE 2: Broad commercial alliance (9 cases)

. One-step advanced form from the simple route-by-route alliance.

. Collaboration on more than a few routes - Linking networks, and feeding traffic to each other's hub airports

. UA - LH alliance linking U.S and European networks

. DL-VS on US cities-London routes ('94.4)

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. Some broad commercial alliances are deepening - proving durable.

TYPE 3: Equity alliance (9 cases)

. Most advanced form; at first thought 'most durable'

. Cooperates in almost all areas of joint activities

. One-way investment (investing airlines wants control);
        - Risky, Unstable
        - KLM-NW ('92.11); AA-CP ('94.4)

. Two-way investments: e.g., DL-SR-SQ
        - More stable
        - Does not attempt to control
        - Literature: 50%-50% joint venture is far more stable and long-lasting

Degree of Coordination for Each Type of Alliance

Joint Activities	Type 1*	Type 2	Type 3
Coordination of ground handing	5 (18%)**	7 (78%)	9 (100%)
Joint use of ground facilities	13 (46%)	9 (100%)	9 (100%)
Shared Frequent Flyer Program	9 (32%)	9 (100%)	6 (67%)
Codesharing or Joint Operation	25 (89%)	9 (100%)	9 (100%)
Block Space Sales	10 (36%)	4 (44%)	3 (33%)
Coordination of Flight Schedule	4 (14%)	9 (100%)	9 (100%)
Exchange of Flight Attendants	1 (4%)	2 (22%)	5 (56%)
Joint Development of Systems	1 (4%)	2 (22%)	3 (33%)
Joint Advertising and Promotion	0	3 (33%)	4 (44%)
Joint Maintenance	0	0	1 (11%)
Joint Purchase of Aircraft/Fuel	0	0	4 (44%)
T O T A L	28	9	9

(Notes) * Type 1: Simple route-by-route alliances (28 cases), Type 2: Broad commercial alliances (9 cases), Type 3: Equity alliances (9 cases).
** The number in parenthesis is the percentage of a particular joint activity within the type of alliance.
(Sources) Airline Annual Reports, Airline Business 1994-96, Airline Marketing News, Asian Aviation News, Aviation Europe, Flight International, Gellman Research Associates, US General Accounting Office.

VI. Reasons for Alliance Formation

1. Network expansion by linking between partners' networks

- Consumer preference on airlines with extensive networks.

- Strategic alliances allow the partners:
to expand no. of destinations	(eg) LH/UA
to access to attractive airport	(eg) DL/VS(Virgin)
to enter thin markets	(eg) QF/AV
	(Avianca)

2. Increasing traffic feed between partners

- Mutual traffic feed traffic
  → increase load factors without having to increase flight frequency.

- USAir feeds its domestic traffic onto BA flights to London at five US gateways.
  BA's load factor on the five routes increased
  72.4% → 73.8% after the alliance

- Increase flight frequency via codesharing

3. Cost Savings

- Reduce unit cost via economies of scale, scope, and traffic density
  eg. Joint purchase and promotion
  → Economies of scale
  Linkage of networks → Economies of scope
  Mutual traffic feed → Economies of traffic density

4. Improve quality of service

- *Customer services* are normally enhanced by coordinating flight schedules, locating departure gate close to the connecting flights' arrival gates, coordinating baggage transfer, etc.

- A trans-Atlantic alliance study (Park, 1997) found that *schedule delay times* are reduced by 12-25% after alliance, depending on the routes.

  Schedule delay time = time between passengers' desired departure and actual departure times

5. Expand passengers' itinerary choices:

- Alliances allow partners to offer more alternatives to passengers.

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- Alliances may increase demand
  (cf) Trans-Atlantic alliances:
    Demand curves for BA/USAir, KLM/NW, and LH/UA shifted up after the alliances

6. **CRS display advantage:**

- Codeshared flights get listed three times on CRS screen;
- Codeshared flights get listed prior to interline flights on CRS screen;
- Multiple and priority display of codeshared flights together "crowd out" other airlines' flight info on CRS screen.

V. **Effect of alliances on Carriers and Passengers**

- **Trans-Atlantic Alliance Study**
- **Asia-Pacific Codesharing Alliance Study**
- **Other studies**
- **Policy Implication**

(A) Trans-Atlantic Alliance Study (Park, 1997)

(a) BA/USAir, KLM/NW, and LH/UA (complementary alliances) *increase aggregate demand on the alliance routes*, while DL/SN/SR (parallel alliance) decreases aggregate demand on the alliance routes.

(b) After the KLM/NW and DL/SN/SR alliances, equilibrium fares on respective alliance routes decreased by 22% and 19%.

(c) Altogether, equilibrium *annual passenger volume increased* by an average 35,998 passengers, while equilibrium *air fares decreased* by an average of $41 on the alliance routes.

→ Consumers in the North Atlantic markets are generally better off due to the alliances.

(d) Service improvement: *Schedule delay time (decreasing function of frequency)* is significantly reduced only for the case of complementary alliances.

(e) Most alliance partners have experienced *greater traffic increases on their alliance routes* than those on non-alliance routes.

(B) Effects of Airline Code-sharing Agreements:
    Asia-Pacific Alliances

● **Objectives of Oum-Park-Zhang (1996) Study**

- to measure systematically **the effects of code-sharing between non-market-leaders on market leader's behaviour and air fares.**

The Method and Empirical Results:

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- Developed a model based on profit maximization behaviour of n oligopoly firms in a market.

- *Applied it to a panel data for 57 transpacific air routes over the 1982-92 period.*

- *Codesharing between two non-leader major carriers* makes the market leader behave more competitively. As a result, the leader's output rises by 10,052 passengers per year and its price falls by $84 per passenger.

- It's important to distinguish the demand effect from the collusive/competitive effect.

- Future work:
  . to use true O-D data rather than using route segment data;
  . desirable to estimate followers' equations as well.

(C). Other studies
- Bruckner (1997), "The Economics of Internationatl Codesharing: Analysis of Airline Alliances"
  (Beneficial effect of codesharing outweighs harmful effect)

- Park and Zhang (1998), "Complimentary vs. Parallel Alliances"
  (Two types of alliances have different effects on total output and consumer surplus; complimentary alliances is always positive)

(D) Policy Implications of the Studies

- To encourage *alliance partners to coordinate beyond-gateways,* in addition to coordinating between gateways.

  ✈ *Complementary alliances*

- Need to be cautious in granting anti-trust immunity when the major benefit of an alliance occurs by *pooling capacity on the same route.*

- Need to encourage *alliance between minor players* in a market dominated by a major player as this will strengthen the aligned competitor

- Need to monitor *the partners' combined flight frequency* before/after the alliance (to see if there is a case for anti-trust measure)

VI. Future Direction of Global Network Formation and Research Agenda

Future Direction of Global Network Development.
- Global network will be formed *via strategic alliances among a group of airlines* from each continent.
  - Airlines will continue to face severe difficulty establishing a global network through

M&A.

- *Major strategic alliances will become more stable* because each partner will have incentive to stick with a global alliance group.
    - Cost of getting out of a major alliance network will increase over time.

- *A limited number of major global networks* will be formed via strategic alliances of airlines from each continent.

    - Each alliance is likely to include:
        one major North American carrier as *an anchor carrier;*
        one major European as *an anchor carrier;* and
    one or more Asian carriers (possibly an anchor carrier ?)
        one or more South American carriers
    - Anchor carriers will capture *a majority of long-haul intercontinental services,* while their junior partners on each continent will provide *primarily feeder services to hubs* of their alliance network.

Future Research

- What are the factors contributing success of an alliance?

- Indepth study comparing commercial alliances vs. equity alliances

- Regional structure of airlines

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Strategic Airline Alliances: Complementary vs. Parallel alliances

by

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Abstract

Strategic alliances have occurred in a broad spectrum of industries including the airline industry. This paper presents a model that examines the effects on market outcome and welfare of two types of strategic airline alliances: complementary vs. parallel alliances. It is identified that the two alliances have different effects on total output and consumer surplus. The complementary alliance is likely to increase total output, while the parallel alliance is likely to decrease it. Consequently, the former increases consumer surplus, while the latter is likely to decrease it. We find sufficient conditions under which each type of alliance improves total welfare. The empirical test results from the trans-Atlantic alliance routes for the 1990-94 period, confirm the theoretical predictions on partners' outputs and total output.

1. INTRODUCTION

Strategic alliances have occurred in a broad spectrum of industries including the automobile, commercial aircraft, electronic equipment, robotics, steel, and telecommunications industries (*Business Week* July 27, 1992; *Economist* September 11, 1993). Among these industries, the airline industry has had a large number of alliances which have been spurred on by regulatory barriers such as the lack of access to domestic markets by foreign carriers, limits on foreign ownership, or simply the fear of being left behind (Gallacher and Odell, 1994).

In order to attract more passengers in an increasingly competitive environment, major international airlines have been seeking to extend the range of their network and access new markets.[1] Some carriers have tried to expand overseas services by adding foreign spokes to their domestic hub cities. Since this approach requires enormous funding to build such a global network, with bilateral restrictions sometimes limiting their ability to expand international services, most international carriers have focused on integrating two or more existing networks through international airline alliances.

Strategic alliances allow carriers to expand the reach of their networks and services to many parts of the world where it may not be economical to do so on their own or where there may be a lack of authority to operate their own flights. These alliances range from simple route-by-route alliances to broad commercial alliances, and to equity alliances.[2]

Alliances may provide opportunities for partners involved to reduce costs by coordinating activities in some fields: joint use of ground facilities such as lounges, gates and check-in counters; codesharing[3] or joint operation; block space sales;[4] joint advertising and promotion;

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[1] In airline markets, there are demand forces such that consumers prefer airlines which serve a large number of points over ones which serve a smaller number of points, with all other factors such as prices held constant (Tretheway and Oum (1992)).

[2] We analyzed 46 international alliances being formed between the world's top-30 airlines in order to identify the areas of joint activities between alliance partners and measure the extent of coordination. Based on the extent of coordination, 28 cases were classified as simple route-by-route alliances, 9 cases as broad commercial alliances, and 9 cases as equity alliances. The equity alliance is the most advanced and durable form of alliances. It involves strategic linkage between both partners' flight network. One example is the KLM/Northwest alliance signed in January 1993. KLM invested in 25% of Northwest's voting shares and 49% of its equity as of March 1993, and they received antitrust immunity from the U.S. government in November 1992. Although each carrier's management remains separable due to foreign ownership limit, they can closely coordinate. They are able to achieve a high level of integration without fear of legal challenges from competitors and are able to discuss market strategy and pricing.

[3] A codesharing agreement is a marketing arrangement between two airlines whereby one airline's designator code is shown on flights operated by its partner airline. For example, Lufthansa has been codesharing on United Airlines' flight between Frankfurt and 25 U.S. interior cities via two of United's hubs (Chicago O'Hare and Washington Dulles). For the effects of codesharing, see Hadrovic (1990) and Gellman Research Associates (1994).

[4] If two carriers make a block space sale agreement, each carrier can buy a block of seats in the other carrier's flights and resell them to passengers. For example, Air Canada and Korean Air have signed on such an agreement on the Seoul-Vancouver-Toronto route, under which each buys 48 seats from the other's flights

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exchange of flight attendants; and so on. As a result, the partners may become more cost-effective and increase their competitiveness.

Alliances also produce several benefits for consumers. Alliance partners can better coordinate flight schedules to minimize travellers' waiting time between flights while providing sufficient time for connections. Joint baggage handling eliminates the need to retrieve and re-check baggage at connecting places, and thus reduces the risk associated with interline handling in which no one carrier has the sole responsibility for the baggage. Consumers' choices can increase due to alliances. For example, consider a passenger who wants to fly from Indianapolis to Lyon. She could fly Indianapolis-Washington, D.C.-Frankfurt-Lyon on United-Lufthansa partners' flights. She could also fly Indianapolis-Pittsburgh-London-Lyon on British Airways-USAir alliance flights. Alternatively, she could fly Indianapolis-Detroit-Amsterdam-Lyon on KLM-Northwest alliance flights. Without the alliances, she would have to interline on several different carriers with great inconvenience.

Although alliances generate benefits for both partners involved and consumers, it may reduce the number of competitors and thus increase the combined market power of alliance partners. As a result, the partners may increase air fares if they behave collusively and abuse their strengthened market power. On the other hand, it is also possible for air fares to decrease since alliances between non-market-leaders can increase their competitiveness against the market leader. By focusing on "complementary" alliances in the trans-Pacific markets, Oum, Park and Zhang (1996) empirically show that the alliances between non-leaders reduce the leader's equilibrium price.

Despite the growing importance of international airline alliances, few researchers have devoted effort to constructing formal models of the alliances.[5] This paper constructs a formal model to examine the effects on market outcome and economic welfare of different types of alliances: "complementary" and "parallel" alliances. The "complementary" alliance refers to the case where two firms link up their existing networks and build a new complementary network in order to feed traffic to each other. Major strategic alliances such as KLM/Northwest can be regarded as this type of alliance. For example, KLM and Northwest signed the "complementary" alliance by which they were able to connect 88 U.S. cities to 30 European and Middle Eastern cities via Northwest's hubs (Boston, Detroit, and Minneapolis) and KLM's Amsterdam hub, as of December 1994 (U.S. General Accounting Office, 1995).

The "parallel" alliance refers to collaboration between two firms competing on the same routes. Two types of parallel alliances are considered: "no shut-down" and "shut-down" parallel alliances. The difference between the two is that each partner continues to individually provide services on the route in the first type, while two partners integrate their

on the route.

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[5] The international airline issues have been investigated by researchers. The effects on pricing of bilateral agreements were investigated by, among others, Abbott and Thompson (1991), and Maillebiau and Hansen (1995). The effects of alliances have been empirically investigated by, among others, Youssef and Hansen (1994), Gellman Research Associates (1994), and Oum, Park and Zhang (1996).

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services in the second type. For example, Air Canada and Korean Air implemented the "no shut-down" parallel alliance on the Vancouver-Seoul route. Delta and Sabena formed the "shut-down" parallel alliance on the New York-Brussels route on which Delta stopped flying and purchased a block of seats from Sabena.

More specifically, this study investigates the following questions: After alliance partners make a particular type of alliance in a specific market, what happens to the partners' and non-aligned competitors' outputs in that market as well as in other markets? What happens to profit for the partners and the competitors due to the alliance? What happens to total output and air fare in that market as well as in other markets? Under which conditions do the alliances improve economic welfare?

In the next section, the Basic Model is considered to compare pre-alliance, complementary alliance, and parallel alliances situations. Section 3 examines the effects of complementary alliance on market outcome and total welfare. Section 4 investigates the effects of two types of parallel alliances on the partners' outputs and total welfare. Section 5 provides the Extend Model by relaxing some conditions assumed in the Basic Model. Section 6 tests some testable predictions associated with the effects on firms' output and total output. Section 7 concludes.

2. THE BASIC MODEL
2.1 Pre-alliance Situation
In order to analyze the effects of alliances on market outcome and economic welfare, we need to construct a pre-alliance situation first where none of airlines have yet to make any type of alliance. As depicted in Figure 1, a network is considered, consisting of three gateway cities located in different countries: A, B and H. There are three origin and destination markets, AH, BH and AB, and three firms (or carriers) are operating in the network. Firm 1 is assumed to serve all three markets (AH, BH and AB) using its hub-and-spoke network. Firms 2 and 3 are assumed to serve AH and BH markets, respectively.[6]

If travellers want to fly from city A and arrive at city B by firm 1's airplanes, they must change airplanes at the hub airport H. Or, they can use two segment flights, separately provided by firms 2 and 3, in order to arrive at their final destination. However, it is assumed that in the pre-alliance situation, travellers do not use multiple carriers' interline connecting services because of poor connections between firms 2 and 3.[7]

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[6] Note that two national carriers are assumed to operate on each route of the network. Since international air services between two cities are mainly decided by bilateral agreements between the two countries involving the two cities, this assumption seems to be reasonable.

[7] If connections must be made at connecting airports or hubs, less of the traveller's time will be required with a single airline than when the trip involves switching airlines, because a single airline's connecting flights are more likely to reduce waiting time at the connecting airports and lower probability of baggage being lost than multiple airlines' interline connecting flights.

2.2 Complementary Alliance Situation

Consider a situation where firms 2 and 3 make a "complementary" alliance. Both firms jointly provide connecting services for passengers travelling between cities A and B, while continuing to provide local services as before. In order to compete with firm 1's connecting services, the partners enhance quality of their connecting services. For example, the partners can adjust arrival and departure flights to minimize waiting time between flights while providing sufficient time for connections. They can also re-locate departure gates for connecting flights close to arrival gates, coordinate baggage transfer, and cooperate other joint activities at the connecting airport. They agree to share revenues and costs arising from the connecting services.

To examine the effects of this alliance, we need to consider demands and costs. Consider demands first. The "full" price demand model is considered from the viewpoint that each firm's demand in each market depends not only on its air fare, but also its service quality (De Vany, 1974; Panzar, 1979). Assuming that consumers can place a dollar value on service quality, each firm's demand in each market in the complementary alliance situation may be written as

$$Q_{AH}^i = D_{AH}^i(\rho_{AH}^i, \rho_{AB}^j) \quad for \ i=1,2, \ i \neq j$$

$$Q_{BH}^i = D_{BH}^i(\rho_{BH}^i, \rho_{BH}^j) \quad for \ i=1,3, \ i \neq j$$

$$Q_{AB}^i = D_{AB}^i(\rho_{AB}^i, \rho_{AB}^j) \quad for \ i=1, 2+3, \ i \neq j$$

where ρ_k^i is the full price of using carrier i's service in market k, which is the sum of air fare, denoted by p_k^i, and value of service quality. Solving the demand functions for ρ_k^i may yield the following inverse demand functions:

$$\rho_k^i = d_k^i(Q_k^i, Q_k^j) \quad for \ k = AH, BH, AB, \ i \neq j.$$

We assume that outputs of rival carriers are substitutes in each city-pair market:

$$\frac{\partial d_k^i}{\partial Q_k^j} < 0, \quad for \ k = AH, BH, AB, \ i \neq j. \tag{1}$$

The value of service quality can be regarded as cost of service quality from the viewpoint of carriers. Two different costs of service quality are considered: (i) schedule delay cost on each route, and (ii) inconvenient connecting cost at the connecting airport.

The schedule delay cost is a passenger's schedule delay time arising from the difference between the passenger's desired departure and actual departure time. Research has found that the schedule delay cost depends largely on the carrier's flight frequency, which in turn depends on its *total traffic* (e.g., Douglas and Miller, 1974). Thus, if Q is the total

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passengers carried by carrier i on route k, then the schedule delay cost may be written as $g_k^i(Q)$. It is assumed that $g'(\cdot) < 0$, that is, the schedule delay cost of an airline declines with its traffic on the route. The schedule delay cost for the non-stop services is $g_k^i(Q_k^i + Q_{AB}^i)$ for k = AH and BH, while the schedule delay cost for the connecting service is the sum of the schedule delay cost on each of two local routes, $g_{AH}^i(Q_{AH}^i + Q_{AB}^i) + g_{BH}^i(Q_{BH}^i + Q_{AB}^i)$.

The second component of the cost of service quality is a passenger's inconvenience cost due to connections. Carlton, Landes and Posner (1980) estimate that travellers place an extra cost of $13-17 (in 1978 dollars) for a single carrier's one-stop connecting services, as compared to its non-stop services. This extra cost for alliance partners' connecting services will be even larger, if the partners' connecting service is inferior to the single carrier's connecting service. For convenience of analysis, without loss of generality, we assume that the inconvenient connecting cost for the single carrier's connections is zero, but that for the partners' connections, denoted by γ, is positive. However, the partners' connecting cost will decrease as the level of their coordination increases at the airport H.

Carrier i's production cost function on route k may be expressed as $C_k^i(Q)$, implying its round-trip cost of carrying Q passengers on the route. Note that Q represents *total passengers* carried by the airline on the route. This production cost function reflects economies of traffic density, satisfying $C_k^{i\prime}(Q) > 0$ and $C_k^{i\prime\prime}(Q) < 0$.[8]

Given these demand and cost specifications, profit function for the non-aligned carrier and aligned partners can be expressed as:

$$\Pi^{1c} \equiv Q_{AH}^1 \left[d_{AH}^1(Q_{AH}^1, Q_{AH}^2) - g_{AH}^1(Q_{AH}^1 + Q_{AB}^1) \right] + Q_{BH}^1 \left[d_{BH}^1(Q_{BH}^1, Q_{BH}^3) - g_{BH}^1(Q_{BH}^1 + Q_{AB}^1) \right]$$

$$+ Q_{AB}^1 \left[d_{AB}^1(Q_{AB}^1, Q_{AB}^{(2+3)}) - g_{AH}^1(Q_{AH}^1 + Q_{AB}^1) - g_{BH}^1(Q_{BH}^1 + Q_{AB}^1) \right] \qquad (2)$$

$$- C_{AH}^1(Q_{AH}^1 + Q_{AB}^1) - C_{BH}^1(Q_{BH}^1 + Q_{AB}^1)$$

$$\Pi^{(2+3)c} \equiv Q_{AH}^2 \left[d_{AH}^2(Q_{AH}^1, Q_{AH}^2) - g_{AH}^2(Q_{AH}^2 + Q_{AB}^{(2+3)}) \right] + Q_{BH}^3 \left[d_{BH}^3(Q_{BH}^1, Q_{BH}^3) - g_{BH}^3(Q_{BH}^3 + Q_{AB}^{(2+3)}) \right]$$

$$+ Q_{AB}^{(2+3)} \left[d_{AB}^{(2+3)}(Q_{AB}^1, Q_{AB}^{(2+3)}) - g_{AH}^2(Q_{AH}^2 + Q_{AB}^{(2+3)}) - g_{BH}^3(Q_{BH}^3 + Q_{AB}^{(2+3)}) - \gamma \right] \qquad (3)$$

$$- C_{AH}^2(Q_{AH}^2 + Q_{AB}^{(2+3)}) - C_{BH}^3(Q_{BH}^3 + Q_{AB}^{(2+3)})$$

---

[8] Caves, Christensen and Tretheway (1984) distinguish between economies of traffic density and economies of firm size. Economies of traffic density mean that output is expanded by increasing flight frequency within a given network. Economies of firm size imply that output is expanded by adding points to the network. Many studies reach a common conclusion: roughly constant returns to firm size exist, while sizeable economies of traffic density exist up to fairly large volumes of traffic (See, for example, Caves, Christensen, Tretheway and Windle (1987)).

where superscript c stands for complementary alliance.

It can be shown that $\partial^2 \pi^{ic}/\partial Q_{AH}^i \partial Q_{BH}^i = 0$. This implies that there are no network complementarities between local services. We can also show that

$$\frac{\partial^2 \pi^{ic}}{\partial Q_k^i \partial Q_{AB}^i} = -2g_k^{i'}(\cdot) - g_k^{i''}(\cdot) \cdot (Q_k^i + Q_{AB}^i) - C_k^{i''}(\cdot), \quad k = AH, BH. \tag{4}$$

In (4), the first term is positive because an airline's schedule delay cost decreases with its traffic. The second term is positive if g is linear or concave. The third term is also positive because of economies of traffic density. (4) can be positive even if g is convex. More generally, we assume that (4) is positive, implying that there exist network complementarities between local and connecting services. In other words, a carrier's marginal profit from a local service increases as its connecting passengers increase.

In (1), outputs of rival carriers are assumed to be substitutes in each city-pair market. We further assume that in each market a carrier's marginal profit decreases as the output of the competitor increases:

$$\frac{\partial^2 \pi^{ic}}{\partial Q_k^i \partial Q_k^j} < 0, \quad k = AH, BH, AB, \quad i \neq j, \tag{5}$$

which implies that within each market the outputs of duopolists are "strategic substitutes" in the terms of Bulow, Geanakoplos and Klemperer (1985).

2.3 Parallel Alliance Situation

Next, consider another post-alliance situation where firms 1 and 2 make a "parallel" alliance in a sense that they were competitors in the AH segment of the network before the alliance, but now they coordinate or integrate their operations in that segment. For convenience of notation, among the parallel alliance partners, firm 1 is called as a hub partner, and firm 2 as a non-hub partner. Firm 3 is called as a non-partner.

Two types of parallel alliances are considered. The first is that each partner continues to provide local services in the AH segment and choose their quantities to maximize their joint profits. For example, Air Canada (a hub partner) and Korean Air (a non-hub partner) have implemented this style of parallel alliance on the Seoul-Vancouver-Toronto route since 1993.

Another type is that the partners integrate services in the AH segment in a way that the hub partner continues to provide local services, but the non-hub partner stops producing local services. For simplicity of analysis, it is assumed that the partners equally share revenues and costs arising from the joint services. For example, Delta and Sabena formed this sort of parallel alliance on the New York-Brussels route where Delta stopped non-stop services after the alliance.

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Since the non-hub partner shuts down its operation in the second case, the first case is referred to as "no shut-down" parallel alliance, the second as "shut-down" parallel alliance, hereafter. For both cases, firm 3 continues to operate alone in the BH segment as before.

For consistency of analysis, we consider the same demand and cost specifications as used in the complementary alliance. In particular, by using the "full" price demand specification, the inverse demand functions for the parallel alliance may be written as

$$\rho_{AH}^{i} = d_{AH}^{i}(Q_{AH}^{i}, Q_{AH}^{j}) \quad for \ i=1,2, \ i \neq j$$

$$\rho_{BH}^{i} = d_{BH}^{i}(Q_{BH}^{i}, Q_{BH}^{j}) \quad for \ i=1,3, \ i \neq j$$

$$\rho_{AB}^{1} = d_{AB}^{1}(Q_{AB}^{1})$$

where Q_{AH}^{2} is positive for the "no shut-down" case; Q_{AH}^{2} is zero for the "shut-down" case. We still assume that conditions (1), (4) and (5) hold.

3. EFFECTS OF COMPLEMENTARY ALLIANCE
3.1 Effects on Firms' Outputs and Profits

Let us first analyze the effects of the complementary alliance. We consider an equilibrium that arises when the non-aligned carrier (i.e., firm 1) and the aligned partners (i.e., firms 2+3) play a Cournot game in each market of the network.[9] By using vectors Q^1 and Q^2, (2) and (3) can be simplified as

$$\max_{Q^1} \ \Pi^{1c} = \Pi^{1c}(Q^1, Q^2) \tag{6}$$

$$\max_{Q^2} \ \Pi^{2c} = \Pi^{2c}(Q^1, Q^2; \gamma) \tag{7}$$

where $Q^i = (Q_{AH}^i, Q_{BH}^i, Q_{AB}^i)$ for i = 1, 2. For convenience of notation, superscript 2+3 is replaced by 2. Assume that there exists a "stable" Cournot-Nash equilibrium $(Q^1(\gamma), Q^2(\gamma))$ which satisfies the following first-order conditions for maximization of (6) and (7):[10]

---

[9] The Cournot assumption is not crucial in the duopoly market. Brander and Zhang (1990) and Oum, Zhang and Zhang (1993), using conjectural variations, find some evidence that airlines in duopoly markets behave like Cournot competitors.

[10] This stability assumption is important. If an equilibrium is not stable, then a slight deviation by one player does not cause the equilibrium to return to that point. The stability of Cournot-Nash equilibrium has been studied by, among others, Seade (1980), Dixit (1986), Slade (1994), and Zhang and Zhang (1996). In particular, Zhang and Zhang (1996) extends single-market conditions for stability of Cournot-Nash equilibria to multimarket conditions.

$$\Pi_1^{1c}(Q^1(\gamma), Q^2(\gamma)) \equiv 0 \tag{8}$$

$$\Pi_2^{2c}(Q^1(\gamma), Q^2(\gamma); \gamma) \equiv 0 \tag{9}$$

Assume that the second-order conditions are also satisfied, i.e., the following Hessian matrices are negative definite for $i = 1, 2$:

$$\Pi_{ii}^{ic} \equiv \begin{bmatrix} \Pi_{AH_i AH_i}^{ic} & \Pi_{AH_i BH_i}^{ic} & \Pi_{AH_i AB_i}^{ic} \\ \Pi_{BH_i AH_i}^{ic} & \Pi_{BH_i BH_i}^{ic} & \Pi_{AB_i AB_i}^{ic} \\ \Pi_{AB_i AH_i}^{ic} & \Pi_{AB_i BH_i}^{ic} & \Pi_{AB_i AB_i}^{ic} \end{bmatrix}.$$

With the present specifications, it can be shown that as compared to the pre-alliance situation, firm 1 (the partners, respectively) produces less (more, respectively) output not only in the market where the complementary alliance occurs, but also in the other markets.·

Proposition 3-1. Under the complementary alliance conditions, firm 1 produces less output in markets AH, BH and AB, but the alliance partners produce more output in both their local market and the AB market than under the pre-alliance conditions.

Proof. Differentiating (8) and (9) with respect to γ yields

$$\Pi_{11}^{1c}\frac{dQ^1}{d\gamma} + \Pi_{12}^{1c}\frac{dQ^2}{d\gamma} = 0, \tag{10}$$

$$\Pi_{21}^{1c}\frac{dQ^1}{d\gamma} + \Pi_{22}^{1c}\frac{dQ^2}{d\gamma} + \Pi_{2\gamma}^{2c} = 0 \tag{11}$$

where $\Pi_{2\gamma}^{2c} \equiv [0, \ 0, \ -1]^T$. Solving (10) and (11) for $(dQ^1/d\gamma, dQ^2/d\gamma)$, we have

$$\frac{dQ^1}{d\gamma} = \left[I - \left(\Pi_{11}^{1c}\right)^{-1}\Pi_{12}^{1c}\left(\Pi_{22}^{2c}\right)^{-1}\Pi_{21}^{2c} \right]^{-1}\left(\Pi_{11}^{1c}\right)^{-1}\Pi_{12}^{1c}\left(\Pi_{22}^{2c}\right)^{-1}\Pi_{2\gamma}^{2c} \tag{12}$$

$$\frac{dQ^2}{d\gamma} = -\left[I - \left(\Pi_{22}^{2c}\right)^{-1}\Pi_{21}^{2c}\left(\Pi_{11}^{1c}\right)^{-1}\Pi_{12}^{1c} \right]^{-1}\left(\Pi_{22}^{2c}\right)^{-1}\Pi_{2\gamma}^{2c} \tag{13}$$

Differentiating (8) with respect to Q^2 yields the following 3-by-3 "derivative" matrix of carrier 1's reaction functions: $R_2^{1c} \equiv \partial R^{1c}(Q^2)/\partial Q^2 \equiv -\left(\Pi_{11}^{1c}\right)^{-1}\Pi_{12}^{1c}$ where $R^{1c}(Q^2(\cdot))$ is carrier 1's reaction function for the aligned partners' outputs. Similarly, a "derivative" matrix of the partners' reaction functions for firm 1's outputs can be defined as $R_1^{2c} \equiv \partial R^{2c}(Q^1)/\partial Q^1 \equiv -\left(\Pi_{22}^{2c}\right)^{-1}\Pi_{21}^{2c}.$

In what follows, we show that every element of R_2^{1c}, R_1^{2c} matrices is negative: First, it turns out that both Hessian inverse matrices are negative matrices. $\left(\Pi_{11}^{1c}\right)^{-1}$ can be expressed as

$$
\frac{1}{\left|\Pi_{11}^{1c}\right|}
\begin{bmatrix}
\Pi_{BH_1BH_1}^{1c}\Pi_{AB_1AB_1}^{1c}-\left(\Pi_{BH_1AB_1}^{1c}\right)^2 & \Pi_{AH_1AB_1}^{1c}\Pi_{BH_1AB_1}^{1c} & -\Pi_{AH_1AB_1}^{1c}\Pi_{BH_1BH_1}^{1c} \\
\Pi_{AB_1AH_1}^{1c}\Pi_{BH_1AB_1}^{1c} & \Pi_{AH_1AH_1}^{1c}\Pi_{AB_1AB_1}^{1c}-\left(\Pi_{AH_1AB_1}^{1c}\right)^2 & -\Pi_{AH_1AH_1}^{1c}\Pi_{BH_1AB_1}^{1c} \\
-\Pi_{AB_1AH_1}^{1c}\Pi_{BH_1BH_1}^{1c} & -\Pi_{AH_1AH_1}^{1c}\Pi_{AB_1BH_1}^{1c} & \Pi_{AH_1AH_1}^{1c}\Pi_{BH_1BH_1}^{1c}
\end{bmatrix}.
$$

By the second-order conditions and the network complementarities condition (4), every element of $\left(\Pi_{11}^{1c}\right)^{-1}$ is negative. Similarly, $\left(\Pi_{22}^{2c}\right)^{-1}$ is also negative matrix. Secondly, Π_{12}^{1c} and Π_{21}^{2c} are negative diagonal matrices because of the strategic substitutes condition (5). Thus, both R_2^{1c} and R_1^{2c} are negative matrices.

By using R_2^{1c} and R_1^{2c}, (12) and (13) can be rewritten as

$$
\frac{dQ^1}{d\gamma} = -\left[I - R_2^{1c}R_1^{2c}\right]^{-1}R_2^{1c}\left(\Pi_{22}^{2c}\right)^{-1}\Pi_{2\gamma}^{2c} \tag{14}
$$

$$
\frac{dQ^2}{d\gamma} = -\left[I - R_1^{2c}R_2^{1c}\right]^{-1}\left(\Pi_{22}^{2c}\right)^{-1}\Pi_{2\gamma}^{2c} \tag{15}
$$

The stability of Cournot-Nash equilibrium implies that the magnitude of the eigenvalues of matrices $R_2^1R_1^2$ and $R_1^2R_2^1$, must be less than one (Zhang and Zhang, 1996). Hence, by the Neumann lemma,[11] $\left(I - R_2^{1c}R_1^{2c}\right)^{-1}$ and $\left(I - R_1^{2c}R_2^{1c}\right)^{-1}$ exists and

$$
\left(I - R_j^{ic}R_i^{jc}\right)^{-1} = I + \left(R_j^{ic}R_i^{jc}\right) + \left(R_j^{ic}R_i^{jc}\right)^2 + \cdots + \left(R_j^{ic}R_i^{jc}\right)^n + \cdots \qquad \text{for } i=1,2, \ i \neq j.
$$

Since $R_j^{ic}R_i^{jc}$ is a positive matrix, then $\left(I - R_j^{ic}R_i^{jc}\right)^{-1}$ is also a positive matrix.

Therefore, $dQ^1/d\gamma > 0$ and $dQ^2/d\gamma < 0$ since R_2^{1c} is a negative matrix and $\Pi_{2\gamma}^{2c}$ is a negative vector.

$$Q.E.D.$$

The intuitive explanations for Proposition 3-1 are as follows: If the partners provide better quality of connecting services in market AB, inconvenience cost (γ) will decrease, which in turn increases connecting traffic for the partners, that is, $dQ_{AB}^{1,3}/d\gamma < 0$. This connecting traffic increase implies that the partners can feed more traffic to each other. As a result,

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[11] Neumann lemma is that if R is a real square matrix and the magnitude of eigenvalues of R is less than one, then $(I-R)^{-1}$ exists and $(I-R)^{-1} = \sum_{i=0}^{\infty} R^i$. See, for example, Ortega and Rheinboldt (1970, p.45).

schedule delay cost for local non-stop services will decrease (i.e., service quality for the local services increases) and average operating costs on the AH and BH routes will decrease due to economies of traffic density. Consequently, increases in $Q_{AB}^{2,3}$ lead to decreases the partners' air fares in the AH and BH markets, which in turn increases AH and BH traffic as well. Therefore, it is possible that increasing qualities of service and decreasing operating cost are jointly achievable if the partners collaborate very well.

On the other hand, increases in $Q_{AB}^{2,3}$ due to the better coordination decrease Q_{AB}^1, resulting in increased carrier 1's unit cost on the AH and BH routes and increased schedule delay cost for its local services. As a result of the complementary alliance, carrier 1 decreases output not only in the AB market, but also in the other market.

Although firm 1 reduces its output in markets AH, BH and AB, it does not necessarily imply that it decreases its profit, because its profit is affected not only by its output in these markets, but also by corresponding air fares. Thus, it is worthwhile to investigate whether each firm's profit increases or decreases due to the complementary alliance.

Proposition 3-2. Under the complementary alliance conditions, firm 1 earns less profit, but the alliance partners earn more profit, as compared to the pre-alliance conditions.
Proof. Substituting the Cournot-Nash equilibrium $\left(Q^1(\gamma), Q^2(\gamma)\right)$ into (6) and (7), and differentiating these with respect to γ, we have

$$\frac{\partial \Pi^{1c}}{\partial \gamma} = \sum_{k=AH}^{AB} \frac{\partial \Pi^{1c}}{\partial Q_k^1}\frac{dQ_k^1}{d\gamma} + \sum_{k=AH}^{AB} \frac{\partial \Pi^{1c}}{\partial Q_k^2}\frac{dQ_k^2}{d\gamma} = \sum_{k=AH}^{AB} \frac{\partial d_k^1}{\partial Q_k^2}\frac{dQ_k^2}{d\gamma}Q_k^1 \tag{16}$$

By the first-order conditions, the first term of the right-hand side of the first equations of (16)

$$\frac{\partial \Pi^{2c}}{\partial \gamma} = \sum_{k=AH}^{AB} \frac{\partial \Pi^{2c}}{\partial Q_k^2}\frac{dQ_k^2}{d\gamma} + \sum_{k=AH}^{AB} \frac{\partial \Pi^{2c}}{\partial Q_k^1}\frac{dQ_k^1}{d\gamma} + \frac{d\Pi^{2c}}{d\gamma} = \sum_{k=AH}^{AB} \frac{\partial d_k^2}{\partial Q_k^1}\frac{dQ_k^1}{d\gamma}Q_k^2 - Q_{AB}^2 \tag{17}$$

and (17) disappears. By condition (1), $\partial\Pi^{1c}/\partial\gamma > 0$ and $\partial\Pi^{2c}/\partial\gamma < 0$.   *Q.E.D.*

3.2 Effects on Market Outcome and Economic Welfare
According to Proposition 3-1, it is not clear whether *total* output in each market increases or decreases due to the complementary alliance since firm 1 decreases output in each market, while the aligned partners increase. Thus, in this section, we examine the effects of the alliances on total output and consumer surplus in each market, and total welfare.

In order to examine changes in *total output* due to the complementary alliance, we further assume that the aligned partners and non-aligned competitors are symmetric and the partners can provide connecting services at the same quality as the non-partner's (i.e., $\gamma = 0$).

Proposition 3-3. For the symmetric case, the complementary alliance results in (i) increased

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total output and (ii) decreased "full" price in markets AH, BH, and AB. Therefore, consumers in these markets are better off due to the complementary alliance.

Proof. Let Q be total output vector and $\rho(Q)$ be corresponding "full" price vector. By definition of Q,

$$\frac{dQ}{d\gamma} = \frac{dQ^1}{d\gamma} + \frac{dQ^2}{d\gamma}$$

(18)

Rearranging (10) and using $R_2^{1c} \equiv -\left(\Pi_{11}^{1c}\right)^{-1}\Pi_{12}^{1c}$, we can have

$$\frac{dQ^1}{d\gamma} = R_2^{1c}\frac{dQ^2}{d\gamma}$$

(19)

Substituting (15) and (19) into (18) yields

$$\frac{dQ}{d\gamma} = -\left[I + R_2^{1c}\right]\left[I - R_1^{2c}R_2^{1c}\right]^{-1}\left(\Pi_{22}^{2c}\right)^{-1}\Pi_{2\gamma}^{2c}$$

(20)

By using the symmetric condition and $R_1^{2c} \equiv -\left(\Pi_{22}^{2c}\right)^{-1}\Pi_{21}^{2c}$, (20) can be rewritten as

$$\frac{dQ}{d\gamma}\Big|_{\gamma=0} = -\left[I + \left(\Pi_{22}^{2c}\right)^{-1}\Pi_{21}^{2c}\right]^{-1}\left(\Pi_{22}^{2c}\right)^{-1}\Pi_{2\gamma}^{2c}$$

(21)

Using the result $(AB)^{-1} = B^{-1}A^{-1}$, we can further simplify (21) as follows:

$$\frac{dQ}{d\gamma}\Big|_{\gamma=0} = -\left[\Pi_{22}^{2c} + \Pi_{21}^{2c}\right]^{-1}\Pi_{2\gamma}^{2c}$$

(22)

Notice that both Π_{22}^{2c} and Π_{21}^{2c} matrices are negative definite. Consequently, $\Pi_{22}^{2c} + \Pi_{21}^{2c}$ is a negative definite matrix. Its inverse matrix, $\left(\Pi_{22}^{2c} + \Pi_{21}^{2c}\right)^{-1}$ can be expressed as

$$\frac{1}{|\Pi_{22}^{2c} + \Pi_{21}^{2c}|}\begin{bmatrix} \left(\Pi_{B_2B_2}^{2c} + \Pi_{B_2B_1}^{2c}\right)\left(\Pi_{C_2C_2}^{2c} + \Pi_{C_2C_1}^{2c}\right) - \left(\Pi_{B_2C_2}^{2c}\right)^2 & \Pi_{A_2C_1}^{2c}\Pi_{C_2B_2}^{2c} & -\Pi_{A_2C_1}^{2c}\left(\Pi_{B_2B_2}^{2c} + \Pi_{B_2B_1}^{2c}\right) \\ \Pi_{C_2A_1}^{2c}\Pi_{B_2C_2}^{2c} & \left(\Pi_{A_2A_2}^{2c} + \Pi_{A_2A_1}^{2c}\right)\left(\Pi_{C_2C_2}^{2c} + \Pi_{C_2C_1}^{2c}\right) - \left(\Pi_{A_2C_2}^{2c}\right)^2 & -\Pi_{B_2C_2}^{2c}\left(\Pi_{A_2A_2}^{2c} + \Pi_{A_2A_1}^{2c}\right) \\ -\Pi_{C_2A_1}^{2c}\left(\Pi_{B_2B_2}^{2c} + \Pi_{B_2B_1}^{2c}\right) & -\Pi_{C_2B_1}^{2c}\left(\Pi_{A_2A_2}^{2c} + \Pi_{A_2A_1}^{2c}\right) & \left(\Pi_{A_2A_2}^{2c} + \Pi_{A_2A_1}^{2c}\right)\left(\Pi_{B_2B_2}^{2c} + \Pi_{B_2B_1}^{2c}\right) \end{bmatrix}$$

where subscripts A, B and, C represent AH, BH, and AB, respectively. Since every element of $\left(\Pi_{22}^{2c} + \Pi_{21}^{2c}\right)^{-1}$ is strictly negative, the inverse matrix is a negative matrix. Combining it with $\Pi_{2\gamma}^{2c}$ vector implies, we have $dQ/d\gamma|_{\gamma=0} < 0$. Thus, $d\rho(Q)/d\gamma|_{\gamma=0} > 0$. Consequently, consumer surplus in each market increases due to the complementary alliance. *Q.E.D.*

In order to analyze changes in total welfare due to the complementary alliance, we assume a partial equilibrium framework in which consumer demand for air travel in each market is

derived from a utility function which can be approximated by the form

$$\sum_{k=AH}^{AB} U_k(Q_k^1, Q_k^2) + Z$$

where Z is expenditure on a competitively supplied *numeraire* good, and $\partial U_k/\partial Q_k^i = \rho_k^i$. Recall that ρ_k^i is the full price of using carrier i's service in market k, i.e., $\rho_k^i = p_k^i + g_k^i(\cdot)$.

Then consumer surplus in each market can be written as

$$CS_k = U_k(Q_k^1, Q_k^2) - \rho_k^1 Q_k^1 - \rho_k^2 Q_k^2, \tag{23}$$

and total surplus can be written as

$$W = \sum_{k=AH}^{AB} CS_k + (\Pi^1 + \Pi^2) \tag{24}$$

where W may be interpreted as "World Welfare" if the markets under consideration involves different countries.

Substitution of (2) and (3) into (24) can yield the following expression for W:

$$W = \sum_{k=AH}^{AB} U_k(Q_k^1, Q_k^2) - \sum_{i=1}^{2} \left[g_{AH}^i(Q_{AH}^i + Q_{AB}^i) \cdot (Q_{AH}^i + Q_{AB}^i) + g_{BH}^i(Q_{BH}^i + Q_{AB}^i) \cdot (Q_{BH}^i + Q_{AB}^i) \right]$$

$$- \sum_{i=1}^{2} \left[c_{AH}^i(Q_{AH}^i + Q_{AB}^i) + c_{BH}^i(Q_{BH}^i + Q_{AB}^i) \right] - \gamma Q_{AB}^2 \tag{25}$$

where again, for simplicity, superscript 2+3 is replaced by 2.

Proposition 3-4. For the symmetric case, total welfare rises due to the complementary alliance.

Proof. Differentiating (25) with respect to γ and using $\partial U_k/\partial Q_k^i = \rho_k^i = p_k^i + g_k^i$, we can show

$$\frac{dW}{d\gamma} = \sum_{i=1}^{2} \sum_{k=AH}^{BH} \left[p_k^i - g_k^{i\prime} \cdot (Q_k^i + Q_{AB}^i) - c_k^{i\prime} \right] \frac{dQ_k^i}{d\gamma}$$

$$+ \sum_{i=1}^{2} \left[p_{AB}^i - \sum_{k=AH}^{BH} \left(g_k^{i\prime} \cdot (Q_k^i + Q_{AB}^i) - c_k^{i\prime} \right) \right] \frac{dQ_{AB}^i}{d\gamma} - \left[Q_{AB}^2 + \gamma \frac{dQ_{AB}^2}{d\gamma} \right]. \tag{26}$$

Notice the first and second bracketed terms of (26) are positive by the first-order conditions. Since $dQ_k^1/d\gamma > 0$ and $dQ_k^2/d\gamma < 0$ for each market k, the overall effect of the complementary alliance on total welfare is not clear.

However, under the symmetric condition and $\gamma = 0$, (26) can be reduced to

$$\frac{dW}{d\gamma}\Big|_{\gamma=0} = \sum_{k=AH}^{BH} \left[p_k^1 - g_k^{1'} \cdot (Q_k^1 + Q_{AB}^1) - c_k^{1'} \right] \left(\frac{dQ_k^1}{d\gamma} + \frac{dQ_k^2}{d\gamma} \right)$$

$$+ \left[p_{AB}^1 - \sum_{k=AH}^{BH} \left(g_k^{1'} \cdot (Q_k^1 + Q_{AB}^1) - c_k^{1'} \right) \right] \cdot \left(\frac{dQ_{AB}^1}{d\gamma} + \frac{dQ_{AB}^2}{d\gamma} \right) - Q_{AB}^2.$$

By the first-order conditions and Proposition 3-3, $dW/d\gamma|_{\gamma=0}<0$. $\qquad$ Q.E.D.

Proposition 3-4 provides sufficient conditions for the complementary alliance to raise welfare. However, welfare can increase even for a small positive γ. For example, in (26), $dW/d\gamma|_{\gamma=0}<0$ if the partners' markup in each market is greater than firm 1's markup and the $\gamma \cdot (dQ_{AB}^2/d\gamma)$ term is sufficiently small.

4. EFFECTS OF PARALLEL ALLIANCE
4.1 Effects of No Shut-down Parallel Alliance
Let us turn to the effect of the parallel alliances. We first analyze the effect of the "no shut-down" parallel alliance where two partners continue to individually provide local services after their alliance. However, it is hard to directly sign the "overall" effect of the no shut-down parallel alliance since the effect involves switching from one situation (i.e., individual profit maximization) to another (i.e., joint profit maximization). Farrel and Shapiro (1990) use differential techniques in order to avoid similar difficulties faced in the analysis of horizontal merger effects.

To use the differential techniques, we define θ as: $\theta = 1$ for post-parallel alliance; $\theta = 0$ for pre-alliance. We then treat θ as continuous in the range $0 \le \theta \le 1$, and assume that carrier i's output in market k, $Q_k^i(\theta)$, is continuous and differentiable in θ in the entire range. By these assumptions, the overall effect of switching from the pre-alliance to the "no shut-down" parallel alliance can be calculated as the integral of the infinitesimal effect as follows:

$$\Delta Q_k^i(\theta) \equiv Q_k^i(1) - Q_k^i(0) = \int_0^1 \left[dQ_k^i(\theta)/d\theta \right] d\theta.$$

It turns out to be easy to sign the infinitesimal effect, $dQ_k^i(\theta)/d\theta$. Consequently, the overall effect, $\Delta Q_k^i(\theta)$, can be determined as well if the sign of the infinitesimal effect remains unchanged in the range, which can be verified.

Based on the demand and cost specifications in Section 2, each firm's post-alliance profit function can be expressed as

$$\max_{Q^1} \Pi^{1P}(Q^1, Q^2, Q^3; \theta) \equiv \Pi^1 + \theta \cdot \Pi^2$$

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$$\max_{Q^2} \Pi^{2p}(Q^1, Q^2, Q^3; \theta) \equiv \Pi^2 + \theta \cdot \Pi^1$$

$$\max_{Q^3} \Pi^{3p}(Q^1, Q^3) \equiv \Pi^3$$

where superscript p stands for parallel alliance; $Q^1 \equiv \left(Q_{AB}^1, Q_{BH}^1, Q_{AH}^1\right)$, $Q^2 \equiv Q_{AH}^2$, $Q^3 \equiv Q_{BH}^3$;

and $\Pi^1 \equiv Q_{AH}^1\left[d_{AB}^1(\cdot) - g_{AH}^1(\cdot)\right] + Q_{BH}^1\left[d_{BH}^1(\cdot) - g_{BH}^1(\cdot)\right] + Q_{AB}^1\left[d_{AB}^1(\cdot) - g_{AH}^1(\cdot) - g_{BH}^1(\cdot)\right] - C_{AH}^1(\cdot) - C_{BH}^1(\cdot)$,

$\Pi^2 \equiv Q_{AH}^2\left[d_{AH}^2(\cdot) - g_{AH}^2(\cdot)\right] - C_{AH}^2(\cdot)$, $\Pi^3 \equiv Q_{BH}^3\left[d_{BH}^3(\cdot) - g_{BH}^3(\cdot)\right] - C_{BH}^3(\cdot)$.

We will show that unlike the complementary alliance, parallel alliance partners are more likely to decrease their total output in market AH after their alliance.

Proposition 4-1. If the non-hub partner (i.e., firm 2) produces the same amount of output after the "no shut-down" parallel alliance, then the hub partner (i.e., firm 1) produces less output in all three markets, and the non-partner (i.e., firm 3) produces more output in market BH than under the pre-alliance.

Proof. Since the non-hub partner does not change its output in the parallel alliance, the first-order conditions for firms 1 and 3 may be respectively written as

$$\Pi_1^{1p} = 0, \quad \Pi_3^{3p} = 0.$$

Assuming that there exists a "stable" equilibrium, $\left(Q^1(\theta), Q^3(\theta)\right)$, which satisfies the first-order conditions for firms 1 and 3, that is,

$$\Pi_1^{1p}\left(Q^1(\theta), Q^3(\theta); \theta\right) \equiv 0 \tag{27}$$

$$\Pi_3^{3p}\left(Q^1(\theta), Q^3(\theta)\right) \equiv 0 \tag{28}$$

Differentiating (27) and (28) with respect to θ yields

$$\Pi_{11}^{1p}\frac{dQ^1}{d\theta} + \Pi_{13}^{1p}\frac{dQ^3}{d\theta} + \Pi_{1\theta}^{1p} = 0, \tag{29}$$

$$\Pi_{31}^{3p}\frac{dQ^1}{d\theta} + \Pi_{33}^{3p}\frac{dQ^3}{d\theta} = 0 \tag{30}$$

where $\Pi_{1\theta}^{1p} \equiv \left[Q_{AB}^2 \cdot \left(\partial d_{AB}^2 / \partial Q_{AB}^1\right), 0, 0\right]^T$, the first element of which is negative by condition (1).

Since both $\left(\Pi_{33}^{3p}\right)^{-1}$ and Π_{31}^{3p} are negative matrices, $dQ^1/d\theta$ and $dQ^3/d\theta$ have opposite signs

(see equation (30)). Now, we show $dQ^1/d\theta < 0$. Solving (29) and (30) for $dQ^1/d\theta$, we have

$$\frac{dQ^1}{d\theta} = -\left[I - R_3^{1p} R_1^{3p}\right]^{-1}\left(\Pi_{11}^{1p}\right)^{-1}\Pi_{1\theta}^{1p}$$

(31)

where $R_3^{1p} \equiv -\left(\Pi_{11}^{1p}\right)^{-1}\Pi_{13}^{1p}$ and $R_1^{3p} \equiv -\left(\Pi_{33}^{3p}\right)^{-1}\Pi_{31}^{3p}$ are derivative matrices of firm 1's (firm 3's, respectively) reaction function for firm 3's (firm 1's, respectively) output. Imposing the stability condition on the equilibrium yields that $\left[I - R_3^{1p} R_1^{3p}\right]^{-1}$ is a positive matrix. As shown in Proposition 3-1, every element of $\left(\Pi_{11}^{1p}\right)^{-1}$ is negative because of the second-order conditions and the network complementarities condition (4). Therefore, $dQ^1/d\theta < 0$ and $dQ^3/d\theta > 0$.

Next, we show that the signs of $dQ^1/d\theta < 0$ and $dQ^3/d\theta > 0$ remain unchanged in the entire range of interest. In (31), the third term, $\Pi_{1\theta}^{1p}$, remains as negative in the range since the first element of $\Pi_{1\theta}^{1p}$ is always negative regardless of any value of θ in the range. By similar arguments, the signs of the first and second terms remain unchanged in the region. *Q.E.D.*

Notice that the condition which $\Pi_{1\theta}^{1p} < 0$ plays a crucial role in Proportion 4-1. In fact, $\Pi_{1\theta}^{1p} \equiv \Pi_1^2$, thus implying that firm 2's profit decreases as firm 1 produces more output in market AH. Thus, the intuition behind Proportion 4-1 is that by forming the "no shut-down" parallel alliance and maximizing the joint profit, the hub partner chooses Q^1 with taking account of the negative externalities of the hub partner's output on the non-hub partner's profit. This leads to decreases in the hub partner's output in market AH. Consequently, the hub partner decreases its BH and AB traffic due to the network complementarities.

Similarly, we can show

Proposition 4-2. If the hub partner (i.e., firm 1) produces the same amount of output after the parallel alliance, then the non-hub partner (i.e., firm 2) decreases its output, and the non-partner (i.e., firm 3) produces the same amount of output, as compared to the pre-alliance situation.

The next question naturally arises: what if both Q^1 and Q^2 are chosen endogenously? If the two partners endogenously decides their outputs, they cannot simultaneously increase output in market AH after the parallel alliance.

Proposition 4-3. $dQ^1/d\theta$ and $dQ^2/d\theta$ cannot both be positive.

Proof. Denoting a "stable" equilibrium by $\left(Q^1(\theta), Q^2(\theta), Q^3(\theta)\right)$, and differentiating the first-order conditions with respect to θ, we have

$$\Pi_{11}^{1p}\frac{dQ^1}{d\theta} + \Pi_{12}^{1p}\frac{dQ^2}{d\theta} + \Pi_{13}^{1p}\frac{dQ^3}{d\theta} + \Pi_{1\theta}^{1p} = 0,$$

(32)

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$$\Pi_{21}^{2p}\frac{dQ^1}{d\theta} + \Pi_{22}^{2p}\frac{dQ^2}{d\theta} + \qquad \Pi_{2\theta}^{2p} = 0, \tag{33}$$

$$\Pi_{31}^{3p}\frac{dQ^1}{d\theta} + \qquad \Pi_{33}^{3p}\frac{dQ^3}{d\theta} = 0 \tag{34}$$

where $\Pi_{2\theta}^{2p} \equiv Q_{AH}^1 \cdot \left(\partial d_{AH}^1 / \partial Q_{AH}^2\right) < 0$.

Again, from (34), it can be easily verified that $dQ^1/d\theta$ and $dQ^3/d\theta$ have opposite signs. Equations (32) and (33) show that $dQ^1/d\theta$ and $dQ^2/d\theta$ are interdependent with each other. Solving (32)-(34) for $dQ^1/d\theta$ and $dQ^2/d\theta$ yields

$$\frac{dQ^1}{d\theta} = -\left[I - R_3^{1p}R_1^{3p}\right]^{-1}\left(\Pi_{11}^{1p}\right)^{-1}\left(\Pi_{1\theta}^{1p} + \Pi_{12}^{1p}\frac{dQ^2}{d\theta}\right), \tag{35}$$

or

$$\frac{dQ^2}{d\theta} = -\left(\Pi_{22}^{1p}\right)^{-1}\left(\Pi_{2\theta}^{2p} + \Pi_{21}^{2p}\frac{dQ^1}{d\theta}\right). \tag{36}$$

Since $\Pi_{12}^{1p} < 0$ and $\Pi_{21}^{2p} < 0$ due to the strategic substitutes condition, both $dQ^1/d\theta$ and $dQ^2/d\theta$ cannot be positive in (35) and (36). $\qquad\qquad Q.E.D.$

Notice that if $dQ^2/d\theta = 0$, then (35) reduces to (31) and Proportion 4-1 follows. Similarly, if $dQ^1/d\theta = 0$, then (36) can be used to show Proposition 4-2.

Although both $dQ^1/d\theta$ and $dQ^2/d\theta$ cannot simultaneously be positive in (35)-(36), it is possible that both $dQ^1/d\theta$ and $dQ^2/d\theta$ are negative in (35)-(36). This can be illustrated by the following numerical example. Assume that demand is linear as follows:

$$d_k(Q_k^i, Q_k^j) = \alpha - (Q_k^i + Q_k^j), \quad for \ k = AH, BH, AB.$$

Assume further that schedule delay cost, $g_k(\cdot)$, is also linear and that operating cost, $C_k(\cdot)$, is concave:

$$g_k^i(Q_k^i) = 1 - \delta Q_k^i, \quad c_k^i(Q_k^i) = Q_k^i - \frac{\mu}{2}\left(Q_k^i\right)^2, \quad for \ k = AH, BH, AB \tag{38}$$

where μ represents the extent of increasing returns to traffic density. Given these specifications, the explicit expressions of equilibrium output can be obtained for each firm under the pre-alliance and the "no shut-down" parallel alliance situations. In particular, when $\alpha = 4$, $\delta = 0.03$, $\mu = 0.04$, both of the partners decrease their outputs, while the non-

partner increases its output. More accurately, changes in each firm's output due to the "no shut-down" alliance are $\Delta Q^1 \equiv \left(\Delta Q^1_{AH}, \Delta Q^1_{BH}, \Delta Q^1_{AB} \right) = (-0.2142, -0.0009, -0.0119)$; $\Delta Q^2 \equiv \Delta Q^2_{AH} = -0.1404$; and $\Delta Q^3 \equiv \Delta Q^3_{BH} = 0.0009$, respectively.

To sum up the effects of the "no shut-down" parallel alliance on each firm's output, the partners' total output is likely to decrease, while the non-partner output may increase (by Proposition 4-1), remain unchanged (by Proposition 4-2), or decrease (by $dQ^1/d\theta > 0$ in Proposition 4-3). Thus, consumer surplus in market AH is likely to decrease due to this type of parallel alliance.

4.2 Effects of Shut-down Parallel Alliance

We now analyze the effects of the second style of parallel alliance where the partners integrate local services in the AH segment in a way that the hub partner continues to provide the local services, but the non-hub partner stops producing the local services. However, it is intractable to compare the pre-alliance and shut-down parallel alliance by using general functions since the number of the first-order conditions for the former is not the same as that for the latter. For tractability of analysis, we impose more structures on the model. First, demands and schedule delay costs for all three markets are assumed to be symmetric. Secondly, in order to use a common cost function, we assume that the distances between cities A and H, and between B and H are the same. Thirdly, we use special functions (37)-(38) for demand, schedule delay cost, and operating cost.[12]

Comparing the solution of the pre-alliance situation to that of the "shut-down" parallel alliance, we first examine the effects of the "shut-down" parallel alliance on each firm's output.

Proposition 4-4. Under the "shut-down" parallel alliance conditions, the partners produce less output in market AH, but produce more output in markets BH and AB, and firm 3 produces less output in its local market BH than under the pre-alliance conditions.

The proofs of the "shut-down" parallel alliance are provided in the Appendix. The intuitive reasons for Proposition 4-4 are as follows: First of all, since the AH market is now serviced only by the name of the hub partner, this market becomes a monopoly market. The hub-partner produces more than its pre-alliance output in this market, but less than total pre-alliance output, i.e., $Q^{1b}_{AH} < Q^{1p}_{AH} \left(\equiv Q^{(1+2)p}_{AH} \right) < Q^{1b}_{AH} + Q^{2b}_{AH}$. Secondly, the hub partner increases its BH and AB traffic due to the network complementarities. Thirdly, the non-partner will decrease its BH traffic since its reaction function to the hub partner's output in market BH is downward sloping.

Next, the effects on each firm's profit are examined. In general, the post-alliance profit of the non-hub partner (i.e., firm 2) increases when the size of markets (α) is sufficiently large for a given economies of traffic density (μ). Joining the "shut-down" parallel alliance, the

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[12] The linear demand and concave operating cost functions are also used in Brueckner and Spiller (1991), Brueckner, Dyer and Spiller (1992), and Nero (1996).

non-hub partner decreases revenue from market AH since total output in this market decreases due to the alliance. But, the non-hub partner becomes more cost-effective by jointly producing the hub partner's connecting services on the AH route. If the size of markets is large enough for the partners to produce a great volume of traffic on the AH route, firm 2's gains from the cost-effectiveness dominate its losses from the decreased revenue.

Proposition 4-5. Under the "shut-down" parallel alliance conditions, the hub partner earns more profit than under the pre-alliance conditions. Given the economies of traffic density, the non-hub partner earns more (less, respectively) profit when the size of markets is sufficiently large (small, respectively) than under the pre-alliance situations. Firm 3 earns less profit, as compared to the pre-alliance conditions.

We next examine the effects of the "shut-down" parallel alliance on total output and consumer surplus in each market. According to Proposition 4-4, passengers in market AH are worse off since total output in this market decreases while the corresponding "full" price increases. Thus, consumer surplus in market AH decreases due to the parallel alliance. However, it is not obvious whether or not consumers in market BH are better off due to the alliance.

Proposition 4-6. The "shut-down" parallel alliance results in (i) increased (decreased, respectively) total output and (ii) decreased (increased, respectively) "full" price in markets BH and AB (market AH, respectively). Therefore, consumers in these markets (this market, respectively) are better off (worse off, respectively) due to the parallel alliance.

Although Proposition 4-6 shows increases in consumer surplus in markets BH and AB due to the parallel alliance, it can be verified that decreases in consumer surplus in market AH dominate the increases in market BH and AB.

To summarize the effects of the "shut-down" parallel alliance on each firm's output, the partners' output decreases in market AH and increases in markets BH and AB, while the non-partner's output decreases. Like the "no shut-down" parallel alliance, consumer surplus in market AH decreases due to the "shut-down" parallel alliance.

5. THE EXTENDED MODEL
The Basic Model have analyzed the effects of three types of alliances on the basis of an assumption that there are no demand shifts due to the alliances. We now extend the Basic Model by taking into account the potential codesharing effect on demand shift. Under a codesharing agreement, one airline's designator code is shown on flights operated by its partner. The codesharing allows the partners to offer a higher frequency service to consumers should the partners maintain or increase their respective frequency. For example, before the alliance, LH and UA provided one daily non-stop service between Washington,D.C. and Frankfurt, respectively. After the alliance, they were able to offer two daily non-stop services on the route thanks to the codesharing. It is therefore possible that demand functions for the partners are shifted up by the codesharing effect.
5.1 Complementary alliance
Assuming that the partners' "full" price demand functions in each market are shifted up due

to the partners' codesharing, the partners' post-alliance (inverse) demand shifts may be written as

$$\rho_k^2 = d_k^2(Q_k^1, Q_k^2) + \xi, \quad for \ k = AH, BH, AB$$

where ξ is an exogenous demand shift due to the codesharing effect.

The post-alliance profit function (6) and (7) can be rewritten as

$$\max_{Q^1} \ \Pi^{1c} = \Pi^{1c}(Q^1, Q^2) \tag{39}$$

$$\max_{Q^2} \ \Pi^{2c} = \Pi^{2c}(Q^1, Q^2; \gamma, \xi). \tag{40}$$

In the Basic Model, ξ is set to zero. Assume that there exists a "stable" Cournot-Nash equilibrium, $(Q^1(\gamma, \xi), Q^2(\gamma, \xi))$, satisfying the first-order conditions for (39) and (40). Differentiating the FOCs with respect to ξ and solving for $\partial Q^1/\partial \xi$ and $\partial Q^2/\partial \xi$, we have

$$\frac{\partial Q^1}{\partial \xi} = -\left[I - R_2^{1c} R_1^{2c}\right]^{-1} R_2^{1c} \left(\Pi_{22}^{2c}\right)^{-1} \Pi_{2\xi}^{2c} \tag{41}$$

$$\frac{\partial Q^2}{\partial \xi} = -\left[I - R_1^{2c} R_2^{1c}\right]^{-1} \left(\Pi_{22}^{2c}\right)^{-1} \Pi_{2\xi}^{2c} \tag{42}$$

where $\Pi_{2\xi}^{2c} \equiv [1, \ 1, \ 1]^T$. Since $\left[I - R_j^{ic} R_i^{jc}\right]^{-1} > 0$, $R_2^{1c} < 0$, and $\left(\Pi_{22}^{2c}\right)^{-1} < 0$, then $\partial Q^1/\partial \xi < 0$ and $\partial Q^2/\partial \xi > 0$. This implies that the codesharing effect on the partners' demand shifts does not change the propositions derived from the Basic Model. In particular, for a given γ, under the demand shift situation, (i) the partners (non-partner, respectively) produce more output (less output, respectively) in the three markets, and (ii) total output in each market increases more than under the Basic Model situation.

What if the non-partner's demand function is also shifted up due to the partners' codesharing effect? If the partners cannot fully capture demands created by the codesharing effect, some of the demands may be left over to the non-partner. We shall assume that the non-partner's "full" price demand function is slightly shifted up, as compared to the partners' demand shifts. We also assume that the non-partner's post-alliance (inverse) demand shift may be expressed as

$$\rho_k^1 = d_k^1(Q_k^1, Q_k^2) + \alpha \xi, \quad 0 < \alpha < 1.$$

Then, it is straight forward to show that

$$\frac{\partial Q^1}{\partial \xi} = -\left[I - R_2^{1c} R_1^{2c}\right]^{-1}\left[\left(\Pi_{11}^{1c}\right)^{-1}\Pi_{1\xi}^{1c} + R_2^{1c}\left(\Pi_{22}^{2c}\right)^{-1}\Pi_{2\xi}^{2c}\right] \tag{43}$$

$$\frac{\partial Q^2}{\partial \xi} = -\left[I - R_1^{2c} R_2^{1c}\right]^{-1}\left[\left(\Pi_{22}^{2c}\right)^{-1}\Pi_{2\xi}^{2c} + R_1^{2c}\left(\Pi_{11}^{1c}\right)^{-1}\Pi_{1\xi}^{1c}\right] \tag{44}$$

where $\Pi_{1\xi}^{1c} \equiv [\alpha, \ \alpha, \ \alpha]^T$. Notice that if $\Pi_{1\xi}^{1c}$ is a zero vector, then (43)-(44) reduce to (41)-(42), respectively. Notice that the sign of the second bracketed term of the right-hand side of (43)-(44) is indeterminate. If demand functions for both the partners and non-partner are simultaneously shifted up, the effects of the complementary alliance on each firm's output and total output are no longer clear.

However, if we assume that the partners and non-partner are symmetric and the partners can provide connecting service at the same quality as the non-partner's, then we have
Proposition 5-1. In case where demand functions for the partners and non-partner are simultaneously shifted up by the complementary alliance, both competitors can increase output under the symmetric and $\gamma = 0$ conditions.

Proof. Under the symmetric conditions, $R_j^{ic} = R_i^{jc} (\equiv R^c)$ and $\left(\Pi_{11}^{1c}\right)^{-1} = \left(\Pi_{22}^{2c}\right)^{-1}$. Thus, (43)-(44) can be rewritten as

$$\frac{\partial Q^1}{\partial \xi} = -\left[I - \left(R^c\right)^2\right]^{-1}\left[\left(\Pi_{11}^{1c}\right)^{-1}\Pi_{1\xi}^{1c} + R^c\left(\Pi_{11}^{1c}\right)^{-1}\Pi_{2\xi}^{2c}\right] \tag{45}$$

$$\frac{\partial Q^2}{\partial \xi} = -\left[I - \left(R^c\right)^2\right]^{-1}\left[\left(\Pi_{11}^{1c}\right)^{-1}\Pi_{2\xi}^{2c} + R^c\left(\Pi_{11}^{1c}\right)^{-1}\Pi_{1\xi}^{1c}\right]. \tag{46}$$

According to the stability condition, the magnitude of the eigenvalues of matrix, $\left(R^c\right)^2$, must be less than one, and so does R^c. Thus, $\partial Q^2/\partial \xi > 0$ since the second bracket term of (46) is negative. It is also possible that $\partial Q^1/\partial \xi > 0$, depending on α. *Q.E.D.*

5.2 Parallel alliance

We will focus on the analysis of the "no shut-down" case here since the same results can be obtained for the "shut-down" case by the same analysis. Assuming that the partners' "full" price demand functions in AH market are shifted up, the partners' post-alliance (inverse) demand shifts may be written as

$$p_{AH}^i = d_{AH}^i (Q_{AH}^i, Q_{AH}^j) + \xi; \quad for \ i, j = 1, 2; \ i \neq j.$$

Denoting a "stable" equilibrium by $(Q^1(\theta, \xi), Q^2(\theta, \xi), Q^3(\theta, \xi))$, and differentiating the first-order conditions with respect to ξ, we have

$$\Pi_{11}^{1p}\frac{\partial Q^1}{\partial \xi} + \Pi_{12}^{1p}\frac{\partial Q^2}{\partial \xi} + \Pi_{13}^{1p}\frac{\partial Q^3}{\partial \xi} + \Pi_{1\xi}^{1p} = 0, \tag{47}$$

$$\Pi_{21}^{2p}\frac{\partial Q^1}{\partial \xi} + \Pi_{22}^{2p}\frac{\partial Q^2}{\partial \xi} + \qquad \Pi_{2\xi}^{2p} = 0, \tag{48}$$

$$\Pi_{31}^{3p}\frac{\partial Q^1}{\partial \xi} + \qquad \Pi_{33}^{3p}\frac{\partial Q^3}{\partial \xi} \qquad = 0 \tag{49}$$

where $\Pi_{1\xi}^{1p} \equiv [1,0,0]^T$ and $\Pi_{2\xi}^{2p} \equiv 1$.

From (49), it can be easily verified that $\partial Q^1/\partial \xi$ and $\partial Q^3/\partial \xi$ have opposite signs. Solving (47)-(48) for $\partial Q^1/\partial \xi$ and $\partial Q^2/\partial \xi$ yields

$$\frac{\partial Q^1}{\partial \xi} = -\left[I - R_3^{1p}R_1^{3p}\right]^{-1}\left(\Pi_{11}^{1p}\right)^{-1}\left(\Pi_{1\xi}^{1p} + \Pi_{12}^{1p}\frac{\partial Q^2}{\partial \xi}\right), \tag{50}$$

or

$$\frac{\partial Q^2}{\partial \xi} = -\left(\Pi_{22}^{1p}\right)^{-1}\left(\Pi_{2\xi}^{2p} + \Pi_{21}^{2p}\frac{\partial Q^1}{\partial \xi}\right). \tag{51}$$

Notice that the sign of the last term of (50)-(51) can be either positive or negative, depending on the difference between the positive direct effects of the demand shift on each partner's marginal profit (i.e., $\Pi_{1\xi}^{1p}$ and $\Pi_{2\xi}^{2p}$) and the negative indirect effects due to strategic substitutes condition (i.e., $\Pi_{12}^{1p}\cdot(\partial Q^2/\partial \xi)$ and $\Pi_{21}^{2p}\cdot(\partial Q^1/\partial \xi)$). If the direct effects simultaneously dominate the indirect effects in (50)-(51) (i.e., $|\Pi_{1\xi}^{1p}| > |\Pi_{12}^{1p}\cdot(\partial Q^2/\partial \xi)|$ and $|\Pi_{2\xi}^{2p}| > |\Pi_{21}^{2p}\cdot(\partial Q^1/\partial \xi)|$), then $\partial Q^1/\partial \xi > 0$ and $\partial Q^2/\partial \xi > 0$. Therefore,

Proposition 5-2. If the parallel alliance shifts both partners' demand functions upward and the direct effects of the demand shifts dominate the indirect effects, it is possible for both partners to simultaneously increase output in market AH. It is therefore possible that total output in market AH increases and thus consumer surplus increases.

6. EMPIRICAL TEST

This section carries on an empirical test for some propositions regarding the effects of the alliances on each firm's output and total output. Previous sections have shown that complementary and parallel alliances have different effects on each firm's output and total output. After the complementary alliance, the partners increase local traffic (see Propositions 3-1 and 5-1). The non-partner can increase (see Proposition 3-1) or decrease (see Proposition 5-1) local traffic, depending on the degree of demand shift. Consequently, total output increases in the local markets (see Proposition 3-3).

On the other hand, from the analysis of the parallel alliances, the partners are likely to

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decrease local traffic on the AH segment under both the "no shut-down" and "shut-down" cases (see Propositions 4-1, 4-2, 4-4 and 5-1). Changes in the non-partners' outputs are uncertain under the "no shut-down" case, but the non-partner decreases local traffic on the BH segment under the "shut-down" case (see Propositions 4-4). Consequently, total output on the AH segment is likely to decrease in market AH (see Propositions 4-3 and 4-6).

In order to test those predictions, we selected seventeen trans-Atlantic routes where either complementary or parallel alliance occurred between US and European carriers. Since major alliances in the North Atlantic markets were formed in the early 1990's, annual data for two-ways of the seventeen routes (e.g., Atlanta to Amsterdam, and Amsterdam to Atlanta) were collected for the 1990-94 period. Observations were collected for alliance partners and their strongest competitor[13] for each of the seventeen routes. The total numbers of observations available for the alliance partners and the largest non-aligned carriers are 151 and 97, respectively.

Data associated with strategic alliances were mainly taken from the *Official Airline Guides: Worldwide Edition*. To classify the data into pre-, post-complementary, and post-parallel alliance situations, we used a variety of data sources including *Airline Business* (1994), *Gellman Research Associates* (1994), and *U.S. General Accounting Office* (1995). Thirty-six observations were classified into the complementary alliance situation, while sixteen were categorized into the parallel alliance situation. Four cases were classified as a mixture of the two types (Lufthansa/United on Chicago-Frankfurt and Washington, D.C.-Frankfurt routes).

The aligned-partners' traffic, non-partners' traffic, and total traffic data on the seventeen routes were gathered from the International Civil Aviation Organization (ICAO) publication, *Traffic By Flight Stage*. The mean value for the aligned-partner's passenger volume during the period is 108,200 people, while the mean value for the total traffic is 247,770 people. The number of carriers on each route was also obtained from the ICAO publication.

The aligned-partners' traffic, non-partners' traffic, and total traffic, respectively, are treated as a dependent variable on each set of regression. As explanatory variables, presence of complementary alliance (CA), presence of parallel alliance (PA), the number of airlines on each route (NUM), year-specific characteristics (YR), and route-specific characteristics are considered. Route Atlanta-Amsterdam and year 1990 is used as a base route and year in the regression. For robustness of analysis, we test the hypotheses by using four different specifications for each set of regression.

Table 1 shows test results. The test results generally confirm the theoretical predictions. First, as shown in the first column of Table 1, the test result on alliance partners' outputs is consistent with the corresponding propositions. As excepted, all coefficients of CA are estimated as positive, regardless of specifications. More importantly, the coefficients of CA are estimated as highly significant under the specifications (1) and (2). This result confirms

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[13] In order to control a firm size effect, we restrict our attention to the strongest non-aligned firm, the largest firm other than alliance partners on each of the alliance routes. Not every non-aligned firm on the route may react to the alliance. Presumably, small firms are not likely to do so.

that each of complementary alliance partners increases its traffic after the alliance. For parallel alliance partners' outputs, all coefficients are estimated as negative, implying that demand shift effects on the partners' outputs are weak. The coefficients of PA under the specifications (3) and (4) are estimated as negative and significant.

Second, the last column of Table 1 shows that test result on total output is highly consistent with the corresponding predictions. The coefficients of CA and PA are estimated as properly and significantly, regardless of specifications. Following the complementary alliance, total traffic increases by an average of 11-17 per cent of the average total traffic. In contrast, total traffic decreases by an average of 11-15 per cent of the average total traffic, due to the parallel alliance. Notice that total passenger volumes of years 1993 and 1994 are not significantly different from that of year 1990.

Third, the second column of Table 1 indicates that the test result on non-partners' outputs is partly consistent with the corresponding propositions. In general, the signs of the coefficients are consistent with the propositions, but statistically insignificant. In three out of the four specifications, the coefficients of CA are estimated as positive. As shown in the Extended Model, the complementary alliances in the North Atlantic markets may generate new demands, some of which cannot be served by the alliance partners and can be left over to non-aligned competitors. The signs of the coefficients of PA are consistent with the theory, although the coefficients are estimated as insignificant.

7. CONCLUDING REMARKS

This study analyzes the effects on market outcome and welfare of two types of alliances: complementary vs. parallel alliances. To recapitulate major findings of this study,

First, the complementary alliance in a specific market has indirect positive effects on the partners' outputs in the other markets. Coordination in connecting markets allows the partners to increase service quality and decrease average operating costs in local markets. This is because multiple products are serviced through the same network and thus the alliance in a specific market has indirect impacts on each firm's output in the other markets within the same network.

Second, the two types of alliances have different effects on total output and consumer surplus. Given the symmetry, the complementary alliance increases total output, and decreases "full" price. Thus, consumer surplus increases as a result of the complementary alliance. On the other hand, both the "no shut-down" and "shut-down" parallel alliances are likely to decrease total output on the alliance route. Consequently, consumer surplus is likely to decrease due to the parallel alliance.

Third, we find sufficient conditions under which complementary alliance improves total welfare. Total welfare can rise if the partners and non-partners are symmetric and if the partners can coordinate to the extent that they are able to provide the same level of connecting services as firm 1's.

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Four, the Extended Model finds that demand shifts due to strategic alliances play a crucial role on changes in firms' outputs under certain conditions. For the complementary alliance case, it is possible for both alliance partners and non-partner to simultaneously increase their outputs in cases where there are some created demands being spilled over to the non-partner. The Extended Model identifies sufficient conditions under which parallel alliance partners simultaneously increase their outputs on the alliance route, resulting in increasing total output in the market.

Finally, the empirical test results generally confirm the theoretical predictions on alliance partners' outputs and total output. The test results indicate that the partners' traffic increases due to the complementary alliance, while the partners' traffic decreases due to the parallel alliance. The results also show that total traffic increases by an average of 11-17 per cent of the average total traffic due to the complementary alliance, while total traffic decreases by an average of 11-15 per cent of the average due to the parallel alliance.

These findings have some important policy implications. Government agents should be very careful to allow would-be parallel alliance partners to have antitrust immunity. Since the partners are significant competitors in the same markets, competition may be reduced if they are able to integrate operation with the protection of antitrust immunity. As a result, the parallel alliance reduces consumer surplus and is more likely to decrease total welfare. However, under certain conditions, allowing more complementary alliances may have the potential of creating a more competitive environment and improving welfare.

ACKNOWLEDGEMENTS

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FIGURE 1. A Simple Air Transport Network
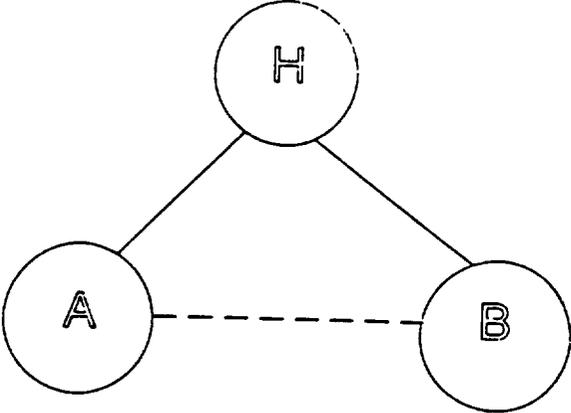
TABLE 1. Effects of alliances on partners' traffic, non-partners' traffic, and total traffic

	Passengers for partners				Passengers for non-partners				Total passengers			
	(1)	(2)	(3)	(4)	(1)	(2)	(3)	(4)	(1)	(2)	(3)	(4)
CA	20,174 c	21,397 c	5,300	7,496	1,189	1,965	-1,262	3,400	42,180 c	43,480 c	29,670 b	27,205 b
PA	-2,273	-6,800	-12,639 c	-13,895 b	3172	-536	-560	-1,836	-28,033 b	-32,843 b	-37,046 c	-35,636 b
NUM		-6,793 c		-3,454		-5,579 c		-5,386 b		-7,216		3,876
YR91			-7,480 b	-4,425			1,503	7,065			-33,490 c	-36,919 c
YR92			10,318 c	11,168 c			15,380 c	16,478 c			5,340	4,386
YR93			10,044 c	10,229 b			17,284 c	18,563 c			1,395	1,186
YR94			22,822 c	21,860 c			13,071 a	10,328			9,521	10,601
ATL-BRU	-17,550 b	-12,778	-19,451 b	-16,741 b					-21,081	-16,012	-23,475	-26,516
ATL-FRA	-2,086	-2,086	-2,086	-2,086	43,418 c	43,418 c	43,418 c	43,418 c	41,332 b	41,332 b	41,332 c	41,332 c
BOS-AMS	13,646 b	6,609	16,621 c	12,728 a	41,651 c	51,537 c	42,141 c	50,903 c	-51,756 c	-59,232 c	-49,254 c	-44,885 c
BOS-LON	67,487 c	79,469 c	70,462 c	76,239 c					214,110 c	226,840 c	216,610 c	210,130 c
BWI-LON	-39,379 c	-43,754 c	-36,772 c	-39,242 c					-99,122 c	-103,770 c	-98,018 c	-95,246 c
CHI-FRA	29,034 c	36,732 c	31,107 c	34,812 c	-4,780	1,540	-4,034	1,607	78,597 c	86,776 c	80,400 c	76,242 c
DET-AMS	2,129	-5,153	2,511	-1,418					67,674 c	-75,411 c	-70,715 c	-66,306 c
LAX-LON	137,530 c	160,630 c	137,530 c	149,270 c	10,037 a	28,301 c	6413	24,059 c	375,050 c	399,590 c	375,050 c	361,870 c
MSP-AMS	25,398 c	21,023 b	28,005 c	25,535 c					-50,217 b	-54,866 b	-49,114 b	-46,342 c
NYC-AMS	127,220 c	144,890 c	127,220 c	136,200 c	8,238	21,069 c	8238	20,625 c	171,010 c	189,770 c	171,010 c	160,930 c
NYC-BRU	36,464 c	58,672 c	35,562 c	46,959 c	-21,447 c	-3,256	-21,191 c	-3,307	97,238 c	120,830 c	96,535 c	83,748 c
NYC-LON	392,920 c	421,450 c	392,920 c	407,430 c	102,600 c	124,850 c	98,980 c	120,470 c	111,530 c	114,560 c	111,530 c	109,900 c
NYC-ZRH	38,204 c	47,052 c	39,375 c	43,771 c	-18,488 c	-11,271 a	-17,486 c	-10,657 a	56,545 c	65,945 c	57,648 c	52,715 c
PHL-LON	24,382 c	25,496 c	27,357 c	27,608 c					-16,017	-14,834	-13,515	-13,797
WAS-AMS	-17,899 a	-18,266 b	-22,729 c	-22,374 c	-11,566 a	4,855	-15,792 b	9,442	-50,064 b	-50,454 b	-55,216 c	-55,614 c
WAS-FRA	14,669 b	23,725 c	16,742 c	21,137 c					81,836 c	91,458 c	83,639 c	78,706 c
CONST	47,131 c	60,471 c	42,965 c	48,807 c	60,763 c	71,765 c	51,806 c	60,606 c	103,730 c	117,900 c	109,680 c	103,120 c
R-squared	0.979	0.981	0.984	0.985	0.877	0.888	0.918	0.918	0.985	0.986	0.987	0.987

[Note]   a: p-value<0.1,   b: p-value<0.05,   c: p-value<0.01

APPENDIX

This part provides the proofs of Propositions 4-4, 4-5, and 4-6. Each firm's pre-alliance profit function can be expressed as

$$\Pi^{1b} = \sum_{k=AH}^{BH} Q_k^1\left[d(Q_k^1,Q_k^2)-g(Q_k^1+Q_{AB}^1)\right]+Q_{AB}^1\left[d(Q_{AB}^1)-\sum_{k=AH}^{BH}g(Q_k^1+Q_{AB}^1)\right]-\sum_{k=AH}^{BH}C(Q_k^1+Q_{AB}^1),$$

$$\Pi^{2b} = Q_{AH}^2\left[d(Q_{AH}^1,Q_{AH}^2)-g(Q_{AH}^2)\right]-C(Q_{AH}^2), \qquad \Pi^{3b} = Q_{BH}^3\left[d(Q_{BH}^1,Q_{BH}^3)-g(Q_{BH}^3)\right]-C(Q_{BH}^3)$$

where superscript b stands for before-alliance. Using specifications (37)-(38) and solving the first-order conditions, we have the following pre-alliance quantities

$$Q_{AH}^{1b} = Q_{BH}^{1b} = \frac{(\lambda^2-2\lambda+2)\alpha-4}{2(3\lambda^2-7\lambda+3)} \tag{A1}$$

$$Q_{AB}^{1b} = \frac{(1-\lambda)[(3+\lambda)\alpha-12]}{2(3\lambda^2-7\lambda+3)} \tag{A2}$$

$$Q_{AH}^{2b} = Q_{BH}^{3b} = \frac{(2-5\lambda)\alpha-4(1-3\lambda)}{2(3\lambda^2-7\lambda+3)}. \tag{A3}$$

where $\lambda \equiv 2\delta+\mu$. It can be shown that the second-order conditions for each firms' profit maximization problem reduce to $\lambda < 2/3$. Since outputs and marginal revenues (costs) should be positive, α is constrained such that $6/(\lambda+3)<\alpha<[6(1-\lambda)]/[\lambda(5-4\lambda)]$ *for* $0<\lambda<2/5$.

The shut-down parallel-alliance profits for the firms can be expressed as

$$\Pi^{(1+2)p}=Q_{AH}^1\left[d(Q_{AH}^1)-g(Q_{AH}^1+Q_{AB}^1)\right]+Q_{BH}^1\left[d(Q_{BH}^1,Q_{BH}^3)-g(Q_{BH}^1+Q_{AB}^1)\right]+Q_{AB}^1\left[d(Q_{AB}^1)-\sum_{k=AH}^{BH}g(Q_k^1+Q_{AB}^1)\right]$$

$$-\sum_{k=AH}^{BH}C(Q_k^1+Q_{AB}^1), \qquad\qquad \Pi^{3p} = Q_{BH}^3\left[d(Q_{BH}^1,Q_{BH}^3)-g(Q_{BH}^3)\right]-C(Q_{BH}^3)$$

where superscript p stands for parallel alliance. Solving the first-order conditions for the shut-down parallel alliance yields the following parallel alliance solutions:

$$Q_{AH}^{(1+2)p} = \frac{(\lambda^3-5\lambda^2+11\lambda-6)\alpha+2(\lambda^2-8\lambda+6)}{6\lambda^3-27\lambda^2+34\lambda-12} \tag{A4}$$

$$Q_{BH}^{1p} = \frac{(\lambda^3-5\lambda^2+6\lambda-4)\alpha+2(\lambda^2-2\lambda+4)}{6\lambda^3-27\lambda^2+34\lambda-12} \tag{A5}$$

$$Q_{AB}^{1p} = \frac{(1-\lambda)[(\lambda^2 - 6)\alpha - 2(5\lambda - 12)]}{6\lambda^3 - 27\lambda^2 + 34\lambda - 12} \tag{A6}$$

$$Q_{BH}^{3p} = \frac{(2-\lambda)[(5\lambda - 2)\alpha - 2(6\lambda - 2)]}{6\lambda^3 - 27\lambda^2 + 34\lambda - 12}. \tag{A7}$$

Again, it can be shown that the second-order conditions reduce to $\lambda < 2/3$. From the positive outputs and marginal revenues constraints, $\frac{6}{\lambda + 3} < \alpha < \frac{2\lambda^8 - 16\lambda + 12}{\lambda(4\lambda^8 - 17\lambda + 12)}$ $for \ \lambda < \frac{2}{5}$.

Proof of Proposition 4-4. Using (A1)-(A6), we can calculate changes in the partners' output due to the shut-down parallel alliance:

$$\Delta Q_{AH}^{(1+2)p} \equiv Q_{AH}^{(1+2)p} - [Q_{AH}^{1b} + Q_{AH}^{2b}] = -\frac{(\lambda-1)(5\lambda^2 - 14\lambda + 6)[(2 - 5\lambda)\alpha + 12\lambda - 4]}{(6\lambda^3 - 27\lambda^2 + 34\lambda - 12)(3\lambda^2 - 7\lambda + 3)} \tag{A8}$$

$$\Delta Q_{AB}^{1p} \equiv Q_{AB}^{1p} - Q_{AB}^{1b} = -\frac{\lambda(1-\lambda)[(5\lambda^2 - 17\lambda + 6)\alpha - 2(6\lambda^2 - 20\lambda + 6)]}{2(6\lambda^3 - 27\lambda^2 + 34\lambda - 12)(3\lambda^2 - 7\lambda + 3)} \tag{A9}$$

$$\Delta Q_{BH}^{1p} \equiv Q_{BH}^{1p} - Q_{BH}^{1b} = -\frac{\lambda^2(2-\lambda)[(2 - 5\lambda)\alpha + 2(6\lambda - 2)]}{2(6\lambda^3 - 27\lambda^2 + 34\lambda - 12)(3\lambda^2 - 7\lambda + 3)}. \tag{A10}$$

Since the denominator of (A8)-(A10) is negative for $\lambda < 2/5$, the sign of these equations depends on the numerator. It can be shown that the numerator of (A8) is negative, while those of (A9) and (A10) are positive for the feasible α and λ. Similarly, we can calculate, using (A3) and (A7), changes in firm 3's output

$$\Delta Q_{BH}^{3p} \equiv Q_{BH}^{3p} - Q_{BH}^{3b} = \frac{\lambda^2[(2 - 5\lambda)\alpha + 2(6\lambda - 2)]}{2(6\lambda^3 - 27\lambda^2 + 34\lambda - 12)(3\lambda^2 - 7\lambda + 3)}$$

which is negative for the feasible range. $Q.E.D.$

Proof of Proposition 4-5. Using (A1)-(A7), we can compute changes in the partners' profit and changes in firm 3's profit

$$\Delta \Pi^{1p} \equiv \Pi^{1p} - \Pi^{1b} = -\frac{I\alpha^2 + J\alpha + K}{4(6\lambda^3 - 27\lambda^2 + 34\lambda - 12)^2(3\lambda^2 - 7\lambda + 3)^2} \tag{A11}$$

$$\Delta \Pi^{2p} \equiv \Pi^{2p} - \Pi^{2b} = \frac{L\alpha^2 + M\alpha + N}{8(6\lambda^3 - 27\lambda^2 + 34\lambda - 12)^2(3\lambda^2 - 7\lambda + 3)^2} \tag{A12}$$

$$\Delta \Pi^{3p} \equiv \Pi^{3p} - \Pi^{3b} = -\frac{\lambda^2(\lambda-2)(12\lambda^3-53\lambda^2+68\lambda-24)[(5\lambda-2)\alpha+2-6\lambda]}{8(6\lambda^3-27\lambda^2+34\lambda-12)^2(3\lambda^2-7\lambda+3)^2} \qquad (A13)$$

where $I = 90\lambda^{10} - 942\lambda^9 + 3949\lambda^8 - 8041\lambda^7 + 6312\lambda^6 + 5352\lambda^5 - 16539\lambda^4 + 15333\lambda^3 - 6794\lambda^2 + 1344\lambda - 72$,
$J = -2(144\lambda^9 + 1302\lambda^8 + 4768\lambda^7 - 8614\lambda^6 + 5640\lambda^5 + 7522\lambda^4 - 19480\lambda^3 + 17324\lambda^2 - 7176\lambda + 1152)$,
$K = -4(324\lambda^M - 4302\lambda^\lambda + 23973\lambda^\Lambda - 74128\lambda^\kappa + 141439\lambda^K - 174420\lambda^\iota + 140005\lambda^I - 70648\lambda^\theta + 20292\lambda - 2520)$,
$L = 180\lambda^{\theta\eta} - 1344\lambda^M + 1592\lambda^\lambda + 14019\lambda^\Lambda - 63462\lambda^\kappa + 120822\lambda^K - 124872\lambda^\iota + 71846\lambda^I - 20996\lambda^\theta + 2064\lambda + 144$,
$M = -2(2016\lambda^M - 22620\lambda^\lambda + 104444\lambda^\Lambda - 256128\lambda^\kappa + 357312\lambda^K - 276612\lambda^\iota + 96936\lambda^I + 5912\lambda^\theta - 14160\lambda + 2880)$,
$N = 4(648\lambda^M - 6300\lambda^\lambda + 22218\lambda^\Lambda - 27160\lambda^\kappa - 30210\lambda^K + 136392\lambda^\iota - 180338\lambda^I + 119176\lambda^\theta - 39768\lambda + 5328)$.
It can be numerically shown that (A11) is positive while (A13) is negative for the feasible α and λ. The sign of (A12) varies depending on value of α and λ. $\qquad$ Q.E.D.

Proof of Proposition 4-6. From (A8), $\Delta P_{AH}^c > 0$. Thus, $\Delta CS_{AH}^c < 0$. Similarly, from (A9), $\Delta P_{AB}^c < 0$. Thus, $\Delta CS_{AB}^c > 0$. Using (A1), (A3), (A5), and (A7), we can calculate

$$\Delta P_{BH}^p \equiv P_{BH}^p - P_{BH}^b = \frac{\lambda^2(1-\lambda)[(2-5\lambda)\alpha+2(6\lambda-2)]}{2(6\lambda^3-27\lambda^2+34\lambda-12)(3\lambda^2-7\lambda+3)}$$

which is negative for the feasible range. Consequently, $\Delta Q_{BH}^c > 0$ and $\Delta CS_{BH}^c > 0$. $\qquad$ Q.E.D.

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Analysis of Airline Schedules Using Boeing's Decision Window Model

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ATRG Dublin Symposium
July 20-21, 1998

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This presentation employs Boeing's Decision Window Path Preference Model to analyze an airline's schedule or the schedules of a group of airlines. The results of the analysis are presented as "Coverage" which is defined as the fraction of passengers whose travel requirements are satisfied by the flights offered by a schedule.

Agenda

- Background
- Decision Window Model
- Coverage
- Examples
- Other Uses

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The agenda for the presentation consists of the following:

First, the background will be presented for an airline system which is to be analyzed as an example.

Next, there is a brief explanation of Boeing's Decision Window Path Preference model. This model was presented in more depth at the first meeting of the ATRG on June 27, 1997, in Vancouver. The Decision Window model leads to the concept of Coverage, which will provide the basis for analyzing the example airline system.

Next, the results of the Coverage analysis will be shown and, finally, some additional types of analysis for which Coverage can be used will be discussed.

Delta & Western Domestic Networks: ca. 1987
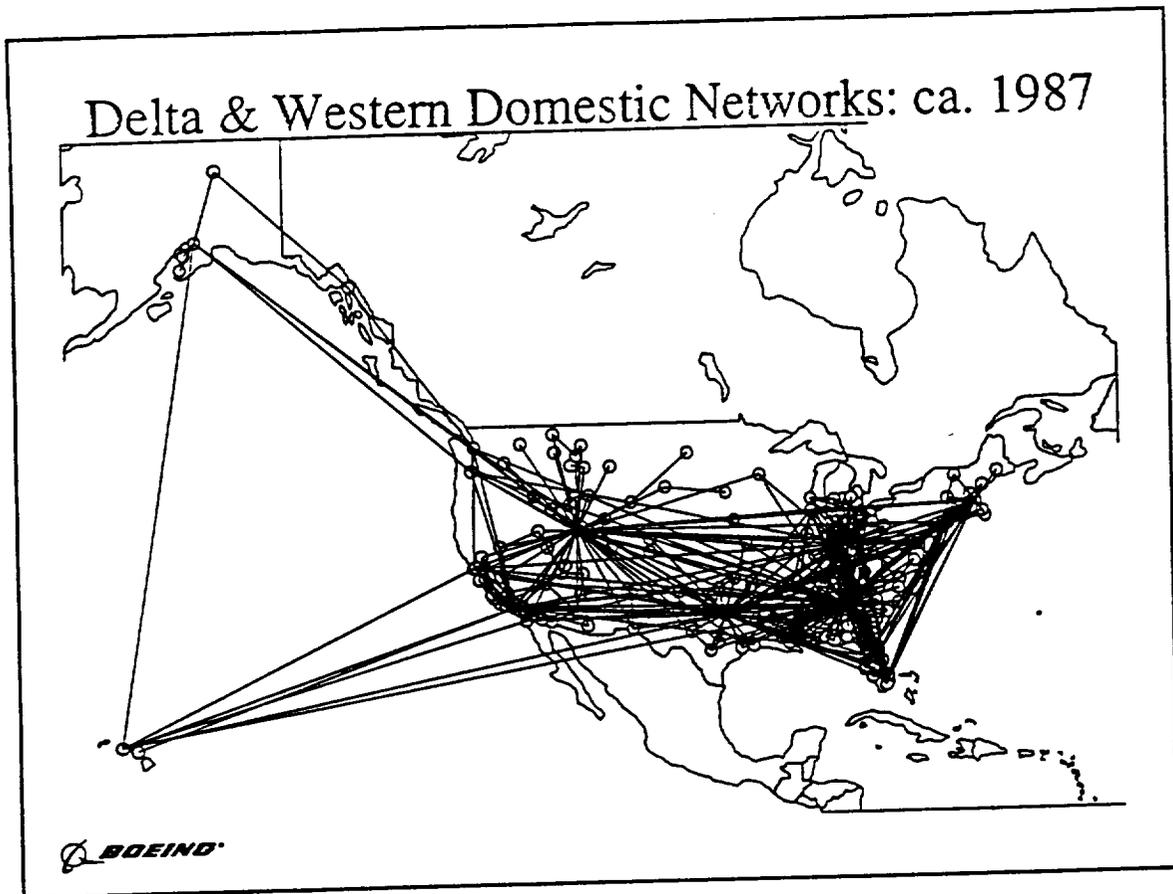
For our example, let's go back to early 1987. At that time, Delta Airlines announced that it would be acquiring / merging with Western Airlines. Imagine that you are given the task of analyzing the effect of this combining of two airline systems. Shown above is the combined route network of Delta and Western as published in the February, 1987 Official Airline Guide (OAG). For the purposes of our example, we are restricting the schedules to cities which are in the U.S. For Delta, we have removed flights to Europe, eastern Canada, and the Caribbean. For Western, we have removed flights to western Canada and Mexico.

Delta Domestic Network: circa 1987
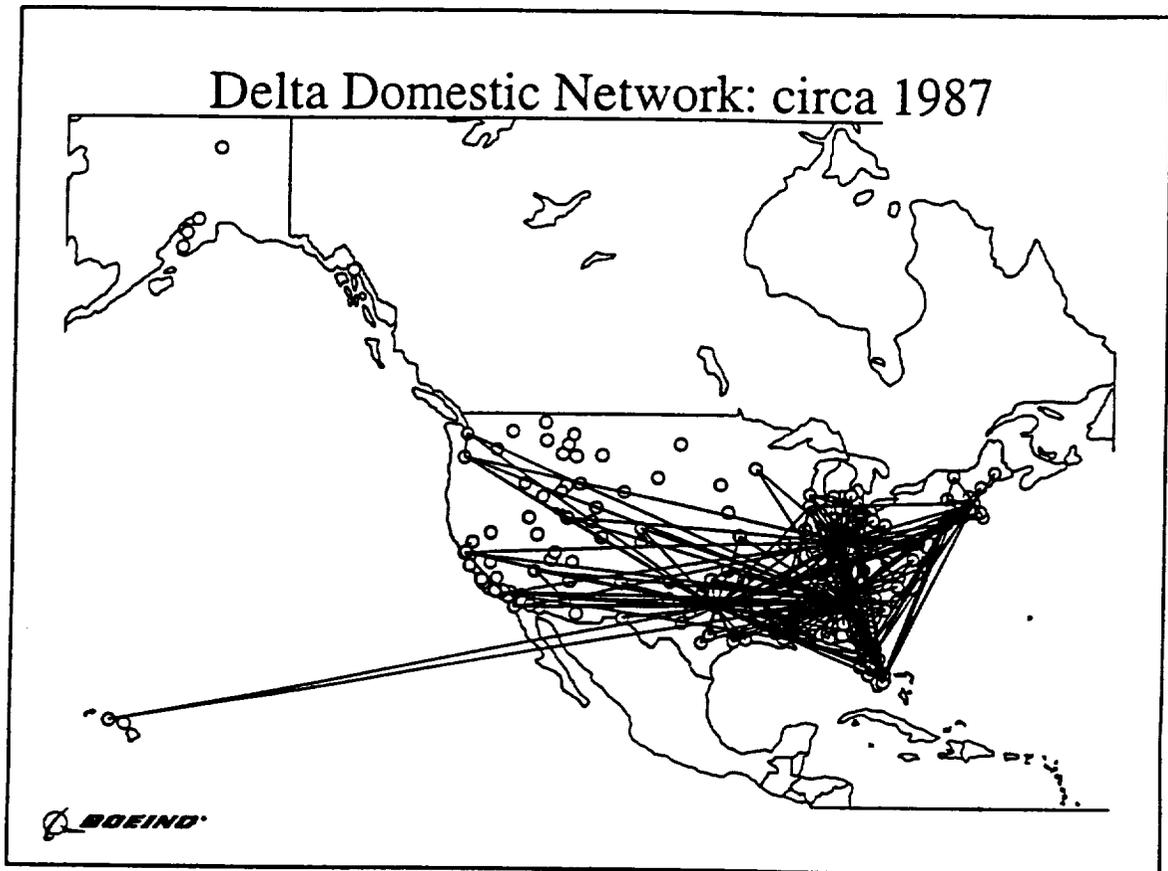
This shows only the Delta Airlines system although the cities to which Western Airlines flew are left on the map. As you can see, Delta had dense service on the East Coast and the Southeast, with some transcontinental service across the southern U.S.

Western Domestic Network: circa 1987
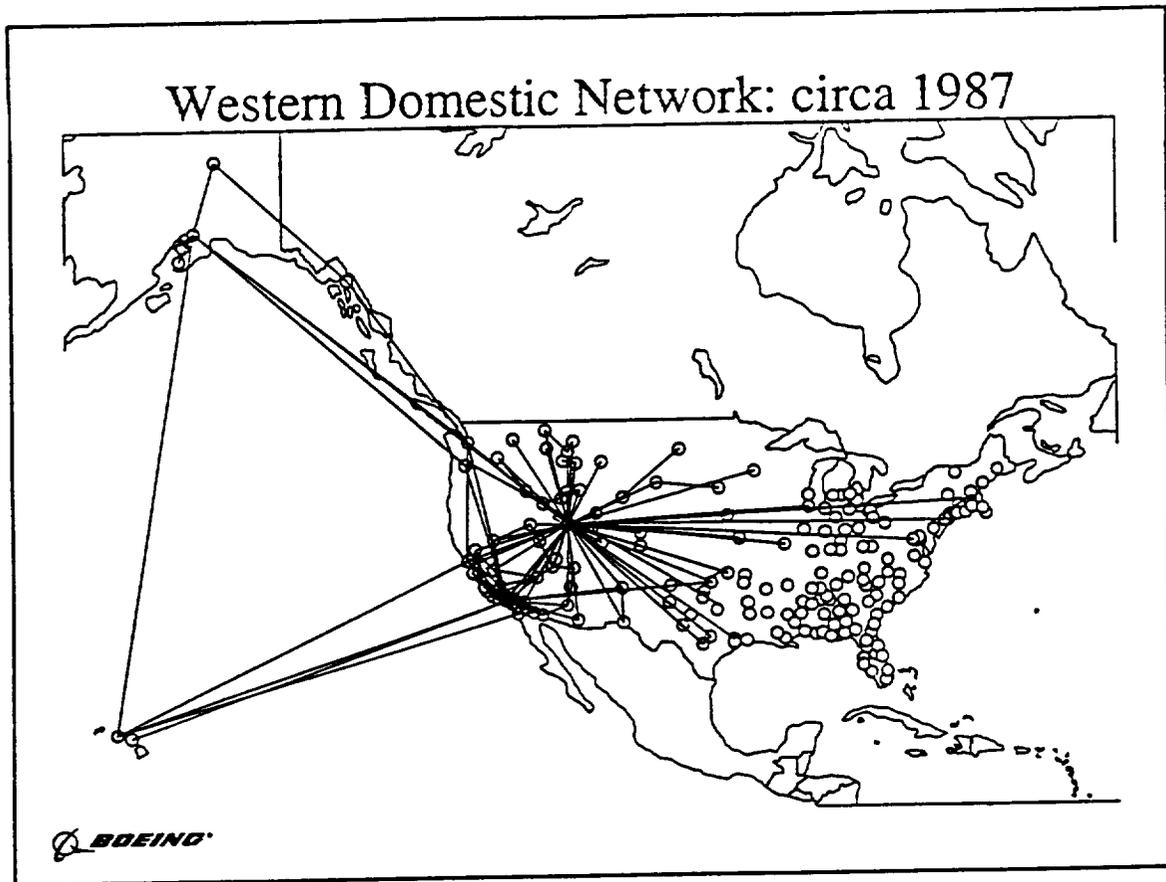
This map shows the Western Airline system with the cities which Delta serves left on the map. From its Salt Lake City hub, Western served the western U.S., with dense service to southern California. It also served Alaska and Hawaii and there were a few transcontinental flights to north-central and northeastern U.S.

Ways To Analyze

- Count non-stop flights in a city pair
- Count all service in a city pair
- **Determine Coverage in markets**
- Determine Path Preference
- Determine Revenue & Profit

More data, assumptions, and complexity

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In performing our task to analyze this merging of airline schedules, there are many ways to do it. We could simply count the number of non-stop flights in a city pair or all services (including through flights and connecting flights) in a city pair. These are characteristics of the airplane network and are not direct measures of the impact on passengers.

A measure of how well a schedule satisfies the travel requirements of passengers is Coverage, which will be defined in this presentation.

Another type of analysis would be to determine path preference and, lastly, revenue and profit. Each of these analyses provides information about the airline schedule. As we move down the list, however, the amount of data, the number of assumptions, and the complexity all increase.

For this paper, we will focus on Coverage. The Decision Window Model (DWM) is used to determine Coverage so, first, let's briefly review the principles of DWM.

Decision Window Arguments

How passengers pick flights

- Solution to a space/time problem is the reason passengers get on airplanes.
  - Wants to go from city A to city B
  - Leave after 8:00 and arrive before 16:00
- Idealize a two-step passenger decision process:
  - Identify those options (paths) which satisfy his requirements
  - Pick one option - trading off airlines, stops/connects, etc.

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The Decision Window Model predicts how passengers pick flights. It rests on the assumption that the reason passengers get on airplanes is to solve their space / time problems. The space / time problem can be stated as follows: The passenger wants to go from city A to city B, leaving after a certain time (for example, 08:00) and arriving prior to a certain time (for example, 16:00). Solving passengers' space time problems (that is, meeting their travel requirements) can thus be thought of as the Product that an airline provides.

In DWM, we idealize a two-step passenger decision process. First, a passenger identifies those options (paths) which satisfy his requirements. Second, he picks one option, trading of the perception of airlines, stops / connects, etc.

Decision Window Arguments

- We idealize a passenger's travel requirements as a window:

- And evaluate available paths:
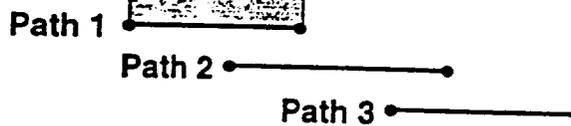
Thus, in DWM we idealize a passenger's travel requirements as a window of time, characterized by an Earliest Departure Time and a Latest Arrival Time. This "decision window" can then be compared to the available paths offered by the airlines.

For the decision window and paths shown above, we see that Path 1 satisfies this traveler because it fits within the decision window and departs after the Earliest Departure time and arrives prior to the Latest Arrival time.

Note: We define "paths" as a flight or combination of flights which takes a passenger from his origin airport to his destination airport.

Decision Window Arguments

- We idealize a passenger's travel requirements as a window:

Earliest Departure   **Latest Arrival**

Time →

- And evaluate available paths:

Path 1

Path 2

Path 3

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Similarly, Path 2 fits within the decision window and, thus, satisfies the traveler.

Decision Window Arguments

- We idealize a passenger's travel requirements as a window:

Earliest Departure   **Latest Arrival**

Time →

- And evaluate available paths:

Path 1 •————•

Path 2 •————————•

Path 3 •————————

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However, Path 3 arrives after the Latest Arrival time, so it does not satisfy this passenger's travel requirements, although it will satisfy other travelers.

Decision Window Arguments
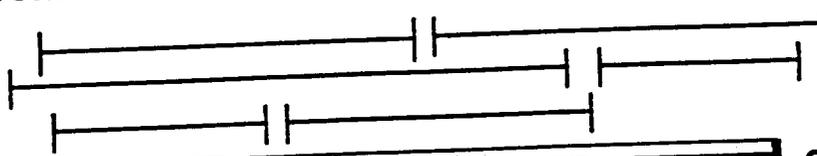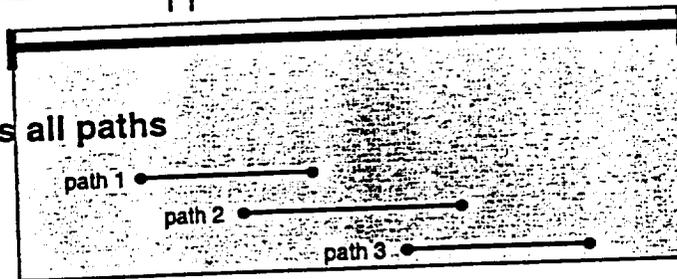
- **Consider some passengers in a market:**

Contains all paths

- **Versus all paths**

  - path 1
  - path 2
  - path 3

- **We Characterize passengers by the paths in their windows**

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If we take a number of decision windows for passengers traveling in a market and compare them to all of the paths in the market, we see that we can characterize passengers by the paths in their windows. For the decision window shown in bold, we see that it contains all paths.
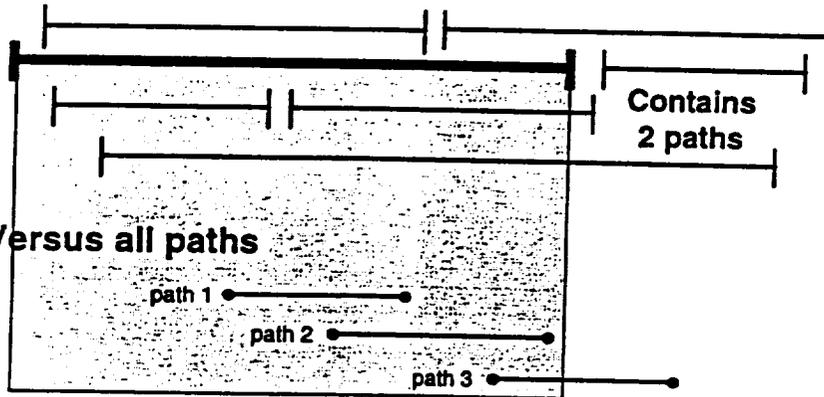
ATRG Dublin Presentation: "Analysis of Airline Systems Using Boeing's Decision Window Model": Soncrant

Decision Window Arguments

- **Consider some passengers in a market:**

Contains 2 paths

- **Versus all paths**

  path 1
  path 2
  path 3

- **We Characterize passengers by the paths in their windows**

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This decision window (shown in bold) contains 2 of the available paths.

Decision Window Arguments
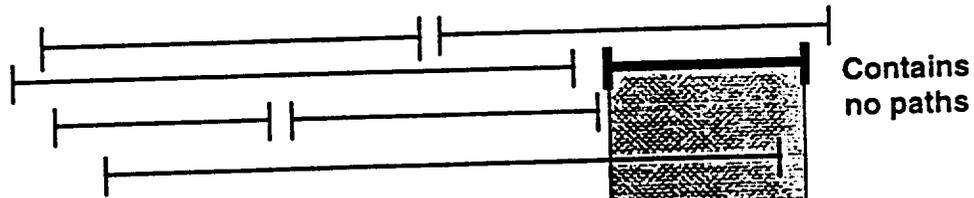
- **Consider some passengers in a market:**

Contains no paths

- **Versus all paths**

  path 1
  path 2
  path 3

- **We Characterize passengers by the paths in their windows**

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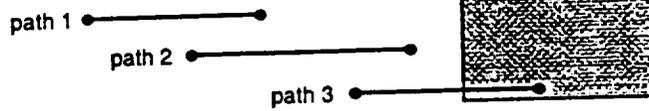
And this decision window (also shown in bold) contains no paths. This passenger will have to redefine his travel requirements in order to find a path that satisfies him.

Paths Within Window = Coverage

- Path Coverage:
  The fraction of passengers whose windows contain a path

- Airline Coverage
  The fraction of passengers whose windows contain at least one of an airline's paths

- Market, hub, leg, equipment . . . coverage

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Thus, Coverage can be thought of as occurring when paths fit within passengers' decision windows. We can determine the fraction of passengers whose decision windows contain a path or group of paths. Thus, we can define Path Coverage as the fraction of passengers whose windows contain a specified path. Airline Coverage would then be the fraction of passengers whose windows contain at least one of an airline's paths. This concept can be extended to any grouping of paths desired, such as those that serve a particular market, include a hub airport, include a specified flight leg, or utilize a specified equipment type.

Shared vs Unique Coverage
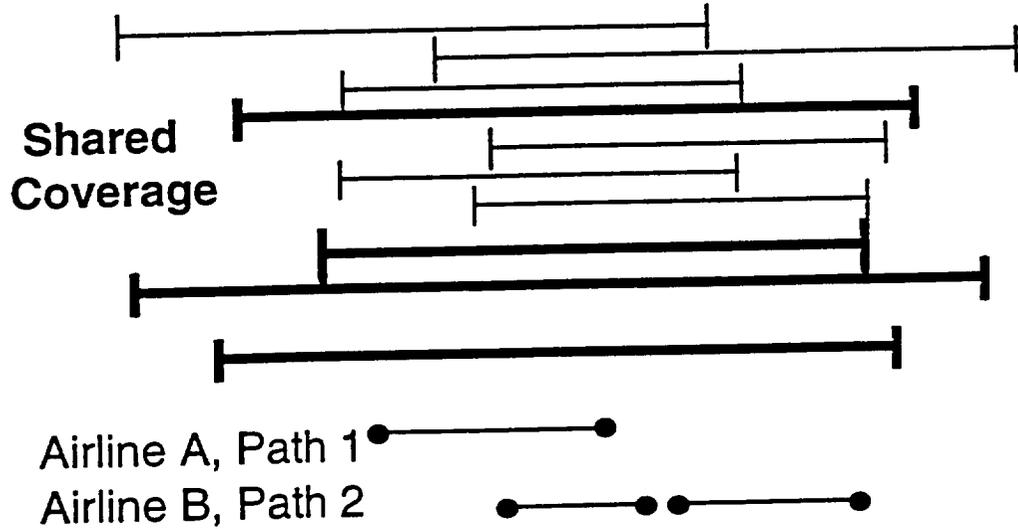
Consider the group of passenger decision windows shown and the two paths by Airline A and Airline B. The windows shown in bold contain both paths. This is Shared Coverage since these passengers will be shared between Airline A and Airline B.
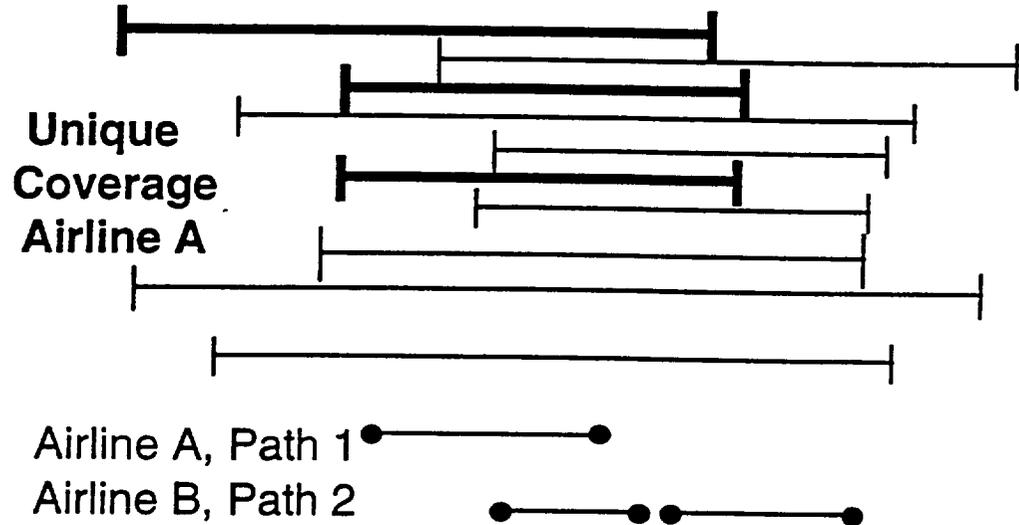
The decision windows shown in bold contain only the path by Airline A. This is called Unique Coverage for Airline A since Airline A is the only airline producing paths which meet these passengers' travel requirements.

Shared vs Unique Coverage
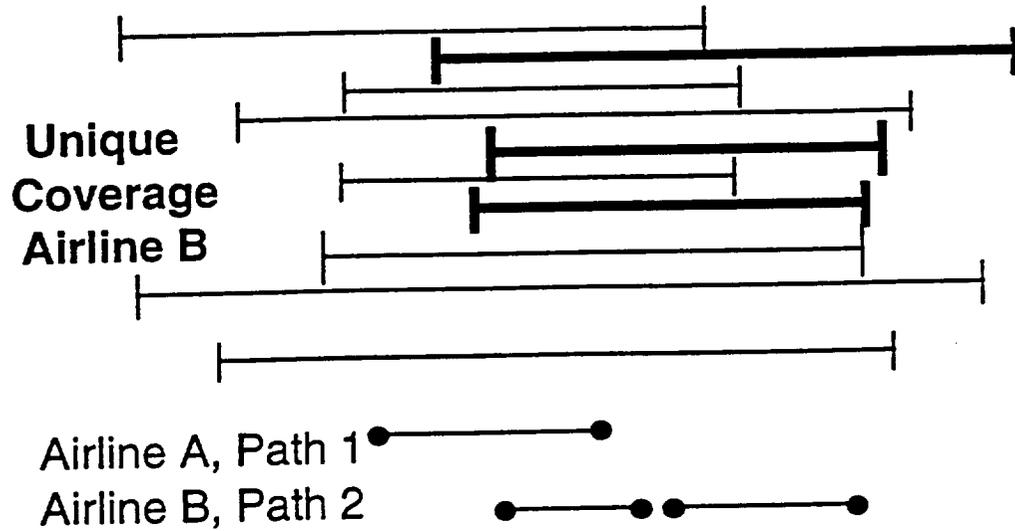
Similarly, the decision windows shown in bold contain only the path by Airline B. This is called Unique Coverage for Airline B since Airline B is the only airline producing paths which meet these passengers' travel requirements.

Coverage and the Airline Product

- Satisfying travel requirements is the Airline Product

- Coverage directly measures number of passengers satisfied

- Coverage is Product Value and thus, measures revenue potential

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As we noted previously, the reason passengers get on airplanes is to solve their space / time problems. Thus, satisfying passengers' travel requirements is the Airline Product. Coverage is a direct measure of the number of passengers satisfied by airline schedules. So Coverage is Product Value and, thus, measures revenue potential. In general, when an airline increases Coverage, revenue should increase also, although it is not guaranteed.

Study Groundrules

- February 1987 OAG schedules for Delta and Western (domestic)

- Boeing standard values for Decision Window Model

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For the record, the results about to be presented are based on the following:

The schedules analyzed are from the February 1987 OAG for Delta and Western airlines. The schedules are limited to U.S. domestic cities only.

All values for the Decision Window Model are Boeing standard values.

Coverage By Airline

For All Markets, Coverage = 299,640 Passengers

Delta Only Paths
212,099 passengers

Delta & Western Paths
32,846 pass.

Western Only Paths
118,546 passengers

Overlaps

New
Service

Interline Paths
8,108 passengers

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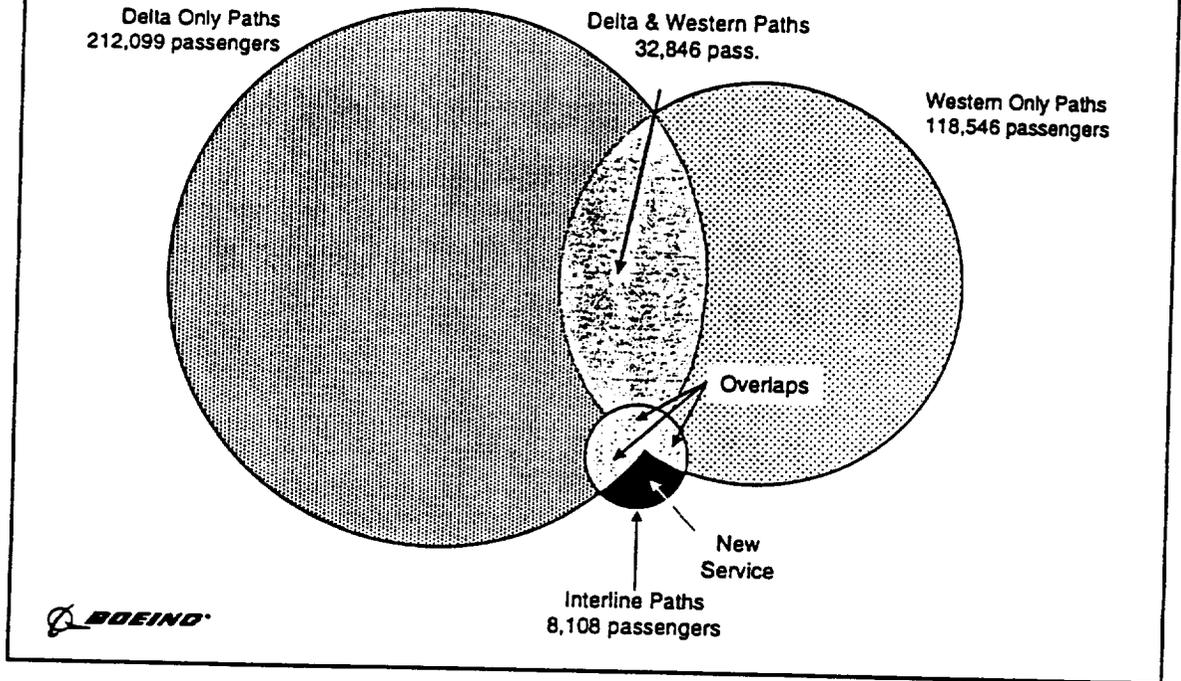
This chart shows the results of the Coverage analysis for Delta and Western. The results are presented in the form of a Venn diagram. The large circle on the left represents the number of passengers whose decision windows contain at least one path which involves only Delta. Similarly, the large circle on the right is the number of passengers whose decision windows contain at least one path involving only Western.

The large area of overlap (32,846 passengers) represents passengers who have a choice between a Delta path and a Western path. This is a reasonable amount of overlap for two merging airlines. There is some overlap when airlines serve the same markets. The worst situation would be if the Western circle fell completely inside the Delta circle. This would mean that merging Western with Delta would add no new Coverage, that is, no new Product.

The small circle at the bottom is Coverage for paths involving an interline connect. It's not surprising that this area is small given the separateness of the two airlines networks. The small wedge marked "New Service" represents the increased Product which would be created by simply combining the two networks. The challenge for Schedule Planners would be to coordinate the new merged airline to generate more new Coverage and to reduce duplicate paths which are inefficient.

Coverage Thru Hubs

Connecting thru Alanta or Salt Lake City: Coverage = 163,615 Passengers

Delta Connects thru
Atlanta
110,162 passengers

Western Connects thru
Salt Lake City
68,476 passengers
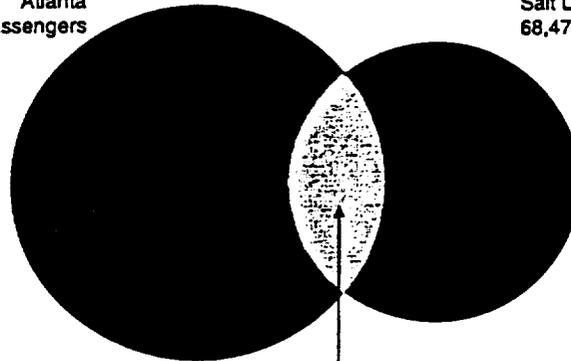
Connect thru Atlanta on Delta or
Connect thru Salt Lake City on Western

15,023 passengers

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This chart is an example of how Coverage can be used to study a subset of an airline system. It shows Coverage for passengers connecting through the Atlanta hub or the Salt Lake City hub. The wedge in the middle is those passengers who could connect through either the Atlanta hub or Salt Lake City hub. This type of analysis can be used to determine the effectiveness of multiple hubs and the extent to which they compete with each other.

Other Types of Studies

- Evolution of combined airlines

- Competition, Competitive Density

- Revenue weighting

- Schedule coordination

- International schedules
    Requires World O&D estimates

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In this presentation, we have shown a couple of ways that Coverage can be used to study airline networks. Numerous other types of studies can be performed.

In our case of Delta and Western, it would be interesting to observe the Coverage changes a year or two after the merger to see how successful the Schedule Planners had been at integrating operations of the two airlines.

Adding paths by other airlines would illustrate effect of competition. The Decision Window Model allows the determination of "Competitive Density" which is the average number of competitors whose paths fit within passengers' decision windows who also have Delta paths in their windows.

Revenue weighting would place increased importance on long range markets or higher-fare markets. In the Delta-Western example, we weighted all passengers the same.

Changes in Coverage can be used to improve coordination of schedules, either within an airline or between airlines (in the case of an alliance).

This study focused on domestic U.S. schedules. A natural extension would include international destinations. One difficulty in doing that would be the estimation of market demand in international markets. Boeing is currently working on methodologies to estimate World O&D demand.

The pros and cons of multi-hub structures in the airline industry*

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Abstract

In this paper, we investigate the cost arising for alternative network structures of a monopoly airline. We include airport operation, which is subject to diseconomies of scale, as well as the cost of transport which is subject to economies of densities. We find that in most circumstances, the monopoly airline will find profitable to operate either a point-to-point network or a central hub, the "bang-bang" solution. It is only in the presence of different cost functions for hubs and spoke airports that network featuring multi-hub will be profitable.

JEL : L52, L93.

Keywords : Airline, Airport, Economies of Densities, Hub-and-Spoke, Network.

1   Introduction

A major change in the airline industry has been the deregulation process started in the late 70's on the North American continent. Deregulation, by removing restrictions on the need for a route certificate, allowed carriers to expand and rationalise their route structure. It is often argued that the development of hub-and-spoke system has been a consequence of this liberalisation. Such a configuration allowed airlines to reach economies of scale for flight operations in a large network and to benefit from economies of density (e.g. Bailey and Panzar (1981), Keeler (1972), and Caves, Christensen and Thretheway (1984)). The latter type of economy occurs when the cost per passenger on a route declines with the number of travellers flying on that route. They arise in part because of a concentration of passenger on single aircraft rather than a scattering over several segments. Thus, the airline uses larger, more efficient aircraft and operates this equipment more intensively (at higher load factors). As the hub-and-spoke network possesses higher traffic densities than a point-to-point network with more direct connections, carriers benefits from such economies.

The major inconveniences of hubbing are the longer travel times and the increase in airport traffic. In order to deal with both problems, two solutions exist. On one hand, airport operation, subject to diseconomies of scale, can be intensified to manage such increases. On the other hand, direct route services between city-pair may be implemented, thus leading to a fall in hub transit traffic. However, such a policy affects the benefits of economies of density and dramatically extends the number of routes. Based on these arguments, large carriers decided to build up multi-hub systems.

The first aspect of this research determines the optimal network for an airline. Its second objective is to explain how the trade-off between on one side, the economies of density and scale that hub-and-spoke network provides, and on the other side, the diseconomies of scale ensued by the airport operation costs affect the carrier in her network structure choice.

To analyse such questions, we develop a model for an airline operating in a monopoly context. One firm is given the exclusive right to satisfy a finite demand for air travel on different city-pair markets. Her main objective is the minimisation of total network cost. This cost is an aggregation of the costs supported on various routes and airports. To optimise her problem, the monopolist selects an appropriate network structure through her hub and route numbers.

The main results of our analyis are the following. We find that in most circumstances, the monopoly airline will find profitable to operate either a point-to-point network or a central hub, the "bang-bang" solution. It is only in the presence of different cost functions for hubs and spoke airports that network featuring multi-hubs will be profitable.

Many studies describe the advantages, and thus the emergence, of hub-and-spoke network. These studies are split into three different categories. The first explains the dominant prevalence of a hub-and-spoke network relative to demand conditions, mainly passenger preferences relative to price and flight frequencies (Barrett (1990), Morisson and Winston (1986)). The second type provides an explanation of hubbing through the strategic advantages, that it confers to the airline (Oum, Zhang and Zhang, (1995); Berechman, Poddar and Shy, (1996)). Even if hubbing raises total cost it might be pursued by an airline, either because it is a dominant strategy in an oligopolistic setting or because it will be useful in deterring entry. In contrast, in this paper, we adopt a cost minimisation approach where the benefits of the hub-and-spoke network arise from the economies of scale and density. This approach has been followed by Starr and Stinchcombe (1992) and Hendricks et al. (1995) who have omitted airport operation costs. However, our entire motivation and contribution is developed below.

The paper is organised as follows : Section 2contains a short literature review. The model is introduced in the third section. Section 4 is devoted to the characterisation of the monopolist optimal solution under various assumptions on cost functions. Extensions are presented in section 5. Concluding remarks follow. Formal proofs of our results are presented in appendix.

2   Related literature

Hendricks et al. (1995) were also interested in identifying conditions under which hubbing is optimal for a monopolist. In their complex environment, the carrier is given the freedom to select the network structure, the passenger flows on connections and prices. They also focus on the effect of economies of scale and density. Their main proposition is that, if there are economies of density in the number of individuals travelling between two directly connected cities, the optimal network is either a hub-and-spoke or a point-to-point network. Nevertheless, our study differs from their research

on many aspects.

First, a much more intuitive approach is adopted over this study. It extends previous authors' results and allows the reader to get a much more comprehensive knowledge of this problem. Second, earlier researches neglect hub-capacity constraints, and thus investment costs for development projects. Third, traffic is an exogenous variable in their model. The monopolist has the power to direct passengers through the different paths of her network. Thus, passengers with the same origin-destination city-pairs do not necessary have the same itinerary. However, in our research, assumptions on individual preferences induce endogenous passenger movements. Indeed, traffic volumes on routes are indirectly influenced by the monopolist network configuration choice. The last divergence lays in prices. Hendrick et al.'s carrier must not charge different prices for different paths of travel between two cities. In this model, price aspects are not considered. Consequently, our monopolist objective is a cost minimisation rather than a profit maximisation problem. In spite of all these divergences, this paper confirms and extends the conclusion the three authors have drawn in a completely different framework.

3 The model

In this section, we formalise the monopolist's behaviour. Our model consists in basic elements: the network components, the demand and the network flows. In the first step, these elements are introduced. In the second step, cost features incurred for passenger movements using the various network components are transcribed into a cost function. Finally, the total network cost is defined as the sum of previously defined costs.

3.1 Network structure

There is a set, N, of n distinct cities, where $N = \{1, 2, ..., n\}$, $n \leq 2$. Each city is served by an airport. Their interconnections is the network. Its stucture is based on *links* and *nodes*. For the airline, these are, on the one hand, the inter-hub and spoke segments, and on the other hand, the hub and spoke airports. Various structures, ranging from a hub-and-spoke to a point-to-point (linear) system, are combinations of these four classes of components. Under the former configuration, passengers in and out
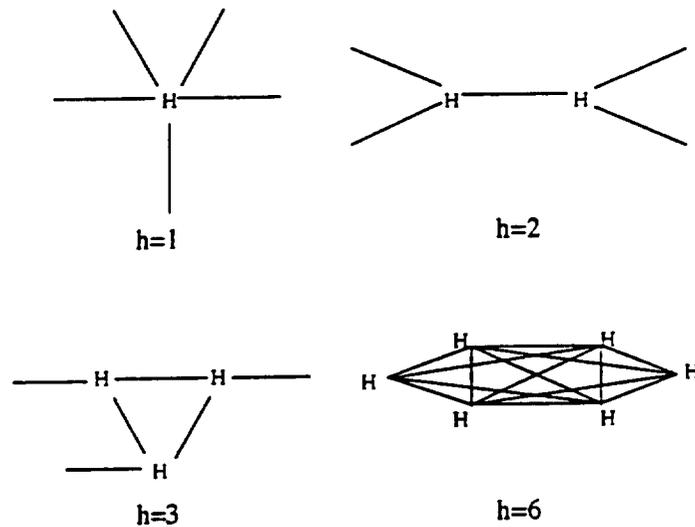
Figure 1: Multiple network structures for $n = 6$.

of a spoke airport are funneled through a major hub. Under the latter, the monopolist establishes a direct connection between all city-pairs. An intermediate solution is a multi-hub structure, where several airports are operated as hubs. These hubs belong to the set $H \subseteq N$, of h cities. In this environment, the linear system is a polar case of such a system.

A major comparison between all those systems is the total number of connections. When the carrier operates a single hub, all peripheric airports are linked to this hub through spoke connections. If the network operates several hubs, all hub-pairs exist, by the way of inter-hub segments, and a symmetry assumption is made on the number of terminal nodes (spokes) directly linked to each of them. Indeed, each of the transit nodes (hubs) is served by an identical number of spoke aiports, such that each of the latter is directly linked to only and only one of the former. The set of peripheric airports, $\frac{n}{h} - 1$, deserved by an hub is a region. The following graph is helpful to understand the previous statements. It illustrates the possible network structure for a given size of the network where $n = 6$.

Formally this is given by :

Definition 1 *A network is a mapping :* $N \times N \rightarrow \{0,1\}$ *such that*

$$\begin{cases} \delta_{ij} = 1, \text{if } i \in H \text{ and } j \in H \\ \delta_{ij} = 0, \text{if } i \notin H \text{ and } j \notin H \\ \forall j \notin H, \exists! i \in H \text{ s.t } \delta_{ij} = 1. \end{cases}$$

$\delta_{ij} = 1$ indicates the existence of a route between a city-pair (i, j), otherwise $\delta_{ij} = 0$. Symmetric route[1] structure is assumed, there exists a direct connection between i and j if and only if there exists a direct connection between j and i.

Definition 2 *A region is a subset,* $A_i = B_i \cup i$ *where* $\exists B_i \subset N$ *s.t.* $\delta_{ij} = 1$, *for each* $i \in H, \forall j \notin H$; *and for which,* $Dim(A_i) = \frac{n}{h}$, *for each* i.

A symmetrical assumption is made on the size of each region. Thus, the set of airports arround a hub, the periphery, denoted by B_i, is of size $\left(\frac{n}{h} - 1\right)$.

Definition 3 *A multi-hub network is a network where* $h > 1$.

The multi-hub structure is a set of regions interconnected through inter-hub segments. Given the region-size symmetry, the number of feasible hubs for a network, h, is such that $h \in \left\{x \in N : \frac{n}{x} \in N\right\}$.

After the statement of these definitions, the total spoke connections are

$$\sum_{i \in H} \sum_{j \notin H} \delta_{ij} = (n - h)$$

and the requisite inter-regional lines are

$$\sum_{i \in H} \sum_{j \in H} \delta_{ij} = \frac{h(h-1)}{2}.$$

The total routes, l, are

$$l(h, n) = \frac{h(h-1)}{2} + (n - h).$$

[1]We call a route, the two-way connection between city i and j.

Definition 4 *A linear or point-to-point network is a multi-hub network for which each region is a singleton,* $A_i = \{i\}$ *, equivalently* $h = n$.

In a linear system, it takes

$$l(h, n) = \frac{n(n-1)}{2}$$

connections to directly link n distinct points in both directions. As we already underlined, this configuration is the furthest advanced multi-hub system for which $h = n$. Given n, the network structure only depends on the operational hub variable, h.

3.2 Demand

In the model, city population is normalised to unity without loss of generality. Individuals preferences for air travel are as follows. Passengers plan to travel one way and care to reach their destination point through the shortest way. However, through this way, they are indifferent to stop-overs and segments used. A more substantive assumption is that demand is identical for each city-pair market. This is equivalent to assuming that no economic pole of attraction exists on the network. Thus, any individual flies to any city with a $\frac{1}{(n-1)}$ probability. This seems a restrictive assumption but it may be generalised to a city population of $(n-1)$ identical groups, each of them willing to fly to a different destination.

Such a specification of demand abstracts from reality in several ways. Demand in each city-pair market is independent of prices. However, it does not affect the cost minimisation objective of the monopolist.

3.3 Traffic

While population and demand for city-pair market are only dependent on n, aircraft and passenger movements vary with respect to the structure. In this section, our attention is focused on these two parts of traffic, and their variations. Given the assumptions on network and demand, we determine the passenger flows and the carrier presences at network-component level in function of h. In fact, there exists an equality in traffic volume within the same class.

3.3.1   Routes

The first element of traffic is passenger movements. There is an unique path connecting a spoke city to its hub. Consequently, everyone travelling from or to this spoke airport flies through this route. For a connected spoke-hub pair (j, r) within a specific region, A_r , $\forall r \in H$ and $\forall j \in B_r$, outflow traffic is city j population. Airport j inflow traffic is a proportion, $\frac{1}{n-1}$, of $(n-1)$-city populations. The two-way traffic on a spoke-city denoted by m_{rj} is independent of the network structure or size:

$$m_{rj}(h, n) = 1 + \frac{(n-1)}{(n-1)} = 2. \tag{1}$$

According to the symmetrical assumptions on population and structure, volumes of travellers on spoke routes are equal such that :

$$m_{rj} = m_{sk}, \forall r, s \in H \text{ and } \forall j \in B_r, k \in B_s.$$

In a multi-hub environment, inter-regional travellers fly through inter-hub lines. One-way passenger traffic on such a route consists of the outflow of an area, A_r, bounding to another region, A_s, $\forall r \neq s \in H$. Indeed, this flow is a proportion, $\frac{1}{n-1}$, of the origin-region population, $\frac{n}{h}$, willing to fly to the $\frac{n}{h}$ cities of the destination area, A_s. Given the symmetrical assumptions, the two-way flows on an inter-hub line, denoted by m_{rs}, is given by :

$$m_{rs}(h, n) = \frac{2}{(n-1)} (\frac{n}{h})^2, \forall h > 1. \tag{2}$$

Polar cases occur for values of $h = 1$ and $h = n$. The first value is the single-region or central hub-and-spoke network, for which no inter-regional traffic exists, $m_{rs} = 0$. The second is the linear case, for which $m_{rs} = \frac{2}{(n-1)}$.

The second component of traffic on a route is aircraft movement, or carrier presence on the route. In this research, it is assumed unitary. Each connection is served·by one and only one airplane. Thus, to satisfy demand for city-market, the carrier selects an appropriate aircraft size. This crucial assumption is needed for cost additivity which is used later.

3.3.2   Airports

Airports are the nodes of the network. They gather passenger and aircraft movements. Both movements for spoke and hub airports, depends on a number of hypothesis. Nevertheless, for our assumptions, traffic movements are equal within a node class.

Passenger volume for a spoke airport, denoted m_j, has already been computed. Indeed, it corresponds to the traveller flow for a spoke connection given in equation (1),

$$m_j(h,n) = m_{rj}(h,n) = 2, \forall j \notin H, \forall r \in H. \tag{3}$$

m_j is independent of the region. For all of them, it is a constant. We already mentioned the fact that it is independent of the size and the structure.

Traveller movements for a hub is a compound. On the one hand, it depends on the population of its region, $\frac{n}{h}$. On the other hand, it consists in the traveller inflow from the existing inter-hub routes connected to this airport. Total inflow is the sum of all one-way passengers for these routes, $(h-1)\frac{m_{ri}}{2}$. The aggregate of these two parts results into the volume of passengers for a hub denoted by m_r :

$$m_r(h,n) = \frac{n}{h} + \frac{(h-1)}{(n-1)}(\frac{n}{h})^2, \forall r \in H. \tag{4}$$

Aircraft-movement variable is an indicator of the airport activity. It gives the number of aircraft servicing an airport or the carrier presence. Given, the previous assumption on aircraft movement on a route, the value of this indicator is equal to unity for spoke airports. However, at hub level, it depends on the network size and structure. If this indicator is denoted by a_r, the value of this indicator is given by, :

$$a_r(h,n) = \frac{n}{h} + h - 2, \forall r \in H. \tag{5}$$

3.4   Network costs

Network management costs involved a series of costs in establishing connections and operating airports. For each route and airport, these costs are influenced by the components of traffic, passengers and aircraft. However,

traffic at the network component level is itself a function of the structure. Thus, for the network, total cost depends directly and indirectly on the size and the structure. This section focus on the development of a cost function specification. It argues on the general economic features beyond the related assumptions.

3.4.1 Connection costs

Establishing a direct connection between two cities induced some costs due to passenger volume and aircraft movement. Part of these costs are more or less independent of the total volume of traffic on a particular connection. We represent such costs by F. The remaining costs are influenced by the size of aircraft required to satisfy demand in either direction on the route. Variable costs for a direct connection between two cities can then be expressed as $V(m)$.

Thretheway (1991) argues on the existence of substantial economies of scale in aircraft size. This kind of economies arises from at least two sources : labour costs and aircraft equipment costs. In fact, while the crew requirements on large aircraft are somewhat greater than on smaller types, the relationship is less than proportional. Therefore, one can expect to impart some economies with respect to increasing aircraft size.

This argument suggests that the first and second derivatives of the variable cost $V(m)$ for a direct connection are respectively positive and negative, such that $V(m)$ is a concave function. Cost of a connection, denoted by $C_c(m)$, is the sum of fixed and variable costs :

$$C_c(m, F) = F + V(m(h, n)).$$

(6)

Such a cost function exhibits economies of density if, for $F \neq 0$ and $V(m) \neq 0$, the following definition is satisfied:

Definition 5 *A connection exhibits economies of density if $C_c(\theta m) < \theta C_c(m)$ for all $\theta > 1$ and for all $m \neq 0$.*

Such a definition is equivalent to the condition that average cost, at a direct connection level, decreases with proportionate increases in traffic on that connection. It is straightforward to show that concavity of $V(m)$ implies economies of density.

An useful assumption on the variable cost function $V(m)$, is the constant return to scale hypothesis[2]. Thus, we may substitute the value of $V(m)$ by m, such that variable cost is linear to the volume of traffic for the specific type of segments. Therefore, connection cost for a spoke route, denoted by C_{rj}, is given by:

$$C_{rj}(F_{rj}) = F_{rj} + 2, \forall r \in H \text{ and } \forall j \in B_r,$$

where F_{rj} are the fixed costs supported on a spoke connection.

Inter-hub connection cost is given, by substituting the value of m_{rs} given in (2) into (6). Connection cost, for this class of routes, C_{rs} is:

$$C_{rs}(h, n, F_{rs}) = F_{rs} + \frac{2}{(n-1)}(\frac{n}{h})^2, \forall r \in H, \text{ and } \forall s \in H,$$

where F_{rs} are the fixed costs supported on a spoke connection.

After cost specification at each segment level, it is straightforward to compute the total cost of route operations for the monopolist's network. For $\frac{h(h-1)}{2}$ inter-hub and $(n-h)$ spoke routes, total connection cost, C_{ct}, is the entire sum:

$$C_{ct}(h, n, C_{rs}, C_{rj}) = \frac{h(h-1)}{2}C_{rs} + (n-h)C_{rj}$$

or by substituting the volume of traffic in the adequate equations :

$$C_{ct}(h, n, F_{rs}, F_{rs}) = \frac{h(h-1)}{2}\left(F_{rs} + \frac{2}{(n-1)}(\frac{n}{h})^2\right) \qquad (7)$$
$$+(n-h)\left(F_{rj} + 2\right).$$

3.4.2 Airport operation costs

Airport traffic, explained by aircraft and passenger movements, generates airport operation cost. Consequently, this cost at the airport level depend on the number of aircraft servicing this destination (or the airport activity) and the flow of passenger.

For each ground operation, part of the cost is independent of passenger traffic, it is the fixed cost of handling, denoted by G. It may also be

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[2]This is relaxed later.

considered as a constant marginal cost for aircraft landings. Thus, for the carrier, cost at the airport level is influenced by its presence[3].

Ground operation cost is also explained by the passenger movement of the airport. A realistic modelisation of the variable cost, $W(m)$, for airport operations can be expressed as an increasing function exhibiting diseconomies of scale:

$$C_a(a_r, m, G) = a_r G + W(m(h, n)),$$

such that $W'(m) > 0, W''(m) > 0$.

A specific airport operation cost function for hub and spoke airport assume that variable cost is also linear in m, and thus also exhibits constant return to scale. This is transcribed by substituting m by its respectives values given in equations (4) and (3).

For a spoke airport, the cost of airport operation, C_{aj} :

$$C_{aj}(G_j) = G_j + 2, \forall j \notin H.$$

where G_j the fixed cost of an aircraft handling operation at a spoke airport.

For a hub, the cost of aircraft movement and passenger flow is denoted by C_{ar} :

$$C_{ar}(h, n, G_r) = \left(h - 2 + \frac{n}{h}\right) G_r + \frac{n}{h} + \frac{(h-1)}{(n-1)}(\frac{n}{h})^2, \forall r \in H$$

where G_r is the fixed cost of an aircraft handling operation at a hub.

Costs for the different node classes have been defined. On the network, implanted costs of airport operations are supported on h hubs and $(n - h)$ spokes. Total cost of airport operations is denoted by C_{at}, and given by the following equation:

$$C_{at}(h, n, C_{ar}, C_{aj}) = hC_{ar} + (n - h)C_{aj}.$$

In term of variables h and n, it is given by the following equation :

$$C_{at}(h, n, G_r) = h\left(\left(h - 2 + \frac{n}{h}\right) G_r + \frac{n}{h} + \frac{(h-1)}{(n-1)}(\frac{n}{h})^2\right) \quad (8)$$
$$+ (n - h)\left(G_j + 2\right).$$

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[3]An indicator of this presence is given by equation (5).

3.4.3 Total network cost

Total network cost is defined as the summation of airport operation and connection costs

$$C_{net}(h, n) = C_{at}(h, n) + C_{ct}(h, n).$$

This cost mainly depends on the size of the network, n, and the structure, h. This results in the sum of equations (7) and (8).

4 Optimisation problem

In this section, we study the objective of the monopolist. Given the absence of prices, it consists in choosing the appropriate number of hubs , h (or $Dim(H)$), such that the total network costs are minimised[4],given the network size n,

$$\underset{h}{Min} \; hC_{ar} + (n - h)C_{aj} + \frac{h(h-1)}{2}C_{rs} + (n - h)C_{rj} \qquad (9)$$

$$s.t. \begin{cases} h \geq 1 \\ h \leq n \\ h \in \left\{x \in N : \frac{n}{x} \in N\right\}. \end{cases}$$

The first two inequalities are the physical constraints. The optimal solution is bounded by the two polar cases, the hub-and-spoke network and the point-to-point system. The third restriction follows from the symmetrical assumptions set on the network structure.

This minimisation problem is analysed under various assumptions on costs. The first two studies are benchmarks. For the *first*, cost of a passenger is assumed negligible, whereas cost functions are mainly determined by connection number. For the *second*, costs per passenger are taken as a constant, while, this time, fixed costs are nul. Both benchmarks are helpful to understand the mechanism of the model. The *third* case deals with varying marginal cost per passenger at the component level.

An heuristic approach is carried out along the following sections. The general minimisation problem in (9) is analysed piecewisely. Thus, the minimisation problem is applied separately to its two elements, the total airport

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[4]Our objective is not to determine which cities should be operated as hub airports.

and connections costs. Such an approach permits a deep examination of the effects of a structure modification on costs.

4.1   Case 1 : A zero marginal cost of passenger

The first benchmark assumes independency between costs and volume of passengers. Costs of airport operations and connections are only function of the fixed costs encountered by the monopolist on her routes and handling services, cost per passenger is negligible. Thus, determinant of the cost functions is the number of routes.

4.1.1   Connection costs

Along this section, the variable costs for a route are held to a zero level, $V(m) = 0$. For each aircraft movement, the monopolist only sustains a fixed cost. The total connection costs follows:

$$C_{ct}(h, n) = \frac{h(h-1)}{2} F_{rs} + (n - h) F_{rj}.$$

The minimisation problem for route optimisation under this context is now stated, as follows, under the constraints specified in (9):

$$\underset{h}{Min} \ \frac{h(h-1)}{2} F_{rs} + (n - h) F_{rj}$$

$$s.t. \begin{cases} h \geq 1 \\ h \leq n \\ h \in \left\{ x \in N : \frac{n}{x} \in N \right\}. \end{cases}$$

The first order condition of the unconstrained problem leads to the following solution :

$$h^*(F_{rj}, F_{rs}) = \frac{1}{2} + \frac{F_{rj}}{F_{rs}}.$$

h^* denotes the optimal solution of this problem. We call the ratio, $\frac{F_{rj}}{F_{rs}}$, the *route coefficient*. This coefficient is unitary when values of fixed costs for both classes of connections are equal. In such an occurrence, the optimal network consists in a structure based on a central or two-step

hubs, resp. $h^* = 1$ or $h^* = 2$. For both configuration, the total number of routes are equal. Consequently, the total connection costs induced are identical. This solution confirms Hendricks et al. (1995) results under similar assumptions[5]. If this ratio is lower than unity, the carrier does not have any incentive to set up a two–step-hub design, and the only feasible structure is based on the central-hub architecture. If the ratio is greater than one, the monopolist seek to operate a multi-hub network, with $h^* > 2$. For a high level of this ratio, the polar linear solution occurs.

4.1.2 Airport operation costs

Here, variable costs for ground operation at the airport level are assumed negligible, $W(m) = 0$. The fixed costs of an aircraft handling are determinants. We already mentioned that these costs may be considered as a constant marginal cost for the airport activity indicator. The minimisation problem is now written as :

$$\underset{h}{Min} \ (h(h - 2) + n)\, G_r + (n - h)G_j$$

$$s.t. \begin{cases} h \geq 1 \\ h \leq n \\ h \in \left\{ x \in N : \frac{n}{x} \in N \right\}. \end{cases}$$

Under a continuous assumption on the size of the H set the solution to the first order condition is given by:

$$h^{**}(G_r, G_j) = 1 + \frac{G_j}{2G_r}.$$

The ratio, $\frac{G_j}{2G_r}$ is called the *airport coefficient*. Its role is analogue to the route coefficient previously studied. If aircraft operations incur identical fixed costs for any class of node, then the optimal network structure includes either one or two hubs, $h^{**} = 1$, $h^{**} = 2$. In these cases, the total number of handling operations carried out by the carrier are the same. Therefore, the justification for a central hub fails to exist. However, this justification exists for values of $G_r > G_j$. Moreover, a multi-hub solution, with $h^{**} \geq 2$, may occur for high value of airport coefficient, then $G_r < G_j$.

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[5]The three authors prooved a similar result when variable costs for passenger traffic are nul. This fails to justify the single hub network, however a multiple hub is a feasible solution.

4.1.3 Optimal structure

The general minimisation problem (9) is solved under the assumption of a negligible marginal cost of passenger. Both minimisation problems, examined in the previous sections, induce an identical network architecture. The cost functions modelised for airport operations and connections are both minimised at $h^{**} = h^*$. Consequently, the constrained problem given in (9) admits a solution where $h = 1$ or $h = 2$. This benchmark leads us to the following proposition.

Proposition 1 *When marginal costs of a passenger are negligible, $V(m) = W(m) = 0$, the carrier's incentives to operate a point-to-point network are inexistent when values of route coefficient and airport coefficient, respectively given by $\frac{F_{rj}}{F_{rs}}$ and $\frac{G_j}{2G_r}$, are (resp.) equal to 1 and $\frac{1}{2}$. Moreover, the monopolist is indifferent in operating either a unique hub architecture, or a two-step hub structure.*

It is that simple, hub-and-spoke airline route structures economise on the number of segments needed to link a large number of origin-destination pairs. When routes is a significant determinant of costs, central hub or two-step hub systems are the best configuration poliicy.

4.2 Case 2 : A non-zero and constant marginal cost of passenger

The second benchmark examines the monopolist's behaviour in her structure choice under the assumption of a constant marginal cost of passenger. Thus, cost functions at network component level are linearly dependent on the volume of traffic. Moreover, fixed costs incurred by the monopolist on her routes and handling services are assumed negiglible.

4.2.1 Connection costs

Transportation costs of passengers on routes are highlighted in this section. Over the entire section, each passenger on any class of connection is assumed to be as costly as another. An assumption on fixed costs is needed to carry on such analysis, such that fixed cost for a connection are held to a zero level, $F_{rj} = F_{rs} = 0$.

With such assumptions, connection cost for a route exhibits constant return to scale in term of passenger movements. At the network level, these total costs are equal to the total route traffic. Equation (7) can now be stated as follows after straightforward simplification:

$$C_{ct}(h,n) = \frac{h(h-1)}{2}m_{rs}(h,n) + (n-h)m_{rj}(h,n) \tag{10}$$

$$= \frac{(h-1)n^2}{h(n-1)} + 2(n-h).$$

The minimising problem for total connection costs is still specified under the same constraints of problem (9). The minimum of this function is reached at $h^* = n$. This seems to be a strong and amazing result. Explanation of such a solution follows.

For a network structure such that $h = 1$, the network is a set of $(n-1)$ spoke segments. The passenger flow for each route is equal to $m_{rj} = 2$. Consequently, the total volume of traffic is $2(n-1)$. The establishment of a new hub, $h = 2$, has two effects. *First*, the network is now characterised by the presence of a connection between the two hubs, an inter-hub line. The volume of passenger travelling on this route is $m_{rs} = \frac{n^2}{2(n-1)}$[6]. *Second*, through the adjuction of a new hub, the spoke segments are reduced. Thus, the total of passenger flying spoke connections decreases. Noteworthy, both effects on total passenger volume are divergent. However, the former dominates the latter, therefore network traffic raise is evaluated at $\frac{n^2}{2(n-1)} - 2 > 0$.

With the existence of additional hubs, $h \geq 3$, a *third* effect can be depicted. For $h = 3$, the structure is composed of three inter-hub lines. Thus, inter-regional traffic is diverted through them. In fact, there exists a negative marginal variation on the volume of travellers at an individual inter-hub route level. Although, traffic on each of these segment is lower to $m_{rs}(2,n)$, total inter-regional passenger traffic increases. Moreover, for low value of h, the sum of the negative effects-the *second* and the *third*-is not sufficient to completely alleviate the raise in traffic ensued by the expansion of direct connections. Therefore, the network total passenger volume increases. However, a maximum of this volume is reached at the *critical value* $h = \frac{n}{\sqrt{2(n-1)}}$[7]. It occurs when the marginal variation for total

[6]This volume of passenger, m_{rs}, is greater than m_{js}, for all $n > 2$.

[7]This occurs for a continous appoximation of the function.

inter-regional traffic flow is equal to the marginal decrease in spoke traffic[8]. Formally, this means that

$$\frac{\partial}{\partial h}\left(\frac{(h-1)n^2}{h(n-1)}\right) = 2.$$

For values of h, above the critical value, the total network traffic decreases. It reached is minimum value in $h = n$.

Proposition 2 *The point-to-point network, characterised by a structure where $h^* = n$, is the system that generates the lowest movement of passengers. Therefore, under the assumption of a constant cost per passenger, it is the cost minimising solution for the monopolist.*

Proof. The proof of this statement requires two steps. We start to assume, without loss of generality, that equation (10) is twice differentiable in the interval $[1, n]$, thus $C_{ct}(h, n) \in \mathbb{C}^2, \forall h \in [1, n]$. Straightforward computation leads to $\frac{\partial^2}{\partial h^2} C_{ct}(h, n) < 0, \forall\, h \in [1, n]$, with $F_{rj} = F_{rs} = 0$. Thus, the function is strictly concave in this interval. Consequently, the value of the minimum is reached at one of the bound of the interval, either for $h = 1$ or $h = n$.

Next we show that the level of cost is the lowest for $h = n$. In fact, substituting the value of h at the bounds, in the cost function $C_{ct}(h, n)$ is such that $C_{ct}(1, n) > C_{ct}(n, n)$. ∎

Two remarks are underlined about the approximated continuous function. First, the level of cost in $h = 1$ is identical to the one in $h = \frac{n^2}{2(n-1)}$. This value is greater than $\frac{n}{2}$, the last feasible multi-hub architecture for which a regional area is not a singleton - the point-to-point network. For n large enough, $\lim_{n\to\infty} \frac{n^2}{2(n-1)} = \frac{n}{2}$. For wide network, the monopolist incurs a cost for a unique hub structure equivalent to a network design based on $\frac{n}{2}$ hubs. Second, for a value $\frac{n}{\sqrt{n-1}}$, traffic flow on all classes of routes are equal,

$$m_{rs} = m_{rj} = 2.$$

However, the total cost of connections is higher, since the number of routes is greater than $(n - 1)$, the single hub network value.

[8]This marginal decrease is equal to m_{rj}. The traffic volume on a spoke connection

This result confirms Starr and Stinchcombe's (1992) results. Such a solution is easily explained, as long as the carrier does not benefit from any economies of density. Thus, the monopolist does not face an incentive to operate a single-hub network. Her optimum is to operate the lowest traffic on each connection and thus the lowest passenger movement on the network.

4.2.2 Airport operation costs

In this section, the cost for a passenger contracted by a monopolist at her airport operation level is also a constant. Thus, an airport operating cost exhibits constant return to scale in term of passenger volume. Such a specification also requires an assumption on the airport operation cost function: the fixed cost for an airport operation are nul, thus $G_r = G_j = 0$.

Equation (8) can now be written

$$C_{at}(h,n) = n + \frac{h(h-1)}{(n-1)}(\frac{n}{h})^2 + (n-h)\,2. \tag{11}$$

This equation is the sum of total connection cost, given by(11), and the size of the network, n. Consequently, the constrained minimisation problem with respect to the decision variable, h, has a similar result than the previous section, $h^{**} = n$. The optimal structure policy is to install n hubs. This ensure the monopolist to operate her network at the lowest costs. Capacity needed for each airport is minimal, and equal to the one required for a spoke airport. The absence of a hub city prevents the increase in cost due to the possibility of traffic accumulation at this hub. The point-to-point network is therefore, the optimal policy in this case.

4.2.3 Optimal structure

The solution to the general minimisation problem is the point-to-point structure. Of course, if this is the solution to the two individual cases, it must also be the solution to the aggregate problem. Therefore the following proposition is forwarded,

Proposition 3 *If the following conditions are respected, such that:*

1. *Airport operating and connection costs are characterised by nul fixed costs, resp. $G = 0$ and $F = 0$, and*

2. *Variable costs, $V(m)$ and $W(m)$ exhibits constant return to scale.*

Then the optimal network structure is a linear network where $h = n$.

Proof. Given the concavity of both cost functions, solutions of connection and airport optimisation problem are respectively $h^* = n$ and $h^{**} = n$. Therefore, the general optimum for problem (9) is given by $h = n$. ∎

4.3 Case 3 : Fixed cost and marginal costs.

In this section we consider cost functions for which network costs of connections and airport operations vary directly with passenger volume and aircraft movement (segment number). This corresponds to an aggregation of the first and second benchmarks. Thanks to the existence of fixed costs, this leads to a varying cost per passenger at the individual component level. Over this case, an additional assumption on the value of fixed costs, F and G is carried out. These are assumed to be constant within a class of routes or for any aircraft handling operations wherever it is operated.

4.3.1 Connection costs

Here, total connection cost directly vary with the number of routes and the traveller volume. Given, the existence of fixed costs and the assumptions on the variable cost for direct connections, for which $\alpha = 1$, the network is characterised by economies of density on its segments. Such economies arise from spreading fixed costs over a larger volume of passengers. The total cost function is now stated as follows,

$$C_{ct}(h, n) = \frac{(h-1)n^2}{h(n-1)} + 2(n-h) + \left(\frac{h(h-1)}{2} + (n-h) \right) F. \quad (12a)$$

The optimal solution to the restricted minimisation problem of this function depends on the value of F. However, given the value of F, the optimal solution is characterised by a "bang-bang" solution. The following proposition is relevant in this case,

Proposition 4 *Suppose $V(m)$ is proportional to passenger volume and a fixed cost, F, is incurred on routes. Then there exists a level of fixed costs, $\widehat{F}$ such that:*

1. *For $F > \widehat{F}$, the hub-and-spoke network is the optimal solution, and $h^* = 1$.*

2. *For $F < \widehat{F}$, the point-to-point network is the optimal configuration, and $h^* = n$.*

3. *No interior solution, with $h^* \in \,]1, n[\,$, is cost minimising.*

Proof. See Appendix ∎

Indeed, for a level of fixed costs on connections, F, higher than the value $\widehat{F}$, the central hub-and-spoke system, for which $h^* = 1$, is always the optimal policy structure. For such a value of fixed costs, the latter and the point-to-point systems are equally profitable. The economic features beyond this proposition are straightforward. Total cost per total passenger movements at network level, defined as the ratio of total connection costs and total traffic movement, increases with respect to fixed cost level on a connection. Moreover, this average cost increases at a higher rate for the linear than the single-hub achitecture, see Figure (2). This reflects the importance of economies of densities for low value of h. Consequently, for a value of $F > \widehat{F}$, the cost per passenger for the point-to-point system is too high to benefits from the advantages it brings. Noteworthy, although economies of density are higher on inter-hub segments, for $h > \frac{n}{\sqrt{n-1}}$, multi-hubbing with $h^* \in \,]1, n[$ is not a first best.

Similar results were obtained by Hendricks et al. (1995). Although, their model differs from ours in many perspectives, conclusions observed are similar in this case study. Their study also revealed a value of fixed cost on routes for which they suggested a similar theorem to Proposition 4.

4.3.2   Airport operations costs

Total cost for airport operations has been defined as the sum of the individual airport costs. Now, in this case study, individual airport cost is dependent on passengers and aircraft movements. Specially, we assumed
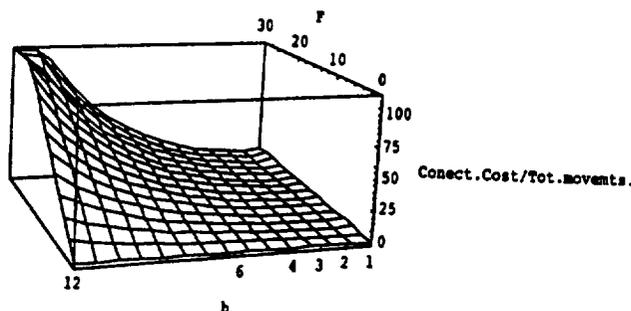
Figure 2: Cost per passenger at network level

that the marginal cost of an handling operation is approximately equal in hub and spoke airports. Thus, total airport costs are equal to

$$C_{at}(h, n) = n + \frac{(h-1)n^2}{h(n-1)} + 2(n-h) + \left(\frac{h(h-1)}{2} + (n-h)\right)2G. \quad (13)$$

This equation is approximately similar to the one previously defined for total connections costs. In fact the total number of handling operations at the network level is simply twice the number of routes. Of course, each aircraft has to be handle at origin and destination for a given connection. Thus the extension of routes increases proportionally the number of handling operations. The cost minimisation solution is also the "bang-bang" solution and depends on the level of fixed cost in aircraft handling operation. The following proposition can be issued.

Proposition 5 *Suppose $W(m)$ is proportional to passenger volume and a fixed cost, G, is incurred on handling operation. Then there exists a level of fixed costs, $\widehat{G}$ such that:*

1. *For $G > \widehat{G}$, the hub-and-spoke network is the optimal solution, and $h^{**} = 1$.*

2. *For $G < \widehat{G}$, the point-to-point network is the optimal configuration, and $h^{**} = n$.*

3. *No interior solution, with $h^{**} \in \,]1, n[$, is cost minimising.*

Proof. A similar proof to Proposition 4 can be developed ∎
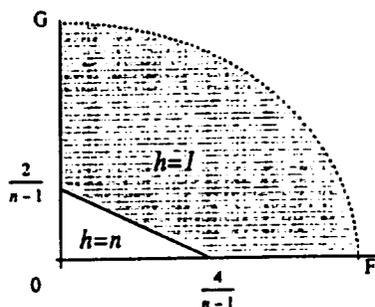
Figure 3: Optimal airport structure in function of F and G.

4.3.3   Optimal structure

The total network cost is the sum of equation (12a) and (13). Although the previous studies are insufficient to determine the optimal cost minimising solution for the general problem, this one depends on the value of the fixed costs F and G. The following table summaries our results under the assumptions of this third study.

		Aircraft handling fixed costs	
		$G < \widehat{G}$	$G > \widehat{G}$
Fixed costs	$F < \widehat{F}$	$h^* = h^{**} = n$	undertemined
on connections	$F > \widehat{F}$	undertemined	$h^* = h^{**} = 1$

The best structure policy can not be predicted when the solutions of airport and connection optimisation problems are divergent. Moreover, if an interior solution exists, it could not be found by first and second order conditions.

However, Figure (3) gives the optimal structure policy for different combinations of fixed costs for connections and handling operations. Indeed for any point (F, G), such that $(F, G) \in \{(x, y) \in \mathbb{R}_+^2 \cdot y = \frac{2}{n-1} - \frac{x}{2}\}$, total network cost is minimised at $h = n$ and $h = 1$. The monopolist is indifferent between the point-to-point and the linear network. For any increase (resp. decrease) in F, and/or G, such that (F, G) is above (resp. below) this line, the raise (resp. fall) in total network cost is more intensive for high value

of h, and more specifically for $h = n$. Therefore, the central hub (resp. the point-to-point) network is the best feasible structure.

Proposition 6 *Suppose $F, G > 0$ and $V(m), W(m)$ proportional to passenger volume. Then the following conditions are satisfied for the general minimisation problem (9).*

1. The central hub-and-spoke is optimal, $\forall (F, G) \in \left\{ (x, y) \in \mathbb{R}^2_+ : y \geq \frac{2}{n-1} - \frac{x}{2} \right\}$.

2. The point-to-point network is optimal, $\forall (F, G) \in \left\{ (x, y) \in \mathbb{R}^2_+ : y \leq \frac{2}{n-1} - \frac{x}{2} \right\}$

3. No interior solution could ever occurs.

Proof. See Appendix ∎

5 Extensions

In the the previous section, an interior solution for which $h \in]1, n[$ has been proven not to be the best optimal structure in any cases. Which assumptions on the model should be relaxed such that a multi-hub structure is chosen by the monopolist to satisfy her cost minimisation objective ? Of course, the answer depends the constant return to scale assumption on the variable costs.

If variable costs are such that $V(m, \alpha)$ and $W(m, \beta)$, where $\alpha \in [0, 1]$ and $\beta \in [1, \infty)$ are convexity parameters, an interior solution occurs. The domain of this parameters depends on the second order condition on variable costs. The different cost functions of our model are now written as follows.

Connection cost for a spoke route, denoted by C_{rj}, is given by:

$$C_{rj}(\alpha, F) = F + 2^\alpha, \forall r \in H \text{ and } \forall j \in B_r,$$

where F are the fixed costs supported on connections,
α is a concavity parameter such that $\alpha \in [0, 1]$.

A similar cost function for an inter-regional line is defined. Connection cost, for this class of routes, C_{rs} is:

$$C_{rs}(h, n, \alpha, F) = F + \left(\frac{2}{(n-1)} (\frac{n}{h})^2 \right)^\alpha, \forall r \in H, \text{and } \forall s \in H.$$

For values of α s.t. $1 > \alpha > 0$, variable cost of passenger traffic, $V(m)$, for a connection exhibits economies of scale. Therefore, economies of density on a route occurs not only from spreading fixed costs on a higher traffic flows, but also from decreasing variable costs of passenger. Indeed, the costs per passenger under a central hub architecture are even smaller than under a point-to-point system, because of the economies of density. Introducing economies of scale in variable costs reduces the incentive to operate linear network.

For a spoke airport, the cost of airport operation, C_{aj} :

$$C_{aj}(\beta, G) = G + 2^\beta, \forall j \notin H.$$

where β is a convexity parameter such that $\beta \in [1, \infty)$.
and G the fixed cost of an aircraft handling operation.

For a hub, the cost of aircraft movement and passenger flow is denoted by C_{ar} :

$$C_{ar}(h, n, \beta, G) = \left(h - 2 + \frac{n}{h}\right) G + \left(\frac{n}{h} + \frac{(h-1)}{(n-1)}(\frac{n}{h})^2\right)^\beta, \forall r \in H$$

For values of $\beta > 1$, diseconomies of scale occurs in production plan of airport operations. Therefore, cost per passenger is high for airport with important traffic volume. It may occurs that this cost per passenger is high enough and induce the monopolist to operate a multi-hub structure. However, the importance of fixed costs on handling operations deter the carrier to operate a point-to-point system.

An example for which $h \in]1, n[$ is given below. Given the total network cost minimisation problem in equation (9), we illustrate an example for which the size of the *network* is a set of 60 cities. The level of the *fixed costs* $F = 30, G = 35$, and the *convexity parameters*, α and β are respectively equal to .9 and 2 The minimum of this cost reached at $h = 6$.

6   Conclusions

In this paper a very simple model was investigated and tried to explain the optimal network structure of a monopolist. Her network is a combination of routes and airports. To benefit of economies of density on her routes and airports, the carrier funnels the traffic through a central hub. However, this

leads to important airport operations, subject to diseconomies of scale, and longer travel time for passengers. To avoid such externalities, the airline is willing to optimise her network structure. She can reach such an objective, by increasing the number of hubs, and implementing additional city-pair segments. Such a strategy leads to the loss of benefits arising from the economies of density on transportation costs. Various circumstances are examined, for which different assumptions on cost specification are carried out. *First*, if routes are the only significant determinants of total network costs, then the optimal network solution is either a central hub structure or a two-step hub network. The number of segments and airport operations for both architecture are equal. *Second*, if cost functions for direct connections or for airport operations are linear in traffic movements, the optimal structure is the point-to-point architecture, for which each airport is a hub platform. This follows from the fact that linear network generates the lowest traffic movements. *Third*, when cost functions are an aggregate of the first two benchmarks, and consequently economies of density emanate from spreading fixed costs over a larger number of travellers, then the cost minimising solution is either the central hub network or the point-to-point system. This characterises a "bang-bang" solution for which interior solutions, multi-hub structures, do not minimise the total network cost. *Fourth*, the last case study illustrates an example, for which the interior solution occurs in presence of different cost functions for hubs and spoke. This possibility is feasible when the variable costs on a route and those for airport operations respectively exhibit economies of scale and decreasing return to scale.

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DRAFT 28 June, 1998

Productivity, Prices and Profitability Trends in the World's Major Airlines 1986-1995.

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Abstract

This paper tracks indices of prices paid for airline inputs relative to the prices received for airline outputs (labelled "total price performance," TPP) in comparison with trends in total factor productivity TFP (ratio of output and input quantity indices). Comparing TFP and TPP reveals the sharing of productivity gains between a company and its customers, and hence the change in the firms' profitability. This is a variation of a model associated with the American Productivity Center (1981) used by a number of authors. This is an update of the paper presented at the ATRG conference a year ago.

Data are from Oum and Yu (1997). Data are for 22 of the world's major air carriers. The output quantity index incorporates five output categories: revenue passenger kilometres from scheduled services, freight tonne-kilometres, non-scheduled passenger and freight services, mail service, and incidental revenues. There are five input categories: labour, fuel, flight equipment, ground property and equipment, and "materials and other inputs." The input and output price indices are dual to the respective input and output quantity indices: total revenues from all services divided by the output index provides the output price index; total costs (including full costs of capital) divided by the input quantity index produces in input price index. The profitability measure is the ratio of total revenues to total economic costs. The multilateral indices enable direct absolute comparions among airlines of output and input levels, productivity, prices and price performance and profitability.

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1. INTRODUCTION

This study tracks the link between productivity gains and changes in economic profitability of the world's major airlines over the period 1986-1995. There is reason to expect some correlation between productivity and financial performance, but the relationship often seems inexact. Stated simply, productivity compares *quantities* of outputs relative to *quantities* of inputs. Financial performance depends on the *revenues* from outputs compared to the *expenditures* on inputs. A firm can be very efficient in terms of outputs per input, but it could be highly unprofitable if the revenues received are low compared to what it pays for inputs. Conversely, a firm with market power might be inefficient in input use but compensate financially by high prices. Nonetheless, it is possible to establish a direct link between total factor productivity (TFP) changes and financial performance. This is shown in part 2. The framework used here turns out to be a variation of the American Productivity Center (APC) (1981) model used to decompose changes in profitability to changes in productivity and output/input price changes. This paper links two separate streams of the productivity literature, that found in management journals and related applications, and that of the mainstream economics literature on productivity measurement and index numbers.

Part 3 summarizes the data on international airlines in Oum and Yu (1997). Part 4 compares output and input quantity indices and trends along with the input and output price indices and trends. Next, Part 5 monitors productivity (TFP) and input/output price ratios over time. This reveals how productivity gains are shared between the company and the customer, and thus how the firm's revenue/cost relationship is changed. The patterns are compared and contrasted for the 22 major airlines. Part 6 introduces a multi-quadrant diagram which portrays simultaneously the time path of outputs, inputs, productivity, output and input prices, revenues and costs. This enables a concise visual summary of the productivity and financial patterns of firms over time. The conclusion in part 7 summarizes the usefulness of making these price/productivity comparisons and what it reveals about the airline industry generally and differences among specific carriers.

2. PRODUCTIVITY, PRICES AND PROFITABILITY

Productivity compares outputs with inputs, more specifically, the change in outputs compared with

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the change in inputs. One can compare one or more output categories with one or more input categories. However, such partial measures of productivity, although popular, are often misleading because they do not allow for other changes in outputs and inputs. For this reason economists advocate comprehensive productivity measures, called multi-factor productivity (MNP) or total factor productivity (TFP). The index number approach to TFP measurement compares the growth rate of a quantity index of all outputs with the growth rate of an input quantity index.[1]

As noted in the introduction, productivity and financial performance do not measure the same thing. Nonetheless, there is a direct connection betweeen them. This is revealed by examining changes in prices received for outputs and prices paid for inputs along with the productivity changes. To illustrate the links, use some simple algebra for two time periods, 0 and 1. One can think of a single product firm employing only one input, or index numbers to represent multiple output and input prices and quantities. Note that for index numbers, the respective price and quantity indices must be dual to one another so that there is computational consistency.[2]

P_0 and P_1 are output prices (indexes);

Y_0 and Y_1 are output quantities (indexes);

W_0 and W_1 are input price indexes;

X_0 and X_1 are input quantity indexes;

hence

R revenue $= P \times Y$

C costs $= W \times X$

Costs include capital costs, i.e., these are total economic costs.

π_0 and π_1 are measure of economic profit; for analytical convenience defined as the ratio of revenues to costs rather than the difference.

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[1] An alternative approach to TFP measurement is to measure the shift in an econometric production or cost function. The interpretation of TFP is not identical in the two approaches (see Oum, Tretheway and Waters, 1992, for an explanation, or Diewert, 1992 for a more rigorous exposition). Because we wish to make comparisons of prices with quantity changes, it is appropriate to use the index number approach to TFP measurement.

[2] The price and quantity indices must satisfy the "product test," i.e., the ratio of price indices over two periods times the ratio of quantity indices should equal the ratio of corresponding expenditure indices.

$$\pi_0 = R_0 / C_0$$

Note that there is no requirement that economic profits be zero.

Total factor productivity (TFP) is measured by the growth of output relative to the growth in inputs:[3]

$$TFP = \frac{Y_1/Y_0}{X_1/X_0} \quad \text{or} \quad \frac{Y_1/X_1}{Y_0/X_0} \tag{1}$$

(The second expression is the ratio of a TFP index for each period).

It is desirable to link productivity measurement with financial performance. This is straight-forward, but note that because TFP data includes capital inputs and their service price in calculating productivity, it is economic and not accounting profits which are to be compared with TFP. As noted, for analytical convenience, we work with economic profit n as a ratio of revenues to costs rather than the difference.

Any change in profitability between the periods is indicated by the change in revenue/cost ratios:

$$\pi_1/\pi_0 = \frac{R_1/C_1}{R_0/C_0} \quad \text{or} \quad \frac{P_1Y_1 / W_1X_1}{P_0Y_0 / W_0X_0} \tag{2}$$

which is rewritten:

$$\pi_1/\pi_0 = \underbrace{\frac{Y_1}{Y_0} \times \frac{1}{X_1/X_0}}_{TFP} \times \underbrace{\frac{P_1}{P_0} \times \frac{1}{W_1/W_0}}_{1/TPP} \tag{3}$$

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[3] For simplicity, the index is written is simple ratio form. For calculations we use the Tornqvist or translog form of an index number, which would take the natural log of these expressions rather than leave them in arithmetic form. For example, the Tornqvist expression for equation (1) would be written: $(\sum_i 1/2(RS_{i1}+RS_{i0}) \ln (y_{i1} / y_{i0}) - (\sum_j 1/2(CS_{j1}+CS_{j0}) \ln (x_{j1} / x_{j0})$ where RS and CS refer to revenue and cost shares, respectively, for output category i and input category j in time periods 0 and 1.

3

Any change in the financial condition of the firm/industry (economic profit) reflects the change in productivity and any change in relative prices of inputs and outputs. The first two expressions on the right-hand side of (3) is TFP. The second half of the right-hand expressions is the growth in output prices relative to the growth in input prices. This is labelled 'price recovery' or 'price-cost recovery' in the management literature on profitability and productivity (American Productivity Center1981; Brayton 1985; Landel 1983; Miller 1984; Miller and Rao 1989; Aboganda 1994), or sometimes 'price performance' (Sink, Tuttle and DeVries, 1984). It can also be thought of as a 'terms of trade' (TOT) concept, i.e., the price (index) the firm gets relative to what it must pay for inputs. In the economics literature on productivity, it is the ratio of input to output price indices which is used as a performance measure. We label this 'total price performance' (TPP) (Tretheway, Waters and Fok 1994; Waters and Tretheway 1997), i.e., 'price-cost recovery' is the reciprocal of TPP.[4] By tracking TPP along with TFP, we can directly monitor any change in the firm's financial status along with its productivity changes.

Note that financial performance is monitored relative to the base period. If R_0/C_0 is not equal to unity, then the firm is not in long run competitive equilibrium. If $R < C$ and the firm is making a loss, it is necessary/desirable that the financial condition improve. It would be quite different if the firm started in a substantial monopoly position. Here public policy would be looking for a decline in the financial position. In brief, one must pay attention to the conditions in the base period R_0/C_0 in assessing the desired link between productivity and financial changes in the firm.

If competitive conditions do prevail, the firm is a price taker for both outputs and inputs and economic profits are zero hence R/C = 1 and TFP = TPP, i.e., all productivity gains (Y/X) are passed on in the form of lower prices for outputs relative to prices paid for inputs. In fact what we call TPP is occasionally used as a measure of TFP because they should be identical under competitive conditions.

One need not assume perfectly competitive conditions; the same relationship holds if there is no change in the market power position of the firm. If competitive conditions change, equation (3) is all the more interesting and useful because we can monitor changes from the initial market power position. For example, suppose a firm is gaining increased market power. It will not pass all productivity gains on to customers, and this will be shown by tracking TFP relative to TPP. If TFP is greater than TPP, the firm has retained part of the productivity gains as increased revenues rather than pass the full productivity gains through to its customers. *In particular, the ratio of TPP to TFP indicates the extent to which productivity gains are shared with customers.*

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[4]   The concept of using input and output prices to measure productivity rather than use input and output quantities has been recognised for some time in the productivity literature in economics but it is rarely calculated or examined, e.g., Jorgenson and Griliches 1967 (who cite Siegel 1952, 1961) and Diewert 1992. In contrast, the link between TFP and profitability has long been recognized in the management literature (cited above), where it is the ratio of output to input prices which are examined, the inverse of what economists would measure. Similar formula to equation (3) can be found in Kurosawa (1975), Garrigosa and Tatje (1992) and Han and Hughes (1997).

Before continuing, we comment further on the treatment of the links between productivity, prices and profitability in the literature. The management literature relevant to productivity measurement (American Productivity Center, 1981 and related references cited elsewhere) focus on determinants of firm profitability. They decompose a profit change into the two components of productivity and price-cost recovery.[5] We approach this issue from the economics literature on productivity. The economics literature emphasizes competitive markets, in which case economic profitability is expected to be zero, hence there is little interest in profitability decomposition. In the economics literature on productivity measurement, the index number approach emphasizes input and output quantity indices. But it has been noted (cites above) that the ratio of an input price index to an output price index is dual to productivity measured by output and input quantity indices for competitive industries. We note that this duality holds whether there is perfect competition or not, and any difference (TFP vs. TPP) indicates a change in economic profitability.[6] Thus we arrive at the same expression as the APC model although we emphasize the inverse of the price relationship, i.e., TPP is the inverse of the price-cost recovery measure which is used in the APC model. The TPP version facilitates a very simple graph to show the link between productivity, prices and profitability, shown later.

3.0 INTERNATIONAL AIRLINE DATA

The data for this study are described in Oum and Yu's (1995 and 1997) study of productivity comparisons among airlines. Only a brief summary is provided here.

The data are a careful and systematic compilation of data on major world airlines, limited to those for which all data categories could be obtained in like fashion. The time period covers 1986 through 1995; 22 airlines are included (one airline, Cathay Pacific, has data only from 1988).

Five categories of output are compiled: (1) revenue passenger kilometres (RPK) of scheduled air service; (2) revenue tonne kilometres (RTK) of scheduled freight service; (3) mail service (measured in RTK); (4) non-scheduled (charter) passenger and freight services, measured as RTK; and incidental services (measured in revenues and deflated by the GDP deflator for the home country; see Oum and Yu, 1992, pp.183-4 for details). The incidental services include a wide variety of services including catering, services supplied to other airlines, and consulting services. The airlines differ substantially in the importance of different output categories. The output index is constructed using revenue shares as weights. The Tornqvist or translog index formula is used.

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[5] Some versions of the APC model make further decompositions, e.g., Banker, Chang and Majumdar (1993, 1996) distinguish fixed and variable inputs and hence incorporate changes in utilisation of fixed factors; Han and Hughes (1997) distinguish productivity (output per input) changes from changes in the level of output.

[6] Han and Hughes (1997) also derive a similar expression starting from the economics literature on productivity.

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There are five categories of inputs: (1) labour measured as number of employees; (2) fuel measured in gallons; (3) flight equipment capital is measured by an index incorporating different aircraft types; (4) ground property and equipment capital constructed using the Christensen-Jorgenson (1969) perpetual inventory method (see Oum and Yu, 1995, p.184); and (5) "materials and other" which is a residual or "catch-all" category for all other expenditures by the airline companies. The materials and other category is estimated by subtracting labour, fuel and capital input costs from ICAO's reported total operating costs. Deflating the residual expenditures by an input price index produces and input quantity index for this category.

The output and input categories are combined into multilateral indexes following the procedures recommended by Caves, Christensen and Diewert (1982). Multilateral indices enable one to compare both absolute productivity differences across firms as well as growth rates over time. The quantity indices are normalized around a particular carrier and year, specifically Oum and Yu use American Airlines in 1990 as the base. That is, the output quantity index and input quantity index are both set at unity for American Airlines in 1990, and all output, input and TFP indices are expressed relative to this base. This is modified shortly.

Oum and Yu (1995, 1997) calculate the total economic cost for each airline, i.e., including a capital service price for capital inputs. Dividing the total economic costs by the input quantity index produces the dual input price index. Similarly, dividing total revenues for each airline by its output quantity index produces the dual output price index. Note that the output and input price indices for the base year and carrier will not equal unity unless revenues and total economic costs are equal in that year. This is the long run expectation in a perfectly competitive industry, but a revenue/cost (R/C) ratio of exactly unity will be rare. The first year (1986) ratio of input to output price indices (TPP) for any airline is determined by the R/C for that airline in that year and the TFP index (which is relative to the American Airlines' base). To illustrate further:

Y = output quantity index

X = input quantity index

R = total revenues

C = total economic costs

Then:

$$TFP = Y/X$$

$$TPP = (C/X) / (R/Y)$$

or $$TPP = [1 / R/C] \, TFP \qquad (4)$$

Given TFP, if $R > C$ in that year then $TPP < TFP$; if R/C were unity in 1986, TPP would equal TFP in that year. Expression (4) applies to subsequent years as well. Divergence between TFP and TPP from one year to another will determine the change in R/C. If $\Delta TFP > \Delta TPP$, then R/C improves because the

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firm has been able to retain part of the productivity gain ΔTFP. Conversely, if a firm faces rising input prices and is unable to offset this by productivity gains, then ΔTPP > ΔTFP and the firm deteriorates financially.

A further adjustment of the base firm and year is desirable. For the base of American Airlines in 1990, the R/C is 0.924 hence the ratio of input to output price indices (TPP) for that year and carrier is 1.082. Because all indices are measured relative to the base year and carrier, it would be more convenient to use a base where the revenue/economic-cost ratio was near unity. For that reason, in this paper the indices are rebased to American Airlines 1988. The R/C was 1.01 in that year, hence setting the output price index at unity is accompanied by an input price index of 0.993. All carriers' (and years') values for output and input quantities, output and input prices, and hence TFP and TPP are measured relative to American Airlines 1988.

Note the interpretation of this "total" price index. Just as the output quantity index reflects the combination of all outputs (weighted by their relative importance as indicated by revenue shares), the dual output price index represents the combined effect on the firm's output prices taking the multiple outputs into account. More typically, most discussion of airline price trends focus only on passenger yields. The total price index is a more comprehensive measure of price.

4.0 OUTPUT AND INPUT, QUANTITY AND PRICE INDICES

The results are presented in three sets of graphs; each set has 22 figures or graphs, presented in the following order:
    Qantas
    UK/Europe
        British Airways
        Air France
        Iberian
        KLM
        Lufthansa
        SAS
        Swiss Air
    North American carriers
        American
        Continental
        Delta
        Northwest
        United
        US Air

Air Canada
Canadian
Asian carriers   -
    All Nippon (ANA)
    Japan Airlines (JAL)
    Korean (KAL)
    Cathay Pacific
    Singapore (SIA)
    Thai Airlines

The input and output quantity indices are plotted for each airline, along with their respective input and output price indices in Set I, Figures 1-22. Note that these are multilateral indices, so one can compare levels of outputs, inputs and respective prices relative to one another, all based relative to American Airlines in 1988. Comparing output relative to input quantity indices indicate productivity, i.e., any growth in output relative to inputs indicates a productivity gain. Comparing input to output price indices compares movements in the "total" prices paid to inputs (i.e., weighted average of prices paid to all inputs) relative to "total" output price index. The link between these graphs and changes in profitability are shown in a subsequent set of graphs in the next section. For the moment, we contrast the levels and trends in these four indices for the 22 airlines.

The indices are based on American Airlines in 1988. Most airlines produce lower output levels (and consume fewer inputs) than American so this is why most airline output and input indices are less than unity. There are examples of higher priced airline services (e.g., Japanese carriers, ANA and JAL), who also face higher input prices than other world airlines. The low input price carriers are the other Asian carriers, notably Thai Airlines.[7] In general, for each airline the input and output quantity indices will be relatively close to one another, as will be the input and output price indices. But the levels and growth trends can differ considerably across airlines.

For many airlines, the respective input and output quantity indices track closely to one another, any divergence of output exceeding input growth indicates productivity gains. For most airlines, input and output prices tend to exhibit a less stable relationship than for the quantity indices. All carriers show input prices rising fairly steadily over the period, and many carriers show input prices rising faster than output prices. Only a few carriers (Thai, ANA, SAS) have been able to sustain output prices noticeably higher than the input prices paid (some other European airlines exhibited this pattern until recently).

The growth of output quantities relative to input quantities indicate productivity growth TFP; the relationship between input prices and output prices (TPP) indicate the sharing of productivity gains, or

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[7] Note that one must distinguish between "low cost" and "low input price" carriers; "low cost" is the product of input quantities and the input prices paid divided by output supplied.

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alternatively, the size of the productivity gains needed to prevent erosion of the revenue/cost ratio. This is described in the next section.

5.0 PRODUCTIVITY AND PRICE TRENDS: THE SHARING OF PRODUCTIVITY GAINS

Figures 1 through 22 of Set II plot the productivity measure TFP along with the ratio of input to output price indices TPP for each airline, for 1986 through 1995. The TFP figures are "raw" or "gross" productivity measures. They do not adjust for endogenous operating characteristics which make some airlines inherently more or less efficient. For example, a carrier serving high density long haul routes will appear highly productive in terms of outputs to inputs. Conversely, a carrier serving lower density shorter haul traffic will require more inputs per RPK. Oum and Yu (1995 and 1997) "decompose" the TFP values to distinguish productivity differences which may be attributed to managerial efficiency rather than to endogenous influences on productive efficiency. For this present study, the source of productivity differences is not important; our interest is in the relationship between productivity and price changes, and for this sources of productivity do not matter. The graphs reveal the productivity changes (TFP) and how prices paid for inputs compare with the prices received for outputs, i.e., the extent to which productivity gains are passed through to customers (TPP). TFP and TPP together will show the revenue to economic cost ratio and how it changes over time. For this reason, revenue/economic cost (R/C) is not plotted in most figures. It is included for one airline (Qantas) in Figure 1 as an illustration.[8]

Figure 1 of Set II for Qantas is described in some detail; the reader can interpret the remaining figures. In Figure 1, the initial (1986) TFP index value is 0.85, indicating a productivity level 85 percent of the productivity level of American Airlines in 1988 (the base of the multilateral index series). The revenue/cost ratio was calculated to be .90. As a result, TPP for that first year is .94 indicating that the prices paid for inputs (on average) are a few percent below the prices received for outputs (remember that these price indexes are dual to the output and input quantity indexes). These three points for 1986 can be seen in Figure 1 of Set II.

In 1987, Qantas shows a modest productivity gain (greater output relative to input quantities), and a decline in the prices paid for inputs relative to prices received for the outputs. The result is a sharp improvement in the ratio of revenues to total economic costs (1.10). The next two years show modest productivity gains and slightly faster growth in the input/output price ratio; the result is the revenue/cost ratio remains greater than one but declining.

1990 shows a decline in productivity and a sharp rise in prices paid to inputs relative to prices

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[8] Oum and Yu (1998) also present a graphical comparison of airline profitability, productivity and prices, but they look only at the trend from 1986 for each airline, i.e., they do not retain the multilateral properties and the data and thus cannot make absolute comparisons among airlines as is done here.

received for outputs. This results in a sharp fall in the revenue/cost ratio (to 0.78). The next three years show increased productivity, which exceeds the input/output price ratio, hence revenue/costs recover. Productivity dips in 1994 but so did the input/output price ratio hence revenue/costs changed little. 1995 saw a rise in productivity with almost constant prices paid for inputs relative to outputs, hence revenue/costs rise (1.10).

TFP and TPP are plotted for British Airways (BA) and European air carriers in Figures 2 through 8 of Set II. For most of these carriers, TFP and TPP track fairly closely, indicating that productivity gains are reflected in output price reductions relative to the prices paid for inputs. For BA, TFP and TPP track particularly close together which is indicative of a fairly competitive market structure overall facing BA. Looking over the whole period, BA's TFP index starts off low relative to the American Airlines' (AA) base (0.61) but rises noticeably to 0.84. TPP tracks TFP closely indicating that these productivity gains have largely been passed through to customers by output prices not rising with input prices, except for 1995 where a portion (about half) are not passed through but retained as revenues in that year.

TFP and TPP track closely for Lufthansa and SAS. KLM and Swissair show TFP growing faster than TPP after 1991 indicating that some of the productivity gains have been retained by these firms. Iberian airlines has seen little productivity growth but there has been pressure on its input/output price ratio hence its economic condition deteriorated.

Figures 9 through 14 of Set II show the major American carriers and Figures 15 and 16 show Air Canada and Canadian Airlines, respectively. The data for most of the carriers suggest a highly competitive industry: TFP and TPP track closely together, and for some of the carriers TPP is greater than TFP indicating weakening financial condition because pressures on prices are not being offset by sufficient productivity gains. American Airlines is the base or reference carrier for the productivity index, hence TFP equals unity for 1988. Its TPP equals 0.99 in that year because the revenue/cost ratio equals 1.01 in 1988. For 1990 through 1992 TPP exceeds TFP indicating deteriorating financial condition, with slight revenue/cost recovery after that.

Despite starting out as a relatively high productivity carrier, Continental's TFP declined until 1990 before rebounding part way. But its TPP is consistently higher indicating that the carrier has been unable to obtain prices for its outputs which kept pace with the prices paid for inputs. Hence its financial condition has steadily worsened until 1995. It is less extreme, but since 1988 US Air also has seen productivity growth not sufficient to offset the rising prices of inputs relative to the prices received for outputs.

Both of the Canadian carriers show signs of financial deterioration over the full period as productivity growth has been modest but there has been sharp pressure on prices, i.e., output prices not keeping pace with rising input prices and productivity gains were not sufficient to offset this. Canadian airlines' productivity improves noticeably after 1992 but again the productivity gains appear to have been

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largely passed through as price reductions (or limited price increases) to customers.

For the most part, the Asian carriers (Figures 17 through 22 of Set II) show a different pattern. The absolute productivity level varies considerably across the carriers, and only two carriers (Korean and Thai) show noticeable improvement in productivity. But several of them show high financial performance, i.e., an ability to obtain prices for outputs which are not offset by rising prices of inputs. The gap between TPP and TFP declines over time for ANA and JAL (Figures 17 and 18, respectively) suggesting rising competition over the period. Korean Air (Figure 19) shows noticeable productivity improvements with most of the productivity gains (but not all) passed through to customers. Cathay, Singapore and Thai (Figures 20, 21 and 22, respectively) have been able to sustain TFP greater than TPP throughout the period, i.e., they have maintained strong financial performance regardless of their productivity performance. For Thai however, it has shown substantial productivity growth (but from a low base) and a substantial portion of these gains (about two-thirds) has been passed through as lower prices for outputs relative to prices paid for inputs.

6.0 LINKING QUANTITIES, PRICES, REVENUES AND COSTS

Set III, Figures 1-22 present a more comprehensive portrait of the time path of the variables over time. Four quadrant graphs portray productivity (output and input quantity indices) in quadrant 1; total revenue index (output price and output quantity indices) in quadrant 2; total cost index (input price and input quantity indices) in quadrant 4; and the comparison of input and output price indices in quadrant 3. The data show the time path of the combinations of variables and thus allow a visual decomposition of the relative importance of changes in each pair of variables.

The first year's observation (1986) is shown as a ray from the origin to each quadrant. Looking at Qantas (Figure 1 in Set III) in quadrant 1, subsequent years show growth of both outputs and inputs, but the former growing faster than the latter in most years, thus showing an overall increase in productivity (a line drawn from the origin to the final year's observation would rotate upward relative to the first year, i.e., a higher ratio of output to input or increased productivity).

Quadrant 2 tracks a total revenue index (the product of the price and quantity indices for output). The first year (1986) is indicated by the ray from the origin, showing the output price index of 0.81 (the minus sign is simply to make the graphing program work) and the output quantity index of 0.22. While output increases (only one year did it dip), output prices varied, rising and falling but finishing with increases. Comparing the finishing point with the first year (the ray from the origin), it shows that the increase in total revenue was more due to output expansion than increases in prices received.

Quadrant 4 tracks the total cost index (the product of the input price and quantity indices). From the 1986 combination, input prices rose while input quantities did not change much until the last two years,

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the latter corresponding to the jump in output levels shown in quadrant 1 (and 2). A line from the origin to the final year observation (not drawn) would show that the rise in total costs was explained slightly more by increases in inputs used that by increased prices (which is an unusual result; most airlines show the increases in input prices was more important than increases in input quantities in explaining the increases in total costs).

Quadrant 3 plots the combinations of output and input price indices. From the first year, at first output prices rose faster than input prices, but then output prices tended to fall while input prices continued to increase, until the last three years when output prices were rising along with input prices. Comparing the final year point with the first year, it shows that input prices rose slightly more than output prices. This tends to reduce the R/C or profitability ratio, although it depends on the size of productivity gains. Since the scales are numerically the same in these figures, drawing a line from the final year productivity figure in quadrant 1 through the origin into quadrant3 will reveal the net change in overall profitability. Such a line would pass just below the final figure for the input-output price combination in quadrant 3, indicating that productivity gains outstripped the rise in input prices relative to output prices hence the firms financial condition improved.

Space does not permit analysing each of the 22 figures in Set III, but the reader can observe the time pattern of outputs and inputs hence productivity, along with revenue and cost trends and the overall profitability result indicated by comparison of productivity (upward rotation of the rays from the origin in quadrant 1) with the downward rotation of the ray from the origin to the input-output price indices in quadrant 3. For the firm to improve its economic profitability, productivity must outstrip the rise in input prices relative to output prices. For almost all airlines, the financial results deteriorate over the period although an improvement in 1994-1995 helped many of them.

7. CONCLUSIONS

This paper compares productivity trends of 22 major world airlines (1986-1995) with changes in input prices paid relative to output prices charged. These reveal whether productivity gains been passed on to customers or retained by the respective airlines thereby improving their financial condition. The analysis is done by constructing the dual input and output price indices which correspond to the input and output quantity indices used to calculate total factor productivity (TFP). This price ratio is labelled "total price performance" (TPP) reflecting the fact that these price indices take all output and input categories into account as do the TFP quantity indices. The framework is a variation of the price and productivity model first outlined by the American Productivity Center (1981). In competitive industries, one expects the growth of input prices relative to output prices to equal productivity gains, i.e., productivity enables the firm to raise output prices by less than the rise in input prices, and competition will force the full productivity gains to be passed on to customers.

The data show both similarities and differences across the carriers. Absolute productivity levels as well as rates of growth differ substantially. Nearly all carriers show at least some productivity gains and, in most cases, most of the productivity gains were passed on to customers as indicated by TPP tracking close to TFP. For several carriers TPP exceeds TFP, i.e., input prices have risen faster than output prices and productivity was not sufficient to offset this, hence these airlines' financial condition has deteriorated. For the most part, the Asian carriers have been able to retain some of the productivity gains as improved financial performance, whereas North American and European carriers have been less successful. That is to say, the data suggest greater competitive forces at work in these other markets. This is particularly so for North America where over the sample period every carrier shows input prices paid exceeding the output prices obtained and these price differences are not offset by sufficient productivity gains. This pattern is changed only for two carriers and for the most recent years. That is, the financial condition of North American carriers has deteriorated despite what productivity gains they have been able to achieve. The European story is in between: TFP and TPP track fairly close together but some carriers have been able to retain at least some of the productivity gains to improve their financial condition, notably KLM and Swissair.

It should be noted that the data to make this comparison of prices and productivity sharing are implicit in the data already compiled to make productivity comparisons. But most researchers have not been making use of the duality relationship between productivity and price changes. Apart from the specific results for airlines, this paper shows how existing data for total factor productivity measurement can be used to also reveal productivity sharing and the changes in overall financial performance. In addition, four quadrant graphs are used to portray the links between output and input quantity indices, indices of total revenues and costs, and input and output price indices. These make it possible to have a single graphical portrait of the trends and changes in these variables over time.

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Set I

Figure 2: British Airways
Output & Input Quantity & Price Indices
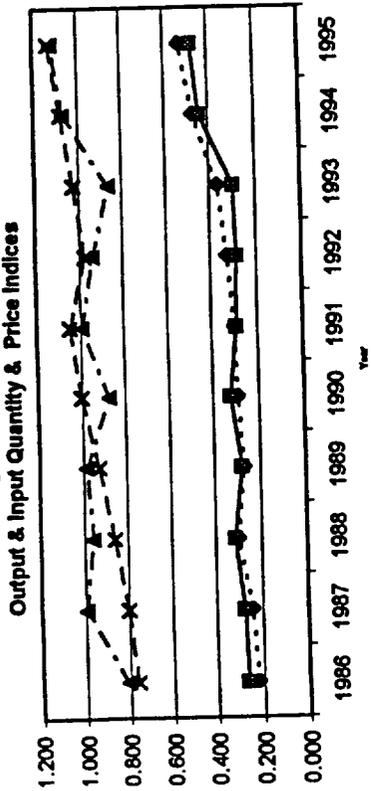
Legend:
- ▲ Output P Index
- ✶ Input P Index
- ◆ Output Q Index
- ■ Input Q Index

Figure 4: Iberia
Output & Input Quantity & Price Indices

Figure 5: Lufthansa
Output & Input Quantity & Price Indices

Figure 1: Qantas
Output & Input Quantity & Price Indices

Figure 3: Air France
Output & Input Quantity & Price Indices
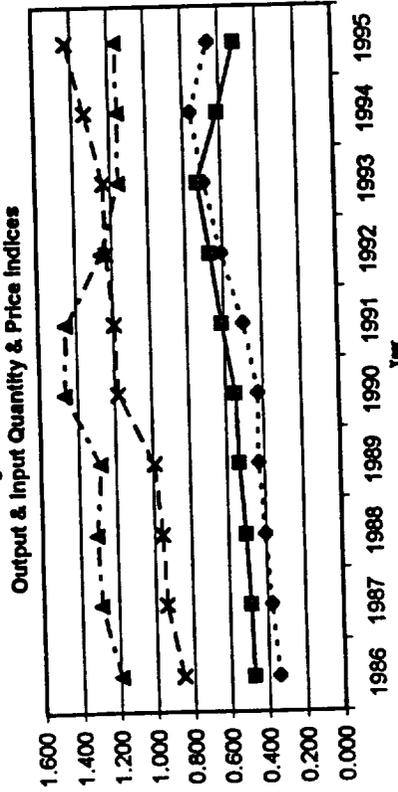
Figure 6: KLM
Output & Input Quantity & Price Indices
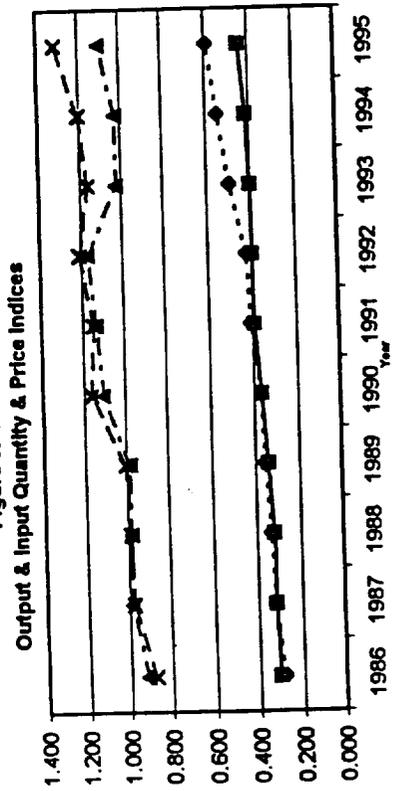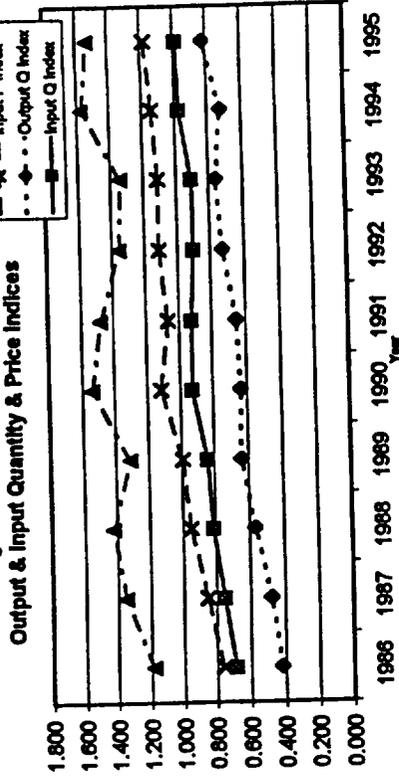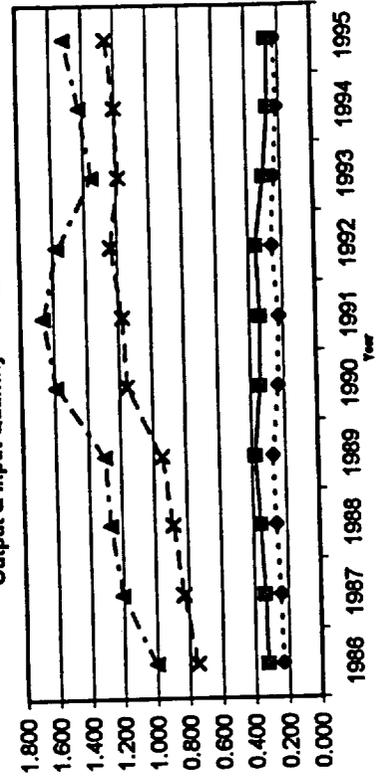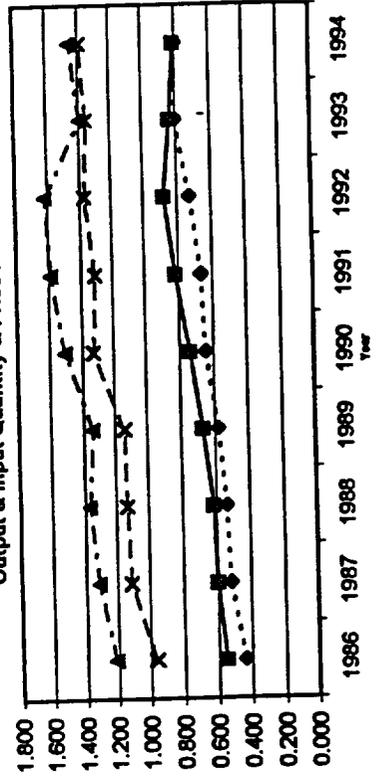
Set I cont.

Figure 7: SAS
Output & Input Quantity & Price Indices
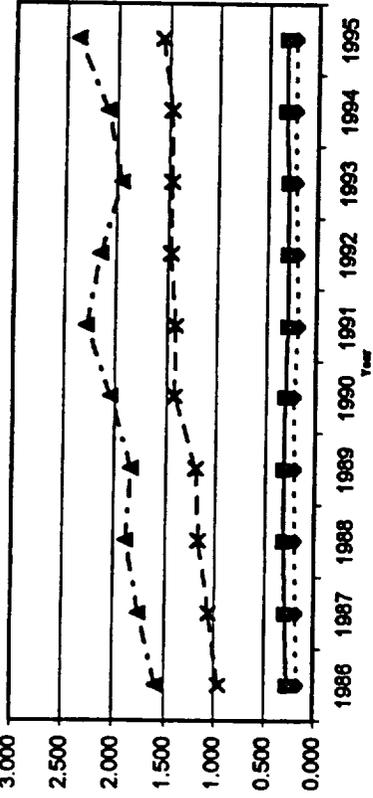
Figure 8: Swiss Air
Output & Input Quantity & Price Indices
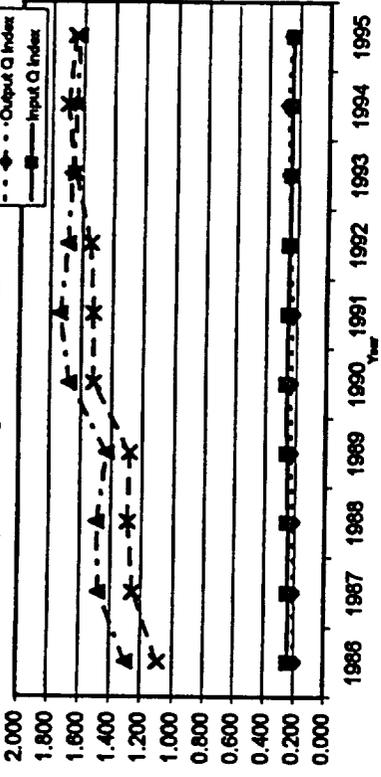
Figure 9: American Airlines
Output & Input Quantity & Price Indices
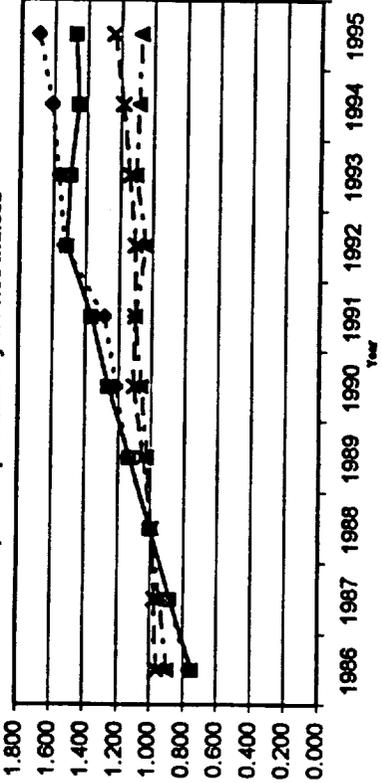
Figure 10: Continental Airlines
Output & Input Quantity & Price Indices
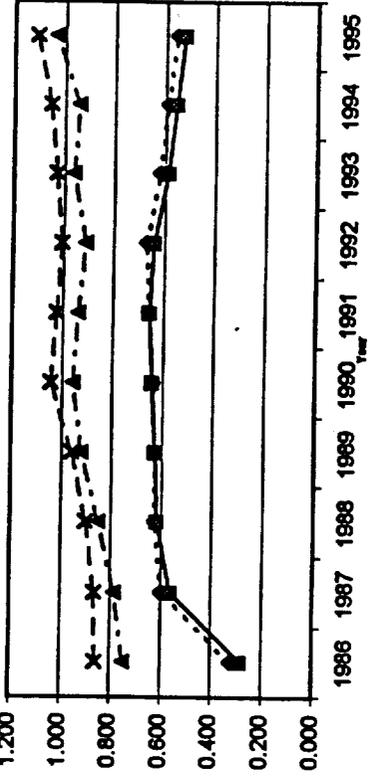
Figure 11: Delta Airlines
Output & Input Quantity & Price Indices
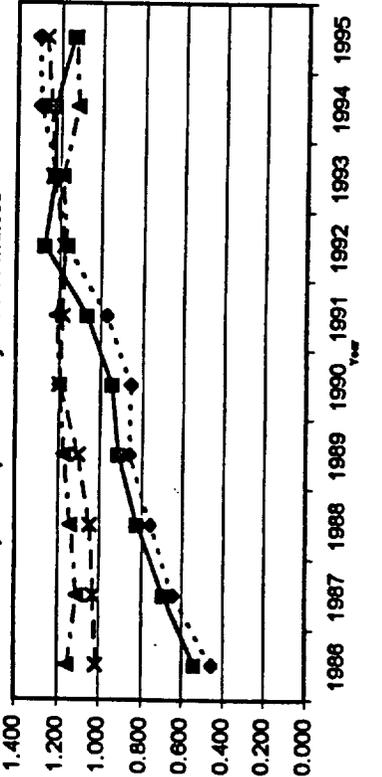
Figure 12: Northwest Airlines
Output & Input Quantity & Price Indices
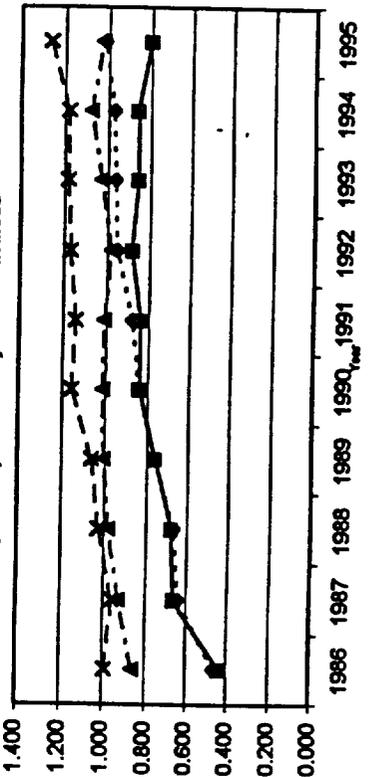
Set I cont.

Figure 13: United Airlines
Output & Input Quantity & Price Indices

Figure 14: US Air
Output & Input Quantity & Price Indices
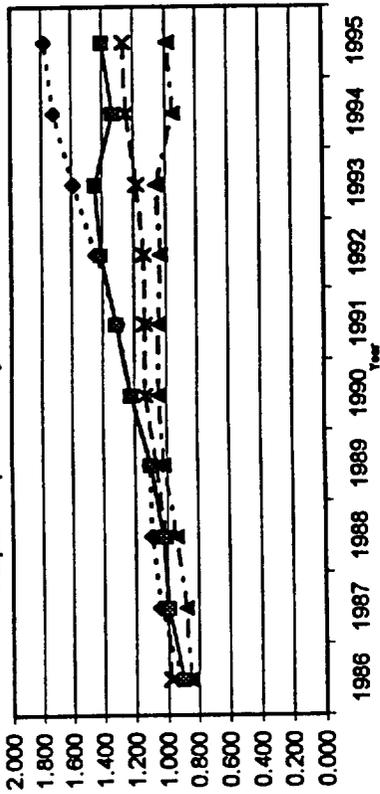
Figure 15: Air Canada
Output & Input Quantity & Price Indices

Figure 16: Canadian Airlines
Output & Input Quantity & Price Indices
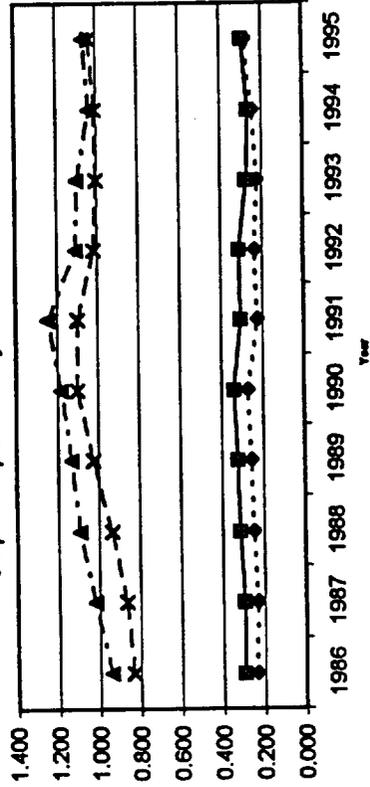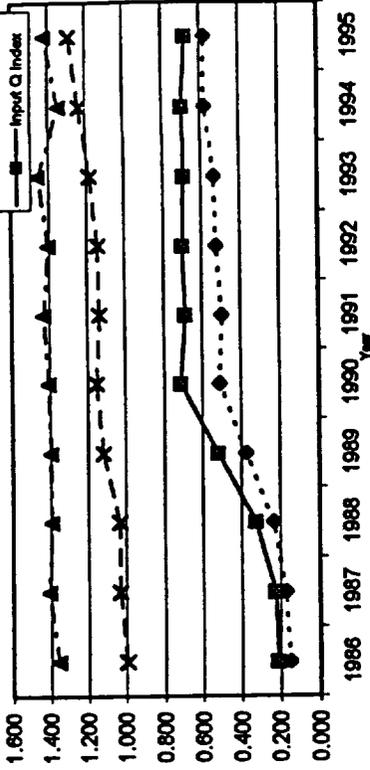
Figure 17: ANA
Output & Input Quantity & Price Indices
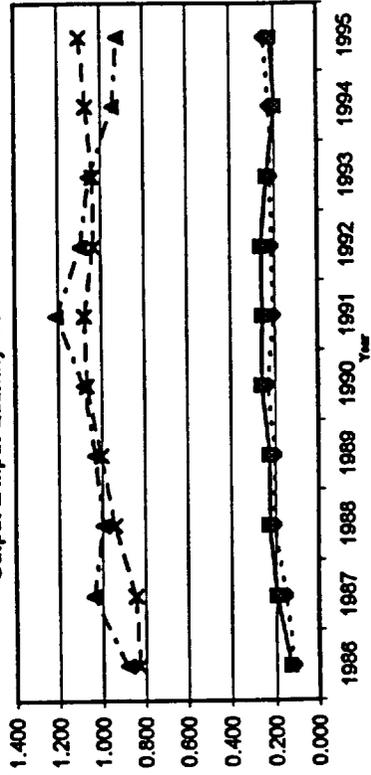
Figure 18: JAL
Output & Input Quantity & Price Indices
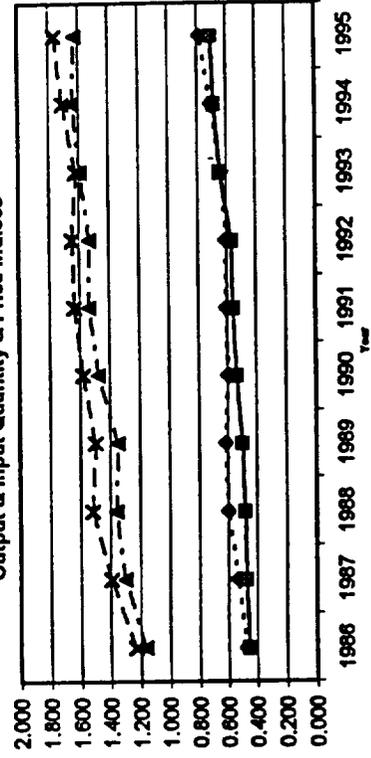
Set I cont.

Figure 19: KAL
Output & Input Quantity & Price Indices
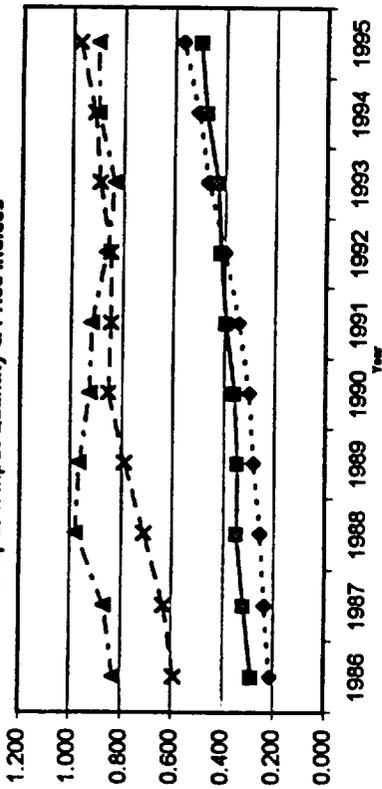
Figure 20: Cathay Pacific
Output & Input Quantity & Price Indices
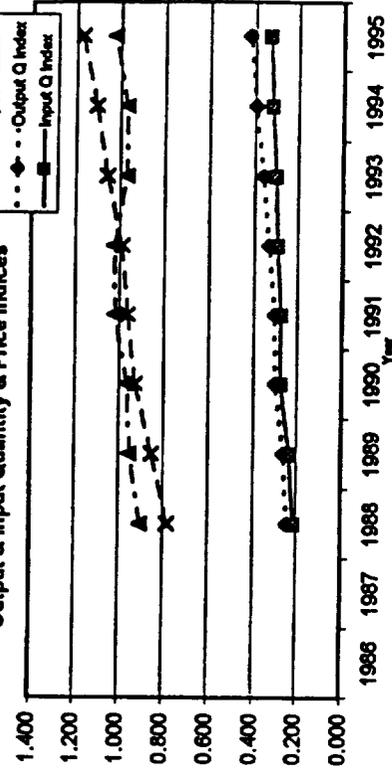
Figure 21: SIA
Output & Input Quantity & Price Indices
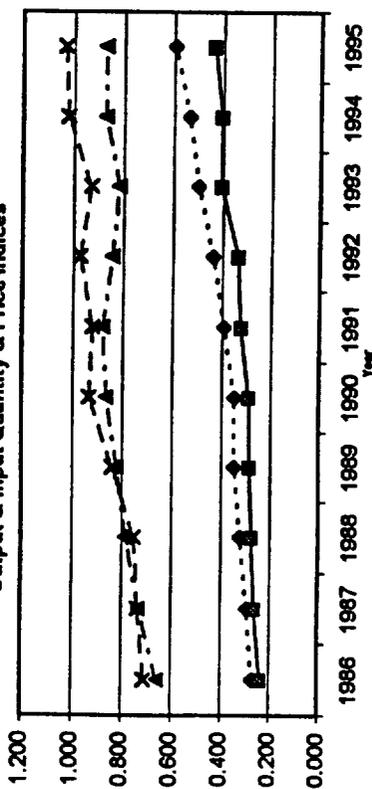
Figure 22: Thai Airlines
Output & Input Quantity & Price Indices

Set II

Figure 1: Qantas (TFP, TPP Indices)

Figure 2: British Airways (TFP & TPP Indices)

Figure 3: Air France (TFP & TPP)

Figure 4: Iberia (TFP & TPP)

Figure 5: KLM (TFP & TPP Indices)

Figure 6: Lufthansa (TFP & TPP Indices)
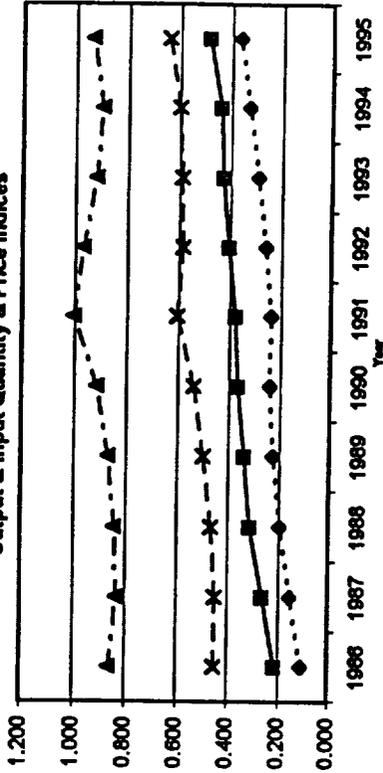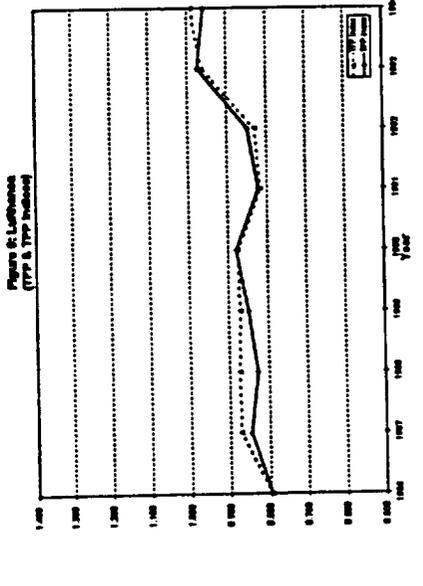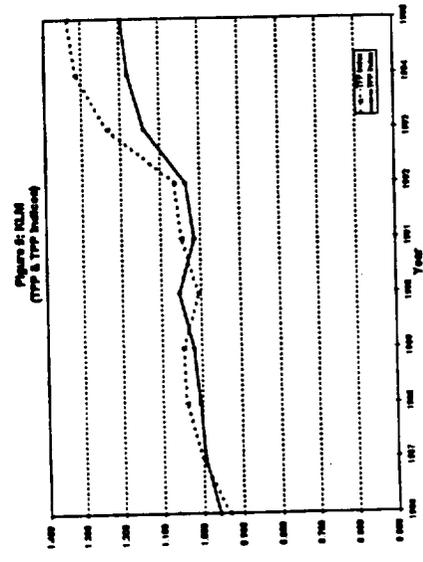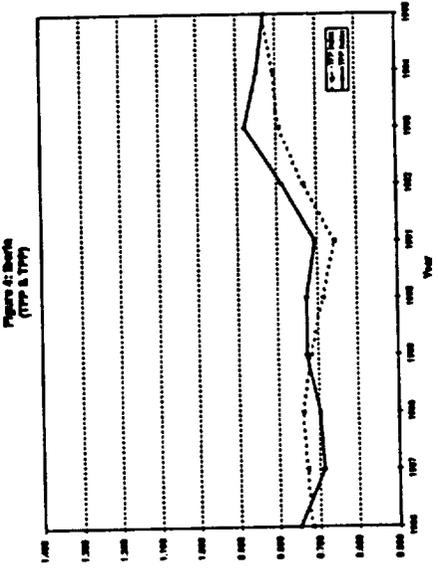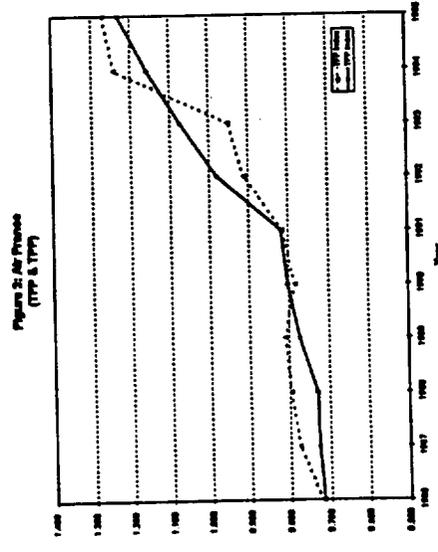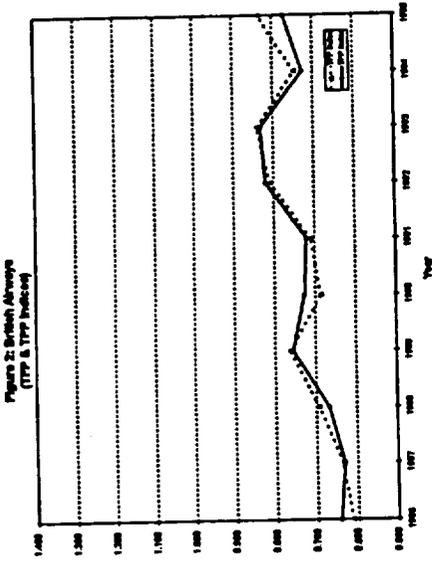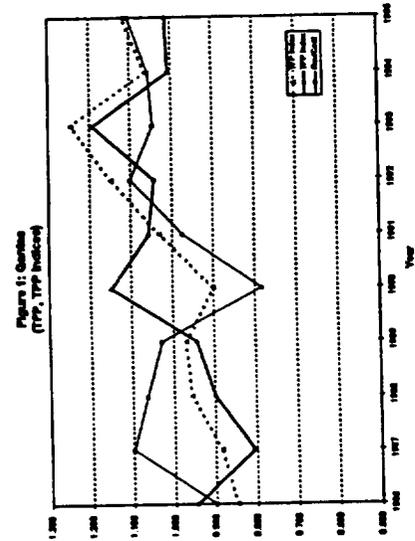
- - TFP Index
——— TPP Index
——— Rev/Cost

- - TFP Index
——— TPP Index

Set II cont.

Figure 12: United Airline
(TFP & TPP Indices)

Figure 14: UNI Air
(TFP & TPP Indices)

Figure 15: Air Canada
(TFP & TPP Indices)

Figure 15: Canadian Airline
(TFP & TPP Indices)

Figure 17: ANA
(TFP & TPP Indices)

Figure 16: JAL
(TFP & TPP Indices)

- ▲ - TFP Index

——— TPP Index

Set II cont.

Figure 5: Delta Air
(TFP & TPP Indices)
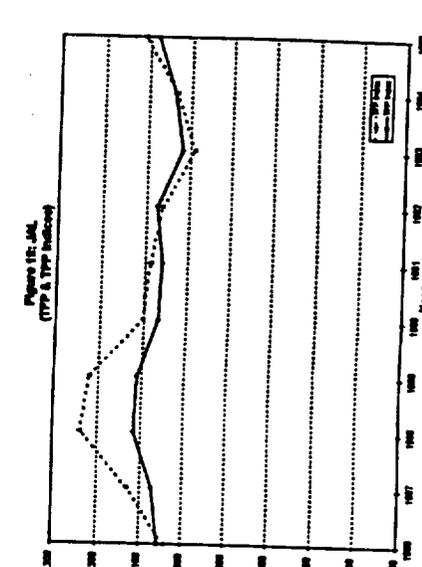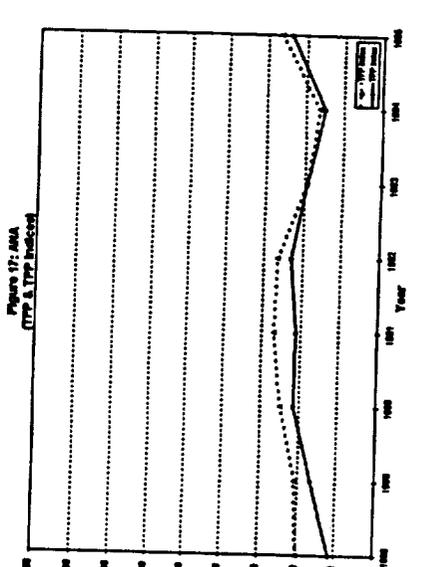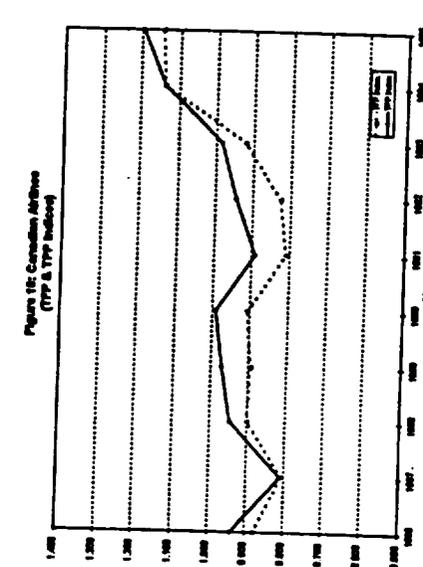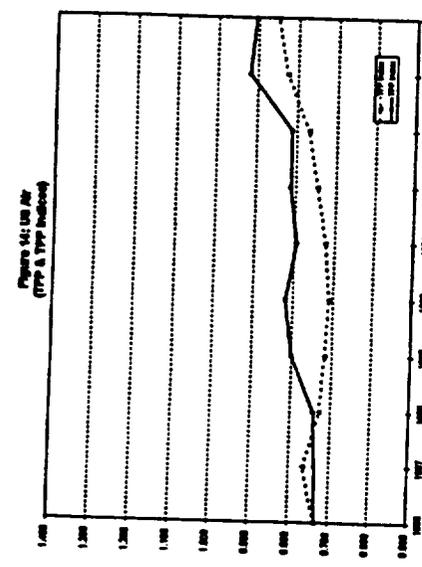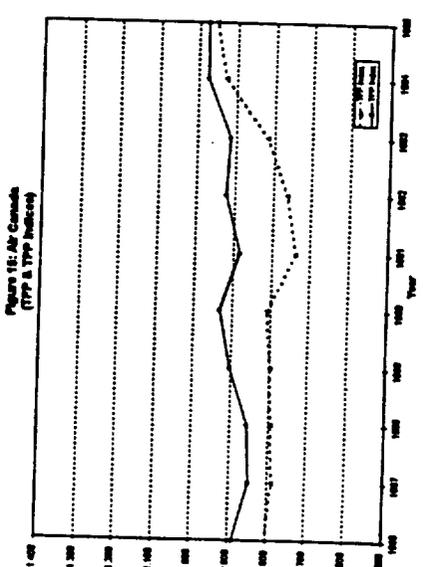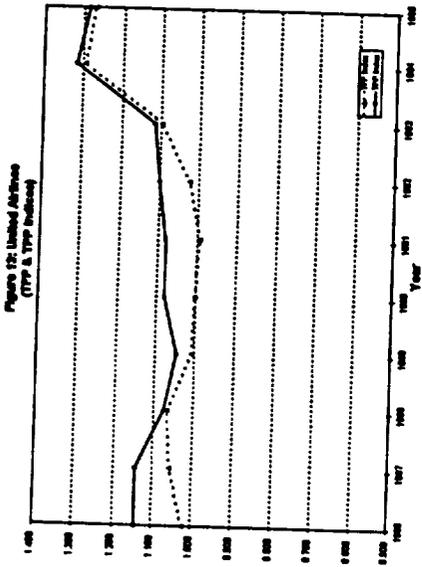
Figure 7: SAS
(TFP & TPP Indices)
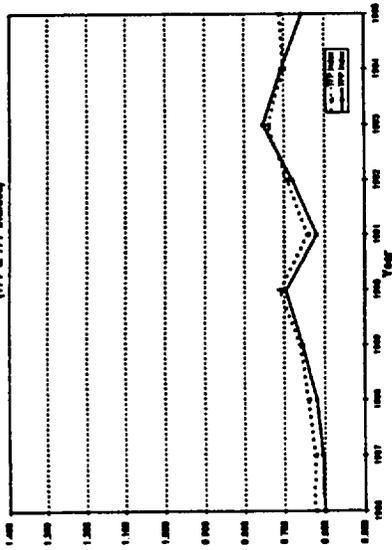
Figure 10: Continental Airlines
(TFP & TPP Indices)
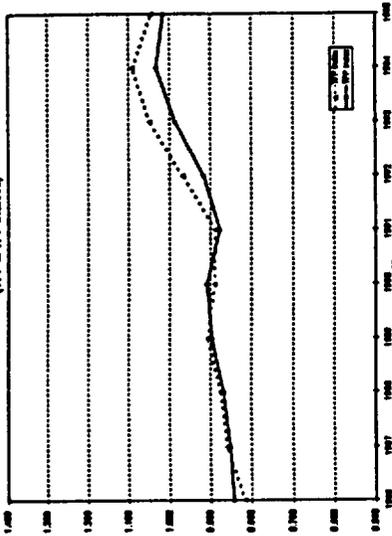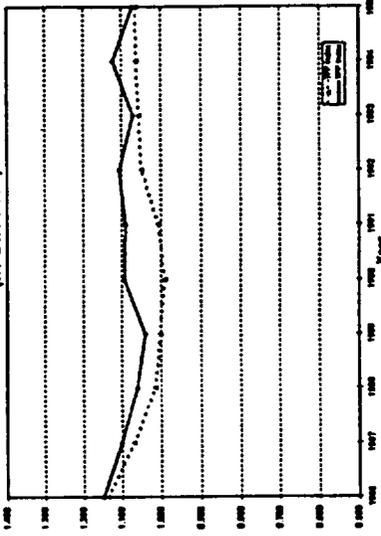
Figure 9: American Airlines
(TFP & TPP Indices)

Figure 12: Northwest Airlines
(TFP & TPP Indices)

Figure 11: Delta Airline
(TFP & TPP Indices)

TFP Index

TPP Index

Set II cont.

Figure 19: HAL
(TFP & TPP Indices)

Figure 20: Cathay Pacific
(TFP & TPP Indices)

Figure 21: SIA
(TFP & TPP Indices)

Figure 22: Thai Airlines
(TFP & TPP Indices)
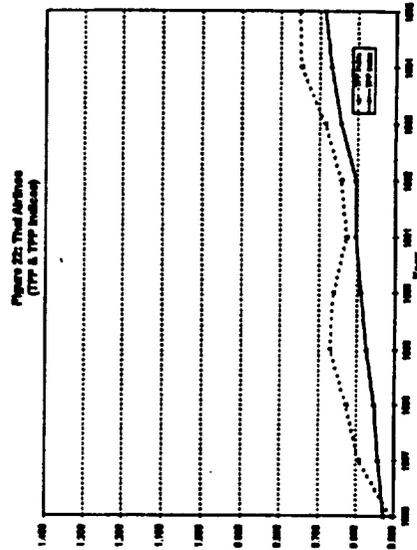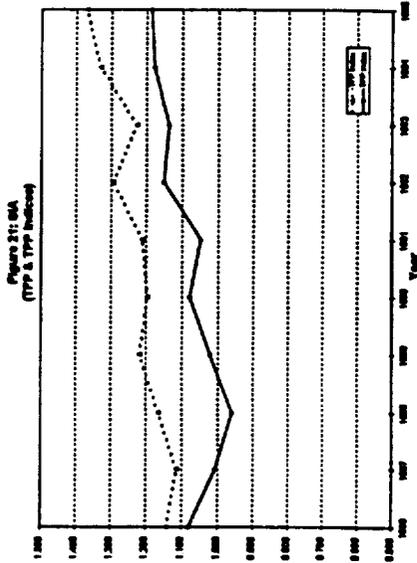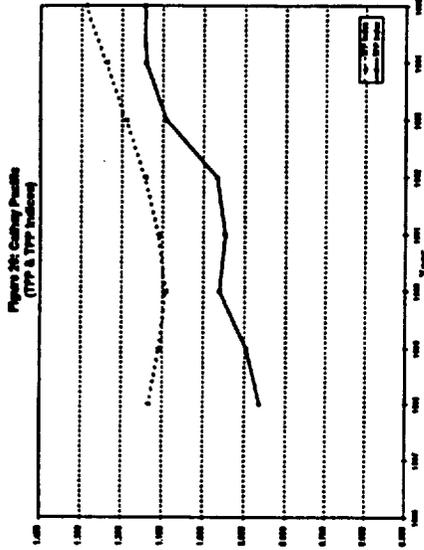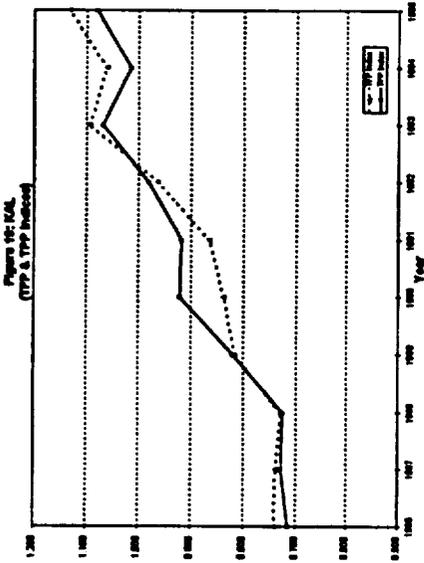
- ▲ - TFP Index

—•— TPP Index

Set III

Figure 2: British Airways
Productivity, Revenue, Cost & Price Trends 1986-1995

Figure 4: Iberia
Productivity, Revenue, Cost & Price Trends 1986-1995

Figure 1: Qantas
Productivity, Revenue, Cost & Price Trends 1986-1995
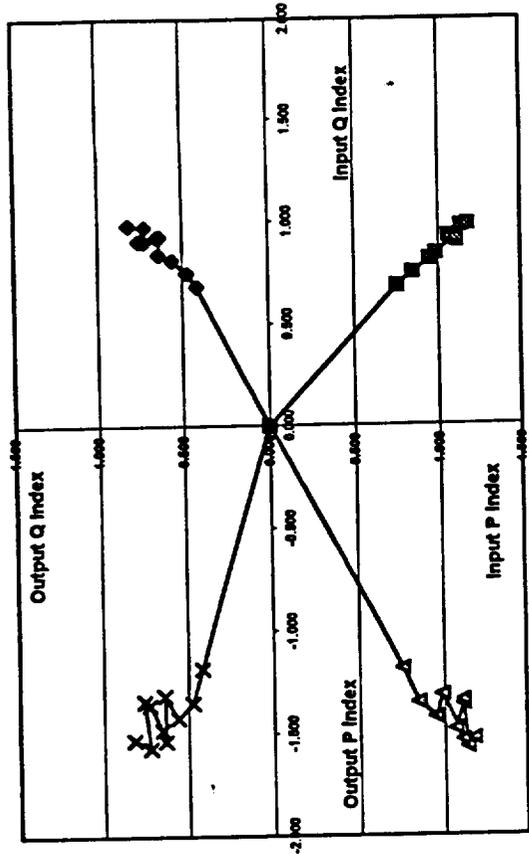
Figure 3: Air France
Productivity, Revenue, Cost & Price Trends 1986-1995
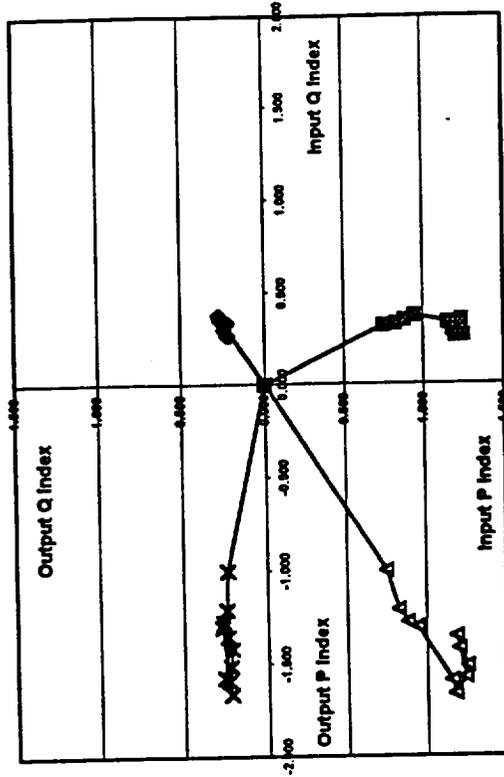
Set III cont.

Figure 6: Lufthansa
Productivity, Revenue, Cost & Price Trends 1986-1995

Figure 6: KLM
Productivity, Revenue, Cost & Price Trends 1986-1995

Figure 8: Swiss Air
Productivity, Revenue, Cost & Price Trends 1986-1995
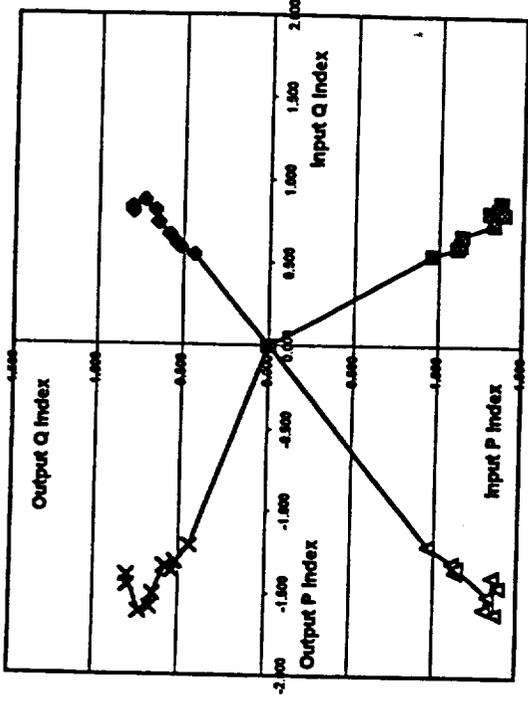
Figure 7: SAS
Productivity, Revenue, Cost & Price Trends 1986-1995
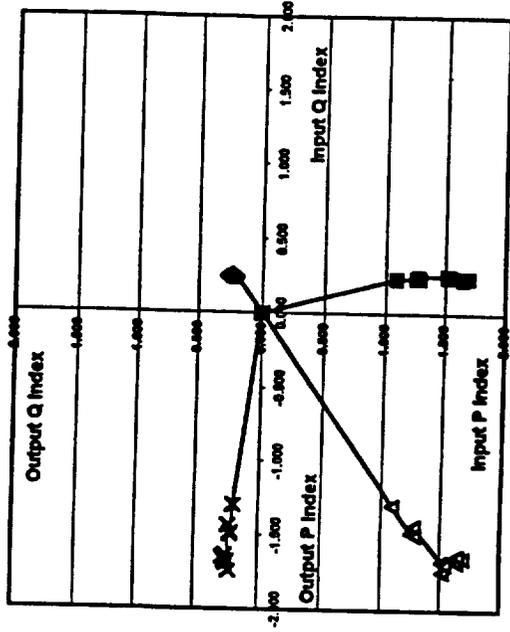
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Figure 9: American Airlines
Productivity, Revenue, Cost & Price Trends 1986-1995

Output Q Index

Input Q Index

Output P Index

Input P Index
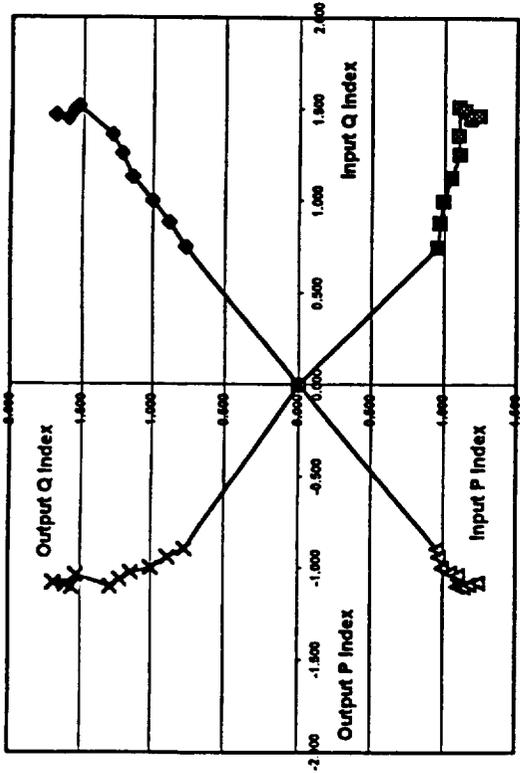
Figure 10: Continental Airlines
Productivity, Revenue, Cost & Price Trends 1986-1995

Output Q Index

Input Q Index

Output P Index

Input P Index
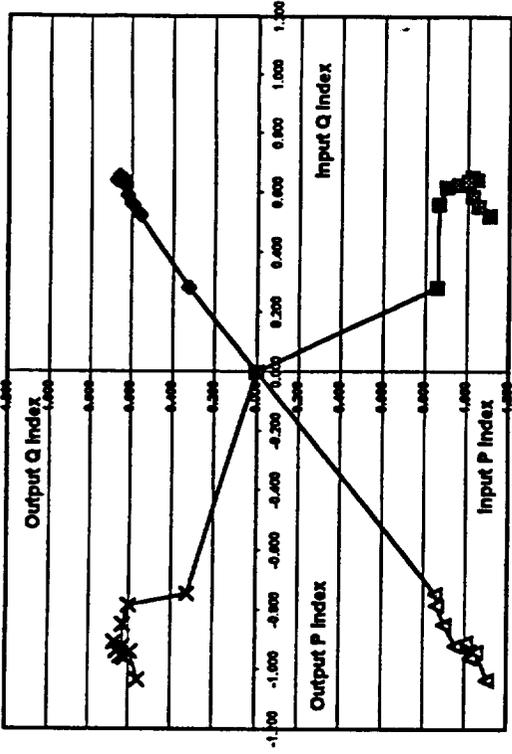
Figure 11: Delta Airlines
Productivity, Revenue, Cost & Price Trends 1986-1995

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Output P Index

Input P Index
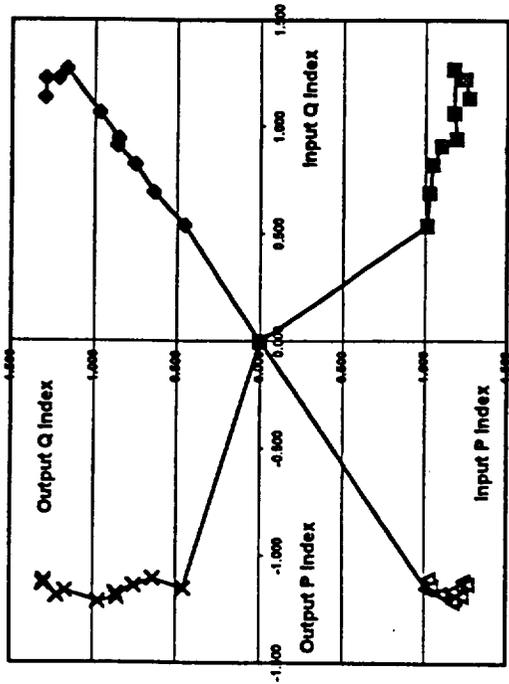
Figure 12: Northwest Airlines
Productivity, Revenue, Cost & Price Trends 1986-1995

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Output P Index

Input P Index
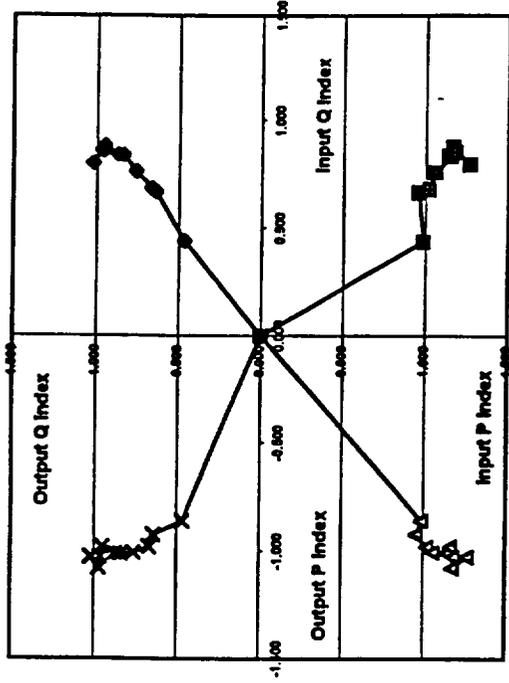
Set III cont.

Figure 13: United Airlines
Productivity, Revenue, Cost & Price Trends 1986-1995
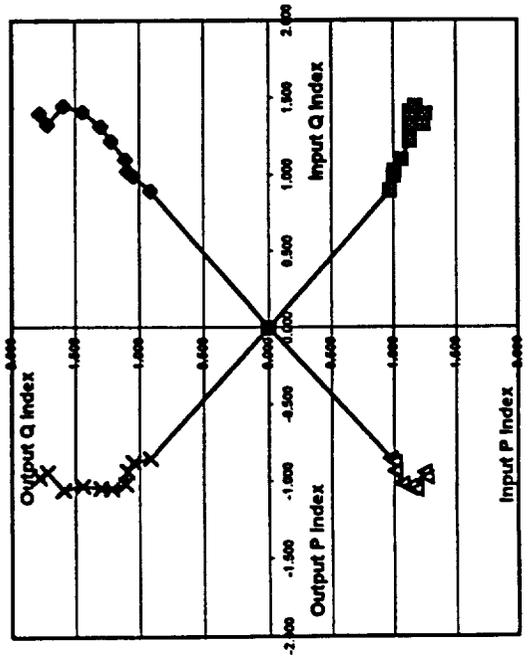
Figure 14: US Air
Productivity, Revenue, Cost & Price Trends 1986-1995
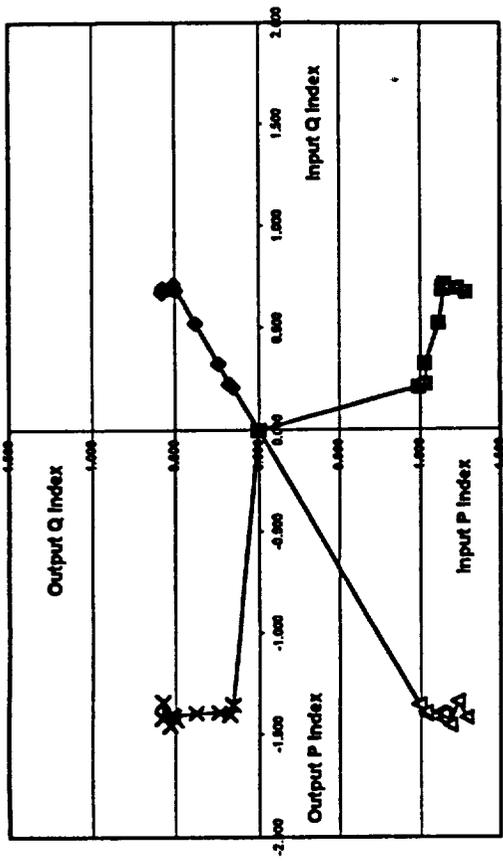
Figure 15: Air Canada
Productivity, Revenue, Cost & Price Trends 1986-1995
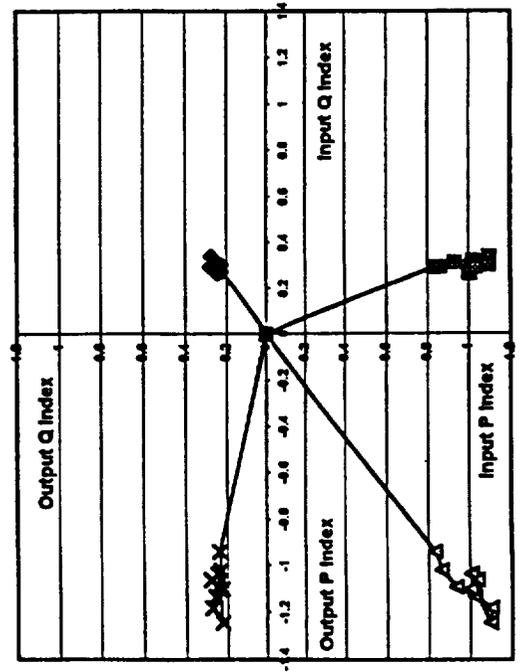
Figure 16: Canadian Airlines
Productivity, Revenue, Cost & Price Trends 1986-1995

Set III cont.

Figure 18: JAL
Productivity, Revenue, Cost & Price Trends 1988-1995

Output Q Index

Input Q Index

Output P Index

Input P Index

Figure 20: Cathay Pacific
Productivity, Revenue, Cost & Price 1988-1995

Output Q Index

Input Q Index

Output P Index

Input P Index
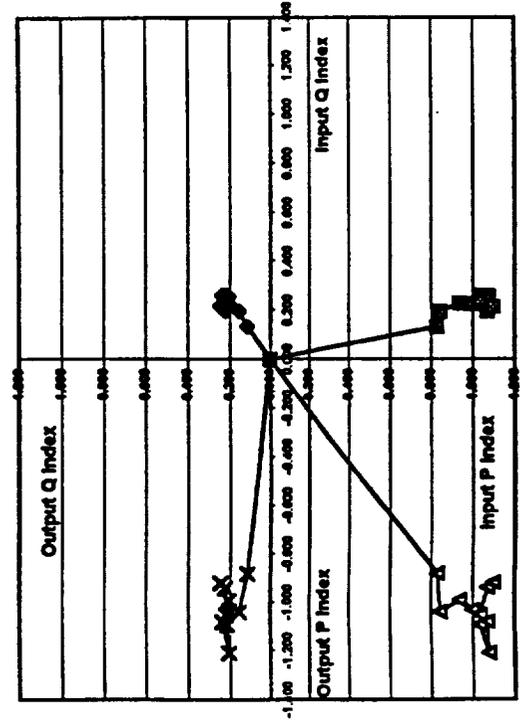
Figure 17: ANA
Productivity, Revenue, Cost & Price Trends 1988-1995

Output Q Index

Input Q Index

Output P Index

Input P Index
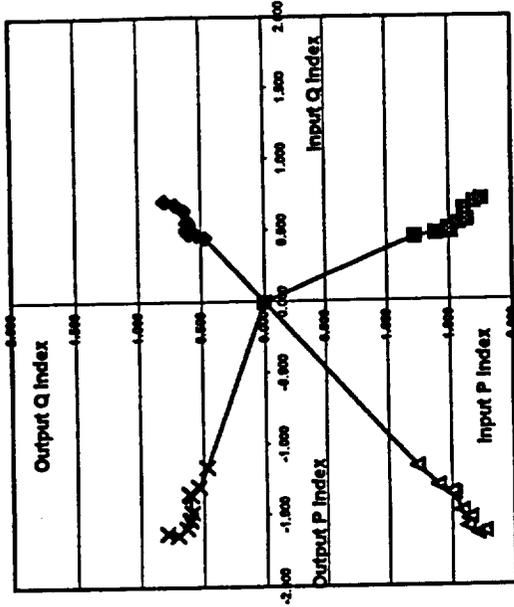
Figure 19: KAL
Productivity, Revenue, Cost & Price Trends 1988-1995

Output Q Index

Input Q Index

Output P Index

Input P Index

Set III cont.
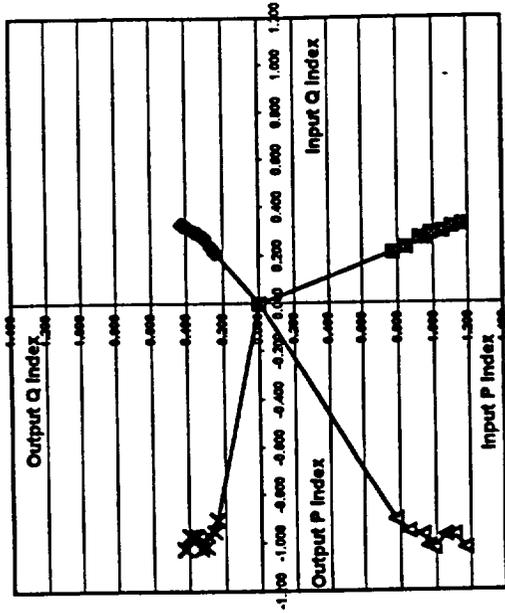
Figure 21: SIA
Productivity, Revenue, Cost & Price Trends 1986-1995
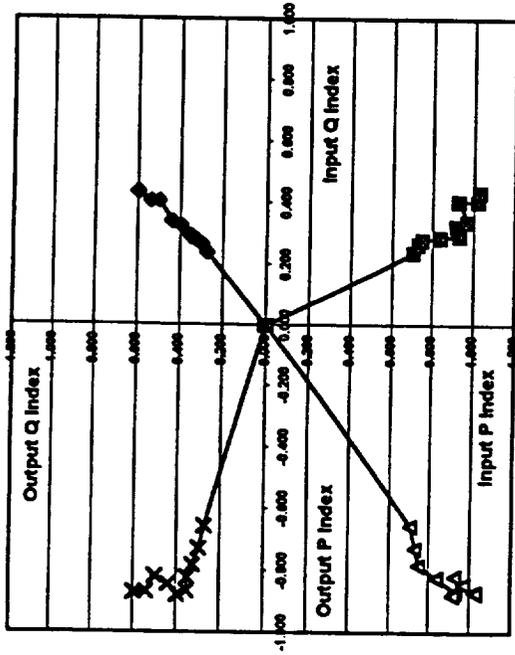
Figure 22: Thai Airlines
Productivity, Revenue, Cost & Price Trends 1986-1995
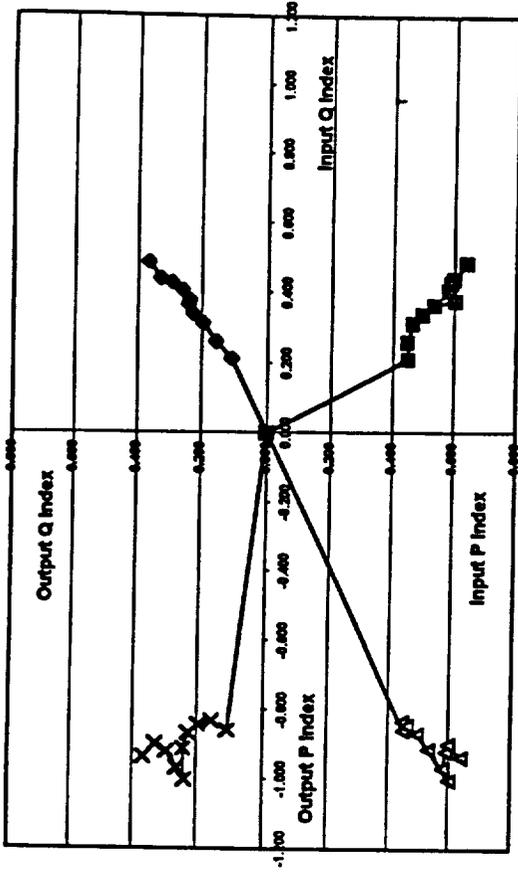
Enhancing Global Competitiveness:
Benchmarking Airline Operational Performance in Highly Regulated Environments

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Abstract

Enhancing competitiveness in the global airline industry is at the forefront of attention with airlines, government, and the flying public. The seemingly unchecked growth of major airline alliances is heralded as an enhancement to global competition. However, like many mega-conglomerates, mega-airlines will face complications driven by size regardless of the many recitations of enhanced efficiency. Outlined herein is a conceptual model to serve as a decision tool for policy-makers, managers, and consumers of airline services. This model is developed using public data for the United States (U.S.) major airline industry available from the U.S. Department of Transportation, Federal Aviation Administration, the National Aeronautics and Space Administration, the National Transportation Safety Board, and other public and private sector sources. Data points include number of accidents, pilot deviations, operational performance indicators, flight problems, and other factors. Data from these sources provide opportunity to develop a model based on a complex dot product equation of two vectors. A row vector is weighted for importance by a key informant panel of government, industry, and consumer experts, while a column vector is established with the factor value. The resulting equation is the dot product of two vectors, C the row vector, and V the column vector. The equation, known as the national Airline Quality Rating (AQR), where Q is quality, C is weight, and V is the value of the variables, is stated $Q = C[i1\text{-}19] \times V[i1\text{-}19]$. Looking at historical patterns of AQR results provides the basis for establishment of an industry benchmark for the purpose of enhancing airline operational performance. A 7 year average of overall operational performance provides the resulting benchmark indicator. Applications from this example can be applied to the many competitive environments of the global industry and assist policy-makers faced with rapidly changing regulatory challenges.

Enhancing Global Competitiveness: Benchmarking Airline Operational Performance
in Highly Regulated Environments

Looking at historical patterns of the Airline Quality Rating (AQR) may provide the
basis for establishment of an industry benchmark for the purpose of enhancing airline
operational performance. Benchmarking is a process that helps companies to find high
performance levels in other organizations and to learn enough about how they are achieving
those levels so the practice producing the high performance can be applied to one's own
company (Keehley, Medlin, MacBride & Longmire, 1997). Enhancing competitiveness in the
global airline industry is at the forefront of attention with airlines, government, and the flying
public. The seemingly unchecked growth of major airline alliances is heralded as an
enhancement to global competition. However, like many mega-conglomerates, mega-airlines
will face complications driven by size regardless of the many recitations of enhanced
efficiency.

Outlined herein is a conceptual model to serve as a decision-tool for policy makers,
managers, and consumers of airline services. The AQR can serve as a model for other
organizations on how to use data as a benchmark to help an organization or industry improve its
performance. The AQR is a summary of month-by-month quality ratings for the major U.S.
airlines during a one-year period. The AQR uses 19 data points such as pilot deviations, load
factors and the number of accidents. (See Table 1). The AQR model uses publicly available
data from the Department of Transportation, Federal Aviation Administration, National
Aeronautics and Space Administration, National Transportation Safety Board, as well as other
sources. Applications from the AQR can be applied to the many competitive environments of
our global industry and assist policy-makers faced with rapidly changing regulatory challenges.

Defining Performance Measurement: The Airline Quality Rating

The majority of quality ratings available rely on subjective surveys of consumer opinion
which are completed infrequently. This subjective approach yields a quality rating that is
essentially non-comparable from survey to survey for any specific airline. Timeliness of survey
based results can be problematic as well in the fast changing airline industry. Before the Airline
Quality Rating, there was effectively no consistent method for monitoring the quality of airlines
on a timely, objective, and comparable basis. With the introduction of the AQR, a multi-factor,
weighted average approach became available. This approach had not been used before in the
airline industry. The method relies on taking published, publicly available data that
characterizes airline performance on critical quality factors important to consumers and

combines them into a rating system. The final result is a rating for individual airlines with ratio scale properties comparable across airlines and across time.

The Airline Quality Rating is a weighted average of 19 factors that have important to consumers when judging the quality of airline services. Factors included in the rating scale were taken from an initial list of over 80 potential factors. Factors were screened to meet two basic criteria; 1) a factor must be obtainable from published data sources for each airline; and 2) a factor must have relevance to consumer concerns regarding airline quality. Data used in calculating ratings represent performance aspects (i.e. safety, on-time performance, financial stability, lost baggage, denied boardings) of airlines that are important to consumers. Many of the factors used are part of the Air Travel Consumer Report prepared by the U.S. Department of Transportation.

Final factors and weights were established by surveying airline industry experts, consumers, and public agency personnel regarding their opinion as to what consumers would rate as important in judging airline quality. Also, each weight and factor were assigned a plus or minus sign to reflect the nature of impact for that factor on a consumer's perception of quality. For instance, the factor that includes on-time performance is included as a positive factor because it is reported in terms of on-time successes, suggesting that a higher number is favorable to consumers. The weight for this factor is high due to the importance most consumers place on this aspect of airline service. Conversely, the factor that includes accidents is included as a negative factor because it is reported in terms of accidents relative to the industry experience, suggesting that a higher number is unfavorable to consumers. Because safety is important to most consumers the weight for this factor is also high. Weights and positive/negative signs are independent of each other. Weights reflect importance of the factor in consumer decision making, while signs reflect the direction of impact that the factor should have on the consumer's rating of airline quality. When all factors, weights, and impacts are combined for an airline and averaged, a single continuously scaled value is obtained. This value is comparable across airlines and across time periods.

The equation, known as the national Airline Quality Rating (AQR), where Q is quality, C is weight, and V is the value of the variables, is stated $Q = C[i1-19] \times V[i1-19]$. Figure 1 presents the formula as a weighted average which results in ratio scale numbers.

Figure 1
Weighted Average Formula for the AQR

$$AQR = \frac{- w_1F1 + w_2F2 + w_3F3 +/- \ldots w_{19}F19}{}$$

$$w_1 + w_2 + w_3 + \ldots w_{19}$$

Table 1

Airline Quality Rating Factors, Weights and Impact

	FACTOR	WEIGHT	IMPACT (+/-)
1	Average Age of Fleet	5.85	-
2	Number of Aircraft	4.54	+
3	On-Time	8.63	+
4	Load Factor	6.98	-
5	Pilot Deviations	8.03	-
6	Number of Accidents	8.38	-
7	Frequent Flier Awards	7.35	-
8	Flight Problems[a]	8.05	-
9	Denied Boardings[a]	8.03	-
10	Mishandled Baggage[a]	7.92	-
11	Fares[a]	7.60	-
12	Customer Service[a]	7.20	-
13	Refunds[a]	7.32	-
14	Ticketing/Boarding[a]	7.08	-
15	Advertising[a]	6.82	-
16	Credit[a]	5.94	-
17	Other[a]	7.34	-
18	Financial Stability	6.52	+
19	Average Seat-Mile Cost	4.49	-

[a]Data for these factors is drawn from the Department of Transportation's monthly *Air Travel Consumer Report*.

The AQR Benchmark: Results in Action

The Airline Quality Rating was developed and first announced in early 1991 as an objective method of comparing airline performance on combined multiple factors important to consumers. Over a span of seven years the Airline Quality Rating has provided a summary of month-by-month quality ratings for the ten major U.S. airlines operating during this period. Using the AQR system and monthly performance data for each airline for the multi-year period provides comparative data for a longer term view of quality in the industry. Since the Airline Quality Rating is comparable across airlines and across time, monthly rating results can be

examined both individually and collectively. A composite industry average that combines the ten major airlines which are monitored each month on 19 criteria over the seven year span is represented in Table 2. Table 3 provides a summary of data.

Table 2
Benchmark Indicators 1991- 1997

AQR Result

1997	1996	1995	1994	1993	1992	1991
0.0001	-0.0762	-0.0948	-0.1103	-0.0706	-0.0309	-0.0167

Source: AQR Reports 1991-1998, Wichita State University and University of Nebraska at Omaha.

Table 3
Summary of Data

Mean   -0.05629
Standard Deviation   0.04072
Standard Error   0.01539
Minimum   -0.1100
Maximum   0.000
Median   -0.07000
Lower 95% C I   -0.09395
Upper 95% CI   -0.09395
t= 3.675 with 6 degrees of freedom
The two-tailed P value is 0.0106, considered significant

Continuing a trend started in 1994, the AQR industry average scores show an industry that is improving in quality. 1997 shows the largest change for industry average AQR scores of any of the past seven years. For 1997 the overall industry average AQR score was the highest of any of the seven years rated. The AQR score improvement was the most of any year-to-year score changes since 1991. While factors of on-time performance, involuntary denied boardings, and mishandled baggage are better, a 20% increase in the number of complaints filed with the Department of Transportation runs counter to a recovered industry. Financial performance has certainly turned the corner along with some indicators of quality performance. Increased consumer dissatisfaction expressed by an increased volume of complaints seems to indicate that how things are done is just as important as what gets done.

The AQR was originally developed for the eventual purpose of benchmarking the U.S. major airline industry, which is highly competitive and highly regulated. Regulatory officials, consumers, financial analysts, and others are interested in monitoring overall industry performance and the resulting effects of situational environment changes. Airlines must monitor operational performance to maintain competitiveness. Each airline must monitor performance to industry standard and previous case history for that air carrier. Thus each airline will have to know the effect of each operational performance indicator and act to effect change.

Applications for the Benchmark Standard

In order for benchmarking to be successful, lasting performance improvements must be made. Sustaining the momentum is crucial to overcoming old practices and implementing new ones. New processes in organizations require constant attention and continual practice. Old practices must be unlearned. Three types of issues arise: ensuring the successful implementation and operation of best practice in organization, institutionalizing benchmarking as the way to search for best practices throughout the agency, and clearly defining the future of benchmarking for best practices as a means for bringing better service to customers (Keehley et al., 1997).

The major airlines are realizing that it is important to attract and retain customers. "Companies are learning that it is important to monitor customers' needs and wants and then strive to meet those needs and wants. If an airline fails to provide quality/satisfaction in its services (i.e. passenger satisfaction), it will lose its customers to its competitors" (Bowen & Headley, 1997, p. 61). "It is essential for all business organizations to retain existing customers and attract new ones. Since the signs from the service provider (emitter) are interpreted by the customer they can either strengthen or weaken the persuasive influence of the company and thereby affect its image and the customer response. It would be interesting to research what these signs are in the area of service provision and their impact on the loss or gain of trade" (Malver, 1988, p. 223). Studies may indicate signs, whether they are positive or negative, and the impact on the customer. These impacts determine whether the customer will remain or leave. You can perform research to detect signs that have "a common international interpretation and the same impact irrespective of the nationality of the passenger" (Malver, 1988, p. 223). Findings from this study may help the "company to improve the delivery of service and to contribute the development of the discipline itself" (Malver, 1988, p. 224). The results from the AQR could most certainly help the major airlines to improve their delivery of service. Alaska Airlines could improve the number of mishandled bags and involuntary denied boardings and American could improve its on-time performance. All of the major airlines can use the results to see how they compare against the competition and improve their respective services. Applications may be modified to fit other highly competitive environments in the global arena.

Benchmarking is not a solution to all of the problems an agency faces but "a powerful weapon in the performance improvement arsenal" (Keehley et al., 1997, p. 207). Benchmarking cannot solve all of the problems, but it allows an agency to look outward and provides the reason and methods that organizations need to seek out best practices and solve performance problems. The need for excellence will become even greater in the future as consumers become more demanding. "Budgets will shrink, the demand for accountability will increase, the need for demonstrable results will grow" (Keehely et al., 1997, p. 206). The use of the AQR as an industry benchmark can enhance airline operational performance.

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Authors

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Dean Headley is Associate Professor of Marketing, W. Frank Barton School of Business, and Faculty Associate of the National Institute for Aviation Research at Wichita State University. He holds a Doctorate in Marketing and Statistics from Oklahoma State University, a Master of Business Administration Degree from Wichita State University, and a Master of Public Health Degree from the University of Oklahoma. Dr. Headley's research interests

include methodology development for measurement of service quality, the connection between service quality and consumer behavior, consumer choice processes in service settings, and the effects of marketing activities on consumers and providers of services.

Collectively, Dr. Bowen's and Dr. Headley's research on the Airline Quality Rating (AQR) has met with widespread acceptance and acknowledgment. The Airline Quality Rating has been featured on *ABC's Good Morning America*, *NBC's The Today Show*, *The Cable News Network*, *C-SPAN*, on network news, in *USA Today*, in *Aviation Week and Space Technology*, and in numerous other national and international media. Bowen and Headley have served as invited expert witnesses before the U.S. House of Representatives Committee on Government Operations and have served on multiple occasions as invited speakers and panelists for such groups as the National Academy of Sciences/Transportation Research Board. Resulting from work with the Airline Quality Rating, Bowen and Headley have been recognized with awards from the American Marketing Association, the American Institute of Aeronautics and Astronautics, Embry-Riddle Aeronautical University, the Travel and Transportation Research Association, the W. Frank Barton School of Business, and others. The AQR research has been published in the *Journal of Aviation/Aerospace Education and Research, Journal of Air Transportation World Wide, Advances in Marketing, Business Research Methods*, as well as other journals, proceedings, text books, and research monographs.

Karisa Kane is a graduate research assistant at the University of Nebraska at Omaha. She has a Bachelor of Science degree in Geography from the University of Nebraska at Omaha. She is currently pursuing a Master of Public Administration degree with an area of specialization in Aviation Administration. Ms. Kane's research interests are in the areas of aviation safety and aviation human factors. She is funded as a research fellow by the Nebraska NASA Space Grant program.

MEASURING THE COMPETITIVENESS OF INTERNATIONAL AIRLINES: IMPLICATIONS FOR DEREGULATION AND LIBERALISATION OF GLOBAL AVIATION MARKETS

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Abstract

In this paper I use annual data on 50 international scheduled airlines over the period 1982-1995 to estimate the approximate magnitude of the dead-weight-loss (DWL) in particular markets resulting from the restrictions on international trade in air transport services imposed by the terms of current Air Services Agreements (ASAs), and attempt to examine the various determinants of carrier efficiency.

After estimating each carrier's "residual" total-factor-productivity (TFP) index (TFP adjusted for factors deemed to be beyond managerial control such as average stage length) using a simple Cobb-Douglas production function. I estimate a total variable cost function equation both including and excluding the estimated "residual" TFP index. and. using six simple assumptions. calculate the approximate DWL in 1995 associated with Japan Air Lines (JAL) providing output. both assuming that the carrier with "average" TFP faces Japanese factor prices and alternatively that factors are freely tradable internationally. I then use the adjusted coefficients technique to estimate the frontier total variable cost equation and use this to estimate the DWL associated with JAL providing its output in 1995. assuming again that the carrier with the highest TFP faces Japanese factor prices. and (alternatively) that factors are freely tradable internationally.

By inspecting the significance (and sign) of the "residual" TFP index in the equations in which it is included. I also analyse whether or not we can assume that this index fully captures the effects of carrier technical efficiency (as well as technological progress) and hence determine both the relative magnitude of the effects of TFP on carrier total variable costs and (from the frontier total variable cost equation output) whether or not the carriers in my sample were allocatively efficient over the time period considered.   I conclude firstly that my analysis of the markets served by JAL in 1995 supports the assertion that the gains from liberalisation would be greater the greater the extent to which current restrictions are relaxed (allowing more carriers to serve markets at minimum cost) and the greater the extent to which factors of production are freely tradable internationally. and secondly. that for the carriers in my sample over the time period considered. a one percent increase in TFP lowered carrier total variable costs by approximately 0.06% on average and that none of the carriers were allocatively efficient.

1. Introduction

The past few decades has seen a growing trend towards deregulation and liberalisation of civil aviation markets across the globe. The deregulation of US domestic aviation markets in 1979 under the Carter Administration[1] and the privatisation of British Airways under the Thatcher Government in 1986 led to a widespread relaxation of restrictions on domestic aviation markets[2] and moves towards privatisation[3] of, and a reduction in direct financial assistance[4] given to, international "flag-carriers". In many countries these measures have been accompanied by government moves to open up international routes to competition. such that markets previously monopolised by national flag-carriers[5] are now served by at least two airlines[6]. At the regional level. the US has been negotiating

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[1] the market access rights granted under deregulation were and remain only available to US carriers: foreign carriers are not permitted to provide cabotage services in the US except in certain cases where the cabotage service is an extension of a service to the US. Other countries which have since deregulated. either partially or fully. have also tended to only extend deregulation privileges to their own carriers.

[2] some countries (such as Australia) followed the US's example and fully deregulated their domestic aviation markets (with the caveat described in footnote 1). while others (such as Japan) adopted a less-extensive package of reforms which somewhat relaxed existing restrictions on the provision of domestic aviation services (for example. by reducing the annual passenger threshold above which multiple designation is permitted).

[3] in some countries (such as Australia and Japan) flag-carriers have been fully privatised. while in others governments have significantly reduced the amount of shares they hold in national carriers (see Table 3.1 in Forsyth (1997) for a comparison of equity holdings of governments of Asia-Pacific carriers in 1985 and 1995).

[4] over the period 1984 to 1993 direct subsidies to the world's airlines fell from $US 235 million to $US 150 million (Findlay. Hufbauer and Jaggi (1996): 18).

[5] flag-carriers "monopolised" these markets in the sense that they were the only carrier from a particular country permitted to serve them. Obviously a carrier from the country at the other end of the route also had market access rights: however. given the prevalence of revenue pooling and capacity-sharing agreements and the regulation of the setting of airfares by the International Air Transport Association (IATA) it seems unlikely that competition was intense on these routes.

[6] in Australia and the Republic of Korea. for example. two carriers from each country now have rights to serve international routes: in Australia. privately-owned domestic carrier Ansett Australia began international operations in September 1993. while in South Korea a new privately-owned carrier Asiana Airlines began services in 1988. Because

"open-skies" agreements[7]. the European Union (EU) has established a Common Aviation Market[8]. and attempts have been made to establish a single aviation market across the Tasman[9].

Despite these measures. a substantial proportion of global trade in air transport services remains tightly regulated. Trade in international services remains governed by the terms of approximately 2000 ASAs involving 160 countries[10], which typically grant particular carriers from each of the bilateral partner countries market access rights. and then stipulate which cities in the two countries they may serve and the weekly frequency and aircraft size with which they may serve these cities[11]. These restrictions not only prevent carriers with market access rights from maximising economies of traffic density and hence lowering their per-unit operating costs[12]. but also prevent other lower-cost (given the restrictions on their operations imposed by the terms of the bilateral agreements to which the country in which they are based in is signatory to) carriers[13] (either from the partner countries or third countries) from serving these markets. These two factors, in turn, prevent passengers and users of air-freight and mail services from exploiting the maximum possible gains inherent in the consumption of these services. either in the form of lower average airfares (through reductions in existing fares. an increase in the level of discount on existing discounted fares. or the availability of a larger number of types of discounted tickets) or greater quality of service (more seats available per week through more flight frequencies per week per route or the use of larger aircraft and a greater number of

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ASAs (which govern the terms of trade in international air transport services between country-pairs) operate on the basis of bilateral reciprocity. the granting of international market access rights to a second carrier from a particular country is usually only agreed to in negotiations if equivalent rights are allocated to a second carrier from the partner country. Given this. the abolishment of revenue-pooling and capacity-sharing agreements over the past decade or so, and the reduction of IATA's status to a mainly fare-monitoring body. carriers based in countries which adopt a multiple designation policy are (usually) effectively faced with competition from at least three other international carriers.

[7] the term "open-skies" is misleading. as it implies unrestricted trade in air transport services, whereas in reality these agreements are strictly bilateral in nature. exclude cabotage rights, and retain existing restrictions on the level of foreign ownership of a country's carriers permitted. This means that although the US has thus far established (separate) open-skies agreements with Canada. ten European nations and six countries in the Asia-Pacific region, the rights granted by the partner country are not automatically granted to all the other countries that the US has such agreements with. At this stage. however, it seems that the US is granting rights to each additional country it establishes an open-skies agreement with of a roughly equivalent form and quantity to those it has granted to countries with whom it has already established such agreements (comments made by Dr Christopher Findlay of the University of Adelaide at the Civil Aviation Roundtable. 3 April 1997).

[8] the Third (and final) Package of reforms were due to be fully implemented by April 1997. The Common Aviation Market allows carriers from Member States to fly within the EU without restriction: carriers are permitted to provide cabotage services without capacity constraints. as well as Sixth and Seventh Freedom services (flights which originate in a country other than the carrier's country of registration and terminate in a second such country, with and without a through-stop in the home country respectively). It is thus a regional multilateral agreement.

[9] The single aviation market envisaged would essentially be a bilateral agreement between Australia and New Zealand permits carriers from one country to provide cabotage services in the other but retains (at least initially) restrictions on the provision of Fifth Freedom ("beyond") services (flights from the partner country to a third country which are an extension of a carrier's flight originating in the country in which it is registered). See Findlay and Kissling (1997) for a discussion of the factors which have thus far hindered the implementation of the agreement.

[10] Findlay. Forsyth and Bora (1996): 128-129

[11] even though for each carrier registered in an EU Member-State trade in air transport services with other Member-States is governed by the terms of the Common Aviation Market agreement. trade with non-Members is still subject to the terms of ASAs (which each Member has negotiated (individually) with them).

[12] econometric studies generally conclude that while economies of scale are negligible in the provision of air transport services. there are considerable economies of traffic density: carriers can achieve cost-savings by expanding their route network (hence increasing the number of cities they serve). increasing the average load factor (that is. the ratio of passengers. freight and mail to capacity available) per flight. consolidating passengers onto larger aircraft (provided of course that the average load factor on flights using these aircraft is relatively high). or increasing the weekly frequency with which existing routes are flown.

[13] assuming. of course. that those carriers with market access rights are not the global lowest-cost carriers

destinations served increases consumer choice and reduces time between flight connections, creating a more convenient. "seamless" service)[14].

Recent studies have attempted to measure the relative competitiveness of international airlines. Oum and Yu (1997). for example. using 1986-1993 data on 23 airlines from 16 countries. measure relative "residual" TFP and unit cost indices for each carrier. adjusted for factors beyond airline management control (such as average stage length[15]). They show that while US carriers (with the exception of US Airways) tend to be highly productively efficient, East Asian carriers (excluding Japanese carriers) and Qantas Airways have much lower input prices[16], and hence that over the sample period. on average. (non-Japanese) East Asian carriers had lower overall unit costs. These results suggest that in many city-pair markets consumer surplus was not being maximised as the lowest-cost carriers (given the restrictions on their operations imposed by the terms of the bilateral agreements the country they are based in is a signatory to) were prevented from providing services. The authors do not attempt to estimate the magnitude of this DWL. The authors also do not attempt to measure the DWL arising from the fact that bilateral agreements prevent these lower-cost carriers from minimising their costs by restricting their ability to exploit maximum economies of traffic density.

In this paper I extend Oum and Yu's (1997) analysis by estimating the approximate magnitude of these two DWLs in a particular market. using data on a greater number of carriers over a longer (and more recent) time period than the two authors. The first DWL is calculated using a standard (short-run) total variable cost equation. A frontier variable cost function is then estimated using the adjusted coefficients method. in order to calculate the second DWL. I consider only DWLs. given that this is a net gain (the other effect of a fall in price is simply a redistribution of surplus which existed prior to the price change among producers and consumers, according to the position and slope of the supply curve and the extent to which consumers of air transport services are also holders of carrier equity).

Contrary to contemporary cost frontier estimation practices, however. I include an index of TFP adjusted for average stage length as an explanatory variable on the right-hand-side of my (variable) cost equation. Furthermore, I examine whether or not it can be asserted that it fully captures the effects of technical inefficiency (as well as technological progress) and hence that the residuals contain the effects of relative carrier allocative efficiency, as well as the usual disturbance terms.

Section 2 discusses the total variable cost equation and DWL estimation methodology. Section 3 describes the data and variables used in these estimations. and presents the production function estimation results used to calculate the "residual" TFP index. Section 4 compares the total variable cost equation estimation results obtained when the calculated "residual" TFP index is included as an exogenous variable on the right-hand-side with those obtained when this index is excluded. and uses the "best" equation to estimate the approximate DWL associated with JAL providing its output in 1995. both under the assumption that the carrier with "average" TFP is subject to Japanese factor prices and under the alternative assumption that factors are freely internationally tradable. The frontier total variable cost equation estimation results obtained when the "residual" TFP index is included and excluded respectively are presented in Section 5. and used to compare the minimum DWL associated with JAL providing its output had ASAs been abolished and hence not only had the lowest-cost carrier been able to provide JAL's output, but also it had been able to fully exploit economies of traffic density inherent in the provision of such services and hence operate at its minimum cost. again under the alternate assumptions that it is subject to JAL factor prices and that factors are freely internationally tradable. Section 6 discusses the implications of my results for the liberalisation debate, and briefly discusses (complementary) issues which would need to be addressed should further liberalisation take place in order to ensure that the gains from trade in air transport services are maximised in more liberalised markets.

2. Total Variable Cost Estimation Methodology

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[14] studies have shown that passengers prefer larger. jet aircraft. further increase the contribution of using larger aircraft on average to service quality.

[15] average stage length refers to the average kilometre-distance of a carrier's flights. Studies have shown that, ceteris paribus. the longer a carrier's average stage length. the lower its per-unit costs tend to be; however. stage length is determined by the geographical location and population dispersion of the country the carrier is based in (thus European carriers. for example. tend to have relatively short average stage lengths). as well as the terms of ASAs which the base country is signatory to. Oum and Yu thus conclude that it is a factor largely beyond the control of airline management.

[16] lower than all US carriers in the sample except Continental Airlines: Thai Airways International. Korean Air and Singapore Airlines large cost advantages over all US sample carriers due to their significantly lower labour costs

Given that the flight services portion of airline output is relatively fixed (at least in the short-term) due to regulation of domestic aviation markets in many countries and the terms of ASAs, it seems reasonable to assume that carrier capital stocks will not always be in equilibrium. Aviation literature which attempts to measure relative carrier costs thus tends to estimate total variable cost functions, as these implicitly assume that the time-frame under consideration is the "short-run", and hence that airline capital stocks may not be in equilibrium. Total variable cost functions also avoid the extremely difficult task of estimating the price of capital, given that capital stocks are fixed in the short-run. The (disequilibrium) stock of capital is simply included as an independent variable on the right-hand-side of the equation.

The cost functions estimated (for panel data) are thus generally of the following form:
$$TVC_{it} = x_{it}'b + (U_{it} + V_{it}) \quad i = 1,..., N; t = 1,..., T$$

where:

TVC_{it} is the (logarithm of the) variable cost of production of the i-th firm in time
  period t
x_{it} is a k x T matrix of the (logarithms of the) output, "characteristic variables",
  capital stock and input prices of the i-th firm in time period t
b is a vector of unknown parameters
U_{it} are non-negative random variables which are assumed to account for the cost
  of inefficiency in production and be iid $|N(0, \sigma_u^2)|$, and
V_{it} are random variables which are assumed to be iid $N(0, \sigma_v^2)$ and independent
  of the U_{it}

The flight services component of total airline output is typically measured in either tonne-kilometres performed (TKP)[17] or revenue-tonne-kilometres (RTKs)[18], such that these highly differentiated services can be aggregated[19]. Studies on the aviation industry have generally concluded, however, that producing relatively large amounts of services with particular characteristics has a non-negligible effect on costs. Given that flight characteristics are not captured by the output variable, "characteristic variables" are typically included in the variable cost equation. The price of capital is not included as an input price variable given that the time-frame considered is the short-run.

Oum and Yu (1997) include a index of "residual" TFP in their total variable cost equation, and then decompose the difference in unit costs across carriers into their potential sources (differences in factors beyond managerial control, input prices and "residual" TFP) in order to estimate the relative contribution of each source to the observed unit cost differences. They then use this to construct an index of relative airline cost competitiveness adjusted for uncontrollable (by airline management) factors.

Total variable cost function estimation, however, also has another extremely useful application not considered by the authors: it enables us to estimate the DWL associated with the restrictions on trade in international air transport services imposed by the terms of ASAs in given markets, given several simple assumptions about the nature of trade in particular city-pair markets. These (seven) assumptions are:

1) carriers price their services in such a way that the average price of carrier output is equal to the average variable cost (AVC) of producing that output;
2) there are approximately constant returns to scale (CRTS) in the supply of airline output (at least over small quantity changes);
3) consumers of air transport services have quasi-linear preferences such that the compensated and uncompensated demand function are equal;
4) the demand for aviation services can be approximately represented by a linear demand function;

[17] TKP for each carrier are calculated as the number of tonnes carried per flight (the weight of passengers, freight and mail, where passenger weight is calculated by multiplying the number of passengers carried by 90 kilograms (which allows for the weight of passengers, their baggage, and any excess baggage)), multiplied by the number of kilometres flown per flight, summed over all flights.

[18] RTKs for each carrier are calculated as the revenue earned per flight from airfares, cargo and mail multiplied by the total weight carried per flight, multiplied by the number of kilometres flown, summed over all flights.

[19] flight services can differ by kilometre-length, the size of aircraft, the type of cargo carried (passengers, freight or mail), the number of seats in an aircraft of a particular size, the number of seats (and hence amount of leg-room) in first-class, business-class, and economy-class respectively, the time of day and day of the week the flight is operated etc.

5) the price elasticity value a carrier faces is approximately the same across all the markets it serves; and
6) there is a perfectly elastic supply of all factors of production. such that any amount of any factor demanded is available at a given factor price. and these factors are homogeneous across countries.

The first assumption implicitly assumes two factors: firstly, that carriers price according to average (rather than marginal) cost. and secondly. that it is variable (rather than total) costs that they are most concerned with. This is possible given the huge fixed costs inherent in the provision of flight services and the fact that (by estimating total variable cost equations) our analysis is limited to the short-run (recall that in the short-run carrier capital stocks are fixed). In reality. it is likely that carriers price above AVC. both in markets governed by the terms of ASAs but where competition between carriers with rights to provide services is high and in markets not under the jurisdiction of ASAs. given that factors such as different average service levels and safety records give carriers a certain amount of market power. By using assumption 1). then. we are effectively estimating the lower bound of the DWL. The second assumption is made given that many studies have concluded that there are negligible returns to scale inherent in the provision of air transport services[20]. The third. fourth. and sixth assumptions are made to simplify the calculations: by making these we can ignore income effects. avoid integrating. and avoid calculating the rise in factor price associated with a rise in the demand for a particular factor (and assume that all countries will source their inputs from the countries which are the cheapest suppliers of those inputs). The fifth assumption is made given the limited availability of information on the relative magnitude of 1) price elasticities of flight and non-flight output. 2) airfare elasticities across city-pair markets. 3) airfare elasticities of business and leisure travelers. and 4) total TKP provided in each market.

Given that Oum and Yu 's (1997) study showed that over the time period considered Japanese carriers had relatively low TFP indices (after adjusting for factors beyond managerial control) and high factor input prices. I decided to use markets served by JAL in my analysis[21]. I also decided to consider the year 1995, as this was the most recent year which aviation data was available for. The (Australian) Bureau of Transport and Communications Economics (BTCE) (1995) estimated that the airfare elasticity for leisure travel on routes from Australia to Japan is approximately -1.16: in the following analysis I invoke assumption 4). and use -1.16 as the price elasticity of demand for JAL output[22].

The (standard) total variable cost equation enables us to measure the DWL arising from the fact that ASAs prevent lower-cost carriers registered in countries not signatory to a particular agreement from serving markets between the two partner countries. Given that the coefficients of this equation are calculated over all carriers in the sample over the time period under consideration, substituting the values of the exogenous variables of a particular carrier in a particular year (here JAL in 1995) into the estimated equation enables us to compare the actual operating variable costs of that carrier with the costs of the "average" carrier in that year. Given assumptions 1) and 2) we can then calculate the (average) prices of (the same level of) output Qjal produced by the carrier under consideration and the average carrier. These are labeled in Figure 1 as Pjal and Pav , respectively.

Given the (assumed) value of the elasticity of airfares η_A. Qjal. Pjal and assumptions 3) and 5), we can calculate the slope of the demand curve as follows:

$$\eta_A = \frac{dQ}{dP} \cdot \frac{Pjal}{Qjal}$$

$$\frac{dQ}{dP} = \eta_A \frac{Qjal}{Pjal}$$

$$\therefore \ dP = Pjal$$

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[20] Oum and Yu (1997) conclude that there are diseconomies of scale inherent in the provision of such services: under this assumption the (carrier output) supply curve would be upward sloping (rather than horizontal). and output-price combinations would be determined by the intersection of the demand and supply curves.

[21] JAL was chosen rather than the other two Japanese carriers in my sample given that data for JAL is reported in all time periods for all the series used in my analysis.

[22] the BTCE (1995) only reports airfare elasticities on routes to and from Australia. It also does not report individual carrier elasticities on these routes. price elasticities of carriers' incidental output. or (in the case of Japan) the relative airfare elasticities of business travel and leisure travel. respectively. From the values reported for routes to and from other countries and Australia. the airfare elasticity of business travel is much lower (in absolute terms) than for leisure travel: hence using the leisure travel value for Japan will tend to over-estimate the welfare loss (offsetting to some extent its underestimation under the assumption that carriers price at average variable cost).

dQ   Qjal.η_A

We can then calculate Qav. given assumption 2). Given assumption 4) the DWL associated with the carrier under consideration rather than the average carrier providing services in these markets is then calculated from the formula for the area of a triangle.

Our total variable cost equation also enables us to take our analysis a step further and measure the magnitude of the DWL if factors of production were also fully (and costlessly[23]) tradable. Under this additional assumption, we would expect that all carriers serving these markets would source their inputs from the lowest-cost producers of these inputs. and hence (given assumption 6)) by substituting in the lowest input prices out of all the carriers in our sample into the total variable cost equation. we can calculate Pav.ftf. Qav.ftf. and hence the DWL ADE in Figure 1.

Frontier total variable cost equations enable us to take our analysis a step further still. Given the flight characteristics and capital stocks of the carriers in our sample and the input prices they faced, such equations allow us to estimate the potential minimum variable cost at which the output of carriers could have been produced over the time period under consideration. In Section 5 I estimate an adjusted coefficient frontier total variable cost equation which takes into consideration carrier-specific production behaviour (that is, carriers use different application methods such that given technology. airlines can produce different levels of outputs with the same levels of inputs) in the estimation of the frontier coefficients[24], and then use this to estimate the minimum variable cost at which the level of output provided by JAL in 1995 could have been produced. given JAL's capital stock, output characteristics and factor prices. The DWL associated with the fact that ASAs prevent lower-cost carriers from serving particular markets at minimum cost. AFG. is then calculated. I then assume that factors are freely tradable internationally, and estimate the DWL AHI by substituting JAL factor prices with the lowest observed factor prices in our sample and doing the necessary calculations.

Programs which estimate frontier cost equations typically calculate predictions of individual firm cost efficiency relative to the cost frontier in each time period, according to the following formula:

$$EFF_{it} = \frac{E(C_{it}*/U_{it}, X_{it})}{E(C_{it}*/U_{it}=0. X_{it})}$$

where $C_{it}*$ is the cost of the i-th firm in time period t. which will be equal to C_i when the dependent variable is in original units and $exp(C_{it})$ when the dependent variable is logged.
The cost efficiency measures will thus take a value between one and infinity, where the closer is the measure to one. the higher is its cost efficiency (or equivalently, the lower is its inefficiency) in time t.

Cost efficiency measures, however. are the sum of two elements: allocative efficiency (that is, how effective a firm is at putting its inputs to their most productive uses) and technical efficiency (how effective a firm is at exploiting the maximum potential out of its inputs). Given that the relative magnitudes of these two efficiency measures are not directly measurable. their individual contributions to firm efficiency cannot be determined a priori. The literature thus typically assumes that firms are allocatively efficient, and hence that all measured cost efficiency is in fact technical efficiency.

However, although allocative and technical efficiency are not individually measurable. the sum of the latter plus technology. which is commonly know as TFP, is measurable via a production function: it is the (exponent of the) constant term[25]

ie from $Y_{it} = x_{it}'b + (a + V_{it})$ i = 1..... N: t = 1...., T

where Y_{it} is the (logarithm of the) output of the i-th firm in
        time period t
        x_{it} is a k x T matrix of the (logarithms of the) capital stock. labour. and (in the   case of
the airline industry). fuel and "other" inputs of the i-th firm in time   period t
        b   is a vector of unknown parameters
        a   is a constant term. and

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[23] such that there were no cost involved in transporting these factors from one country to another etc.

[24] the estimated variable cost frontier is thus a non-neutral shift from the actual variable cost function.
When cost frontiers are estimated under the assumption that firm behaviour can be proxied by an unknown random variable with certain distributional assumptions. the coefficients for the frontier are all the same as those for the conventional cost function except for the intercept term. and hence this shift is neutral.

[25] obviously the TFP measure estimated in this way will also contain the effects of the random disturbance terms.

V_{it} are random variables which are assumed to be iid $N(0, \sigma_v^2)$

$$TFP_{it} = a + V_{it}$$

hence $TFP_{it} \gg a$

Thus if we assume that the TFP measure fully captures technical efficiency (as well as technological progress) and put it in the right-hand-side of our total variable cost equation (as do Oum and Yu (1997) in their (non-frontier) total variable cost equation in order to decompose observed unit cost differentials among carriers into their sources) we can estimate the relative contribution of TFP to carrier variable costs in the case of the usual total variable cost equation, and the maximum possible contribution of TFP to carrier variable costs when airlines are following the best practice techniques of the given technology in the case of the frontier total variable cost equation. Obviously including a TFP index as an independent variable may lead to multicollinearity in the model. if either this index does not fully capture carrier technical efficiency and hence some of its effects are also inherent in the residual term. or if it does fully capture technical efficiency effects but there is a strong correlation between carrier TFP and allocative efficiency. If multicollinearity is present. we would expect (at least) the coefficient of the TFP index to not be individually statistically significant from zero.

Even if multicollinearity is not present in our model, unfortunately we will still be unable to analyse the effects of technical efficiency alone on carrier variable costs, given that TFP measures also capture the effects of technological progress. However. the efficiency measures reported in frontier cost function estimation programs will now reflect allocative. rather than cost, efficiency, and hence carrier allocative efficiency can be tested (rather than simply assumed). Hence in my total variable cost equation estimations a TFP index is included as an exogenous variable and the results obtained are compared with those obtained when this index is omitted.

3. Data and Variable Construction

My analysis uses annual data on 50 carriers from 27 countries over the period 1982-1995 (inclusive)[26]. It includes more US. UK. mainland European and East Asian carriers than Oum and Yu (1997), and (unlike the authors) also includes airlines from South Asia, Central and South America. and parts of Africa. The data is obtained mainly from International Civil Aviation Organization (ICAO) (annual) *Digest of Statistics, Commercial Air Carriers: Traffic, Financial Data,* and *Fleet-Personnel.*

Total variable cost was calculated by deflating total operating expenses for each fiscal year[27] by the manufacturing price index (MPI; 1990=100) for that year[28]. Total airline output can be divided into two broad categories: flight services and incidental (non-flight) services[29]. As already mentioned, flight services are typically measured in either tonne-kilometres performed (TKP) or revenue-tonne-kilometres (RTKs), such that (highly differentiated) flight services can be aggregated. I chose to use the former measure, given the its availability for a greater number of carriers than the latter. Given the heterogeneous nature of incidental services, I measure the quantity of this type of airline output by dividing total incidental revenues by the average price level of investment goods and services in the country in which the carrier is based[30]. This price index is calculated as the purchasing-power-parity (PPP) index for GDP divided by the exchange rate of a particular country relative to the $US, and hence measures the

[26] during this period Cathay Pacific Airways's operations were governed by the terms of ASAs the UK had negotiated with other countries and it is classed as a British carrier in ICAO statistical yearbooks; however, here I class it as an East Asian carrier given that it would have faced mainly Asian factor prices and had the flight operating characteristics Asian carrier. Scandinavian Airlines System (SAS) is jointly owned by Sweden. Denmark and Norway (each country owns 3/7. 2/7 and 2/7 of total equity respectively (of which half is owned by the government and half by private investors of that country)): here I have treated "Scandinavia" as a country.

[27] note that the beginning and end dates of fiscal years vary somewhat across countries

[28] in the calculation of variables. all "values" (total revenues. costs etc) were deflated by the MPI except labour costs. which were deflated by the consumer price index (CPI). It will be assumed that the reader is aware of this. and hence hereafter statements about deflating will be omitted in descriptions of the construction of variables which use "values".

[29] such as activities undertaken for other carriers (eg aircraft maintenance. ground handling. catering and reservations). sales of technology. consulting services and hotel business.

[30] Oum and Yu (1997) use the average price of consumption goods and services in their construction of an incidental services quantity index: however. given the nature of these types of services. it seems more reasonable to me to use the average price of investment goods and services.

price of non-tradable investment goods across countries relative to the US[31][32]. Total airline output is then calculated as the revenue-share weighted sum of flight services and incidental services.

Oum and Yu (1997) include four "characteristic variables" in their total variable cost equation: average stage length. the share of revenue attributable to incidental services. and the shares of total TKP of non-scheduled and freight and mail TKP. respectively. For the carriers in their sample and the time period considered in their analysis. they conclude that there was a significant negative relationship between carrier variable costs and average stage length[33]. the proportion of total TKP which is non-scheduled[34], and the share of revenue attributable to incidental services respectively. and a significant positive relationship between costs and the ratio of freight and mail TKP to total TKP[35]. Findlay and Forsyth (1984) (as well as average stage length and the share of total TKP which is non-scheduled TKP) include two additional such variables: average load factor and average aircraft size[36]. They conclude that in 1980 for the carriers in their sample there was a significant negative relationship between both of these variables and (total) cost. respectively[37]. I decided to analyse all of these six variables. as well as a variable measuring the ratio of international TKP to TKP[38]. Average stage length was calculated by dividing total kilometres flown by total number of departures. Average load factor is the ratio of TKP to tonne-kilometres available (TKA[39]). Average aircraft size was calculated by dividing TKA by total kilometres flown. The revenue share of incidental services was calculated by dividing incidental revenues by total revenues. and the shares of total TKP of non-scheduled TKP, freight and mail TKP, and international TKP were calculated by dividing non-scheduled TKP, total freight and mail TKP, and total international TKP by total TKP, respectively.

Unfortunately. however. for the carriers in my sample over the time period under consideration, simple plots revealed no strong correlation (either positive or negative) between either the revenue share of incidental services or the share of total TKP of international TKP and total variable cost. respectively. Also, whether or not a relationship existed between the shares of total TKP of non-scheduled TKP and freight and mail TKP and total variable cost. respectively. was indeterminate given that the carriers in my sample tended to provide either almost all non-scheduled TKP or almost no non-scheduled TKP, and similarly for freight and mail TKP, over the time period considered. The relationship between average aircraft size and total variable cost appeared positive over some average aircraft size values, and negative over others: nevertheless I included it in my initial total variable cost equation estimations, but its coefficient was never individually statistically significant at even the 10% level[40]. Hence in the final results presented in Section 4 and 5 only two "characteristic variables" are in my total variable cost equations: average stage length and average load factor.

Total airline capital stock can be divided into two broad categories: flight equipment, and ground property and equipment. Flight equipment consists not only of aircraft purchased outright. but also aircraft leased from other

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[31] in the case of consumption goods. this index is commonly referred to as the "Big Mac" index, as it compares the $US dollar price of non-tradable homogeneous goods (such as Big Macs) across countries.

[32] using this as a proxy for the price of incidental services implicitly assumes that each carrier based in a particular country charges the same average price for these services. which in turn assumes that the markets for such services are relatively competitive.

[33] see footnote 15 for a discussion of the relationship between average stage length and carrier costs.

[34] given that the vast majority of non-scheduled services provided tend to be charter flights which often fly out of secondary airports at non-peak times. ceteris paribus we would expect total variable costs to decrease as the proportion of total TKP which is non-scheduled TKP increases.

[35] this last result is somewhat surprising given that the more freight and mail (and less passengers) carried. the lower the number of cabin attendants required by an airline, the lower the total expenditure on in-flight services etc.

[36] see footnote 12 for definitions of these two variables.

[37] see footnote 12 for a discussion of the effects of average load factors and aircraft size, respectively, on carrier variable costs.

[38] literature on carrier costs also generally concludes, as mentioned in footnote 12. that the greater the number of cities served (and hence the more routes a carrier operates) and the greater weekly frequency with which existing routes are served. the lower a carrier's costs will be on average. Unfortunately figures on number of routes operated and number of flights operated per week are not reported.

[39] TKA measures (in tonnes) the total carrying capacity available per flight multiplied by the kilometre-length of the flight. summed over all flights.

[40] the results of these estimations are not presented in this paper. but are available upon request

airlines and capacity purchases on other carriers' flights through block-purchasing[41] or code-sharing agreements[42], which makes it extremely difficult to estimate an aggregate quantity of flight equipment for each carrier. Using the number of aircraft a carrier operates accounts for those planes it leases to or from other airlines, but not the capacity a carrier may offer on other carriers' flights. It also does not take into account the fact that aircraft vary greatly in capacity[43]. Oum and Yu (1997) calculate the total (real) value of each carrier's fleet by multiplying the number of each type of aircraft it operates by the lease price of that aircraft type and summing over all aircraft types, and then divide this by the aircraft price index specified in Oum and Yu (1997b) to obtain a flight equipment quantity index: although this allows for differences in aircraft capacity across carriers. it still does not include capacity offered through block-purchasing and code-sharing agreements and hence underestimates total carrier flight equipment. This approach also uses approximate lease prices obtained from *The Avmark Aviation Economist*. Such lease prices are only available from 1987 onwards and are not reported for all types of aircraft operated by the carriers in my sample (in particular. for aircraft built in the former USSR, the Concordes operated by British Airways and Air France, and aircraft with capacity for less than 50 seats): hence the lease prices would need to be extrapolated backwards and estimated for particular carriers[44]. Using the total number of seats of a carrier includes those offered on other carriers' flights. but again does not take into account average aircraft size differences across airlines[45]. Given that my estimate of capital stock must also be used in a production function to calculate a TFP index which is extremely sensitive to the measurement of the stock of capital, I decided against using any of these measures as a proxy for the stock of capital.

The ICAO statistical yearbooks report the depreciated (asset) value of flight equipment (purchased outright or under a lease considered to be the whole life of the aircraft) and annual expenditure on flight equipment rental (expenses incurred for rental of aircraft under short-term lease agreements or for chartering purposes, and payments for the purchase of capacity on aircraft operated by other carriers), which together account for the total flight equipment operated by carriers. Given the difficulty in aggregating these two series (as the former is an asset value and the latter measured in annual expenditure terms) and given that ground property and equipment is also reported as an asset. I included two variables to account for the total capital operated by carriers: "capital stock", calculated as the sum of the depreciated asset values of flight equipment and ground property and equipment[46], and "working capital". the annual expenditure on flight equipment rental[47][48].

Carrier inputs are commonly separated into four categories: capital, labour, fuel and "other"[49]. Given that capital stock is fixed in the short-run, the prices of only three of the four inputs need to be estimated. Oum and Yu

[41] under these type of agreements, an airline "purchases" a certain number of seats on a flight operated by another carrier, and then sells them according to demand.

[42] under this type of agreement, an airline can sell seats on a flight operated by another carrier under its own two-letter designator code. according to demand (it does not have to purchase seats outright in advance).

[43] two carriers may operate the same number of aircraft, but one may operate mainly jet aircraft, while the other uses mainly smaller aircraft. Differences in average aircraft size may also be due to relative service quality: a carrier may operate services on jet aircraft with relatively fewer seats to provide passengers with greater leg-room.

[44] this is not easy- even the assumption that these aircraft would have approximately the same lease prices as aircraft types for which the lease price is reported with similar number of seats is not without problems, given that the former-USSR built aircraft in service tend to be older on average (which affects lease prices), Concordes have only 100 seats on average but are very expensive to operate (but yield high profit margins per passenger, given that these seats are all first- or business-class). and lease prices are not reported at all for aircraft with capacity for less than 50 seats.

[45] The exact number of seats provided by a carrier is also often difficult to calculate. given that carriers may use the same type of aircraft with different seating configurations (they may operate aircraft with relatively less seats in order to provide more first- or business-class seats, or greater cargo-carrying capacity, on particular flights). In these cases. carrier report a range for the number of seats provided on each aircraft type.

[46] UK carriers include the asset value of land in their estimates of the asset value of ground property and equipment. hence to be consistent I added land asset values to ground property and equipment values for all the other carriers in my sample.

[47] including the two measures of capital stock in quantity terms would have again involved the extremely difficult task of measuring the price of capital. Even if I had have been able to measure this price. however. it is likely that the stock of capital measured in dollar terms would better represent the economic value of the capital stock than a quantity term. given that capital used by carriers is highly differentiated.

[48] obviously in including two variables measuring total capital stock in my equations I will need to check my results for multicollinearity.

[49] all other inputs used in the provision of air transport services. such as airport fees. sales commissions, passenger

(1997) calculate the average price of labour for each airline by dividing total remuneration of all employees by the total number of workers employed by the airline. In some countries where carriers are majority government owned or controlled[49], however, airlines tend to be used to "absorb" excess labour, and hence the price of labour measured in this way will be distorted. I decided to calculate the average labour price by dividing total cabin crew remuneration by the average price of consumption goods in the country in which the carrier is based[51] and the total number of cabin attendants employed at (financial)-year end, given that it seems reasonable to assume that even majority government-owned carriers will not employ "excess" cabin staff due to space limitations inside aircraft, and because country-specific labour laws and union bodies limit carriers' ability to source their cabin staff globally[52,53,54].

ICAO statistical yearbooks do not report the average price paid for, or quantity of, aviation fuel consumed by each carrier, only total expenditure. I thus decided to use the wholesale mid-month average jet fuel prices reported for north-west Europe, the Mediterranean and the US in *The Avmark Aviation Economist* in US cents per gallon, and assume that carriers on average face the price of jet fuel of the region that the country they are based in is part of[55,56,57]. The average price of investment goods and services in the country in which a carrier is based was used as the price of "other".

Estimating "residual" TFP

The TFP index used in my analysis was calculated using a production function of Cobb-Douglas form[58]. Total annual remuneration[59], rather than total number of workers, was used as an estimate of labour input because it better captures the level of skills a carriers' employees possess given that wages are usually linked to productivity[60,61]. The

meals, employee travel, consulting services and non-labour repair and maintenance expenses, stationery etc.

[50] governments can own less than 50% of total carrier equity but be the largest share-holder and hence effectively control the actions of the carrier.

[51] as in the case of the average price of investment goods and services, this is calculated as the PPP divided by the exchange rate, and adjust the total wage bill for cross-country differences in the average price of homogeneous, non-traded goods and services. The average price of consumption (rather than investment) goods and services is used given that wages are typically linked to the CPI.

[52] pilots and aircraft maintenance engineers are (at least to a certain extent) sourced globally, and hence it can be expected that there will be relatively lower variation in their salaries across carriers.

[53] many thanks to Professor Peter Forsyth of the Department of Economics, Faculty of Business and Economics at Monash University for this suggestion.

[54] for the all-cargo carriers in my sample (Hunting Cargo Airlines (UK) and Federal Express (US)) the price of labour was calculated using the same method as in Oum and Yu (1997).

[55] prices were also reported for Singapore for the years 1982-1984. Given that in these years fuel prices were very close those in the Mediterranean, I assumed that East and South Asian carriers and Qantas Airways faced Mediterranean jet fuel prices in my analysis.

[56] although this assumes that the nominal jet fuel price faced by carriers based in countries in a particular region is the same, the real jet fuel price will vary across countries due to differences in the WPI. Obviously, however, this still assumes that carriers based in the same country face the same average jet fuel price, which will depend on how similar the international route networks of these carriers are (as carriers will re-fuel for the return leg of international routes in the foreign country where the average price of fuel may be different from that in the home country), and that this price is similar to the regional average.

[57] Oum and Yu (1997) estimate the price of fuel by regressing total carrier expenditure on jet fuel on a constant and several variables (TKA, total kilometres flown, average load factor, aircraft hours, total number of departures, aircraft type and year effects) which they assume determine the quantity of fuel used.
Given that total expenditure = price x quantity, the price of jet fuel is then the (exponent of) the constant term.
Obviously under this method the price of fuel also contains the effects of random disturbance terms.
I spent several weeks estimating similar regressions, but could not even get fairly consistent relationships between the quantity variables and total expenditure on jet fuel across the carriers in my sample. I thus decided the use figures reported in *The Avmark Aviation Economist*.

[58] experimenting with other functional forms is an area for future research.

[59] again, divided by the average price of consumption goods in the country in which the carrier is based.

[60] among the various categories of airline employees there are vast differences in skill levels; using the total number of

total quantity of fuel was calculated by dividing total fuel expenditure by its price[62]. Total expenditure on "other" inputs was calculated by subtracting depreciation of flight equipment and ground property and equipment and rental of flight equipment costs. total remuneration and total expenditure on jet fuel. and then. given the (heterogeneous) nature of these inputs. this was divided by the average price of investment goods and services to obtain an "other" input quantity index.

My final production function estimation results are shown in Table 1 below. All variables (both independent and dependent) are logged and divided by average stage length in order to obtain a "residual" TFP index (that is. TFP net of factors beyond managerial control). as in Oum and Yu (1997)[63].

Table 1 shows that the coefficients of all variables are individually statistically significant at the 5% level. The coefficients of all variables except the capital stock variable have the expected sign: the negative coefficient may be due to the fact that over the time period under consideration many carriers were in the process of fleet-rationalisation and hence still had excess capacity accumulated over the years when they were government owned. In this case a further increase in carrier capital stock would have re-allocated resources away from more productive uses, lowering total output[64]. The sum of the coefficients of the input variables (0.80154) is relatively low: it suggests that there were significant diseconomies of scale for the carriers in my sample. Nevertheless the conclusion that there were negligible or negative (as in Oum and Yu (1997)) returns to scale in the provision of air transport services can still be drawn from these results.

Table 1
Production Function Estimation Results

Dependent Variable: **output/ average stage length**

	coefficient	standard error	t-ratio (694 df)	p-value
constant	-2.014	0.16277	-12.373	0.0000
capital stock / average stage length	-0.021818	0.010648	-2.049	0.0408
working capital / average stage length	0.009964	0.004817	2.0685	0.0390
labour / average stage length	0.051754	0.010518	4.9207	0.0000
fuel / average stage length	0.65226	0.018277	35.688	0.0000
other / average stage length	0.10938	0.013427	8.1461	0.0000
Number of Observations:	700			
R-Squared:	0.6728			
Log-Likelihood Function:	524.457			

workers. however assumes that each worker provides the same marginal contribution to output, and hence ceteris paribus carriers with a relatively small number of highly-skilled employees appear to have lower output-producing capabilities than carriers with large numbers of unskilled workers (such as government-owned, excess labour-absorbing carriers). Using the total number of hours worked (if such figures were reported) would similarly not capture the skill levels of employees.

[61] measuring labour inputs in this way also means that its units of measurement are the same as those of the capital stock.

[62] quantities of fuel and "other" inputs (rather than expenditure on. or values of. these inputs) are included given that these inputs are used up in the production process in each time period (whereas. in the case of capital and labour, it is the services of these inputs that are used).

[63] Oum and Yu (1997) adjust for other factors such as output mix (the proportion of total revenue attributable to incidental services. and the proportions of total TKP attributable to non-scheduled TKP and freight and mail TKP, respectively): however. given that for the carriers in my sample over the time period under consideration there was no discernible relationship between these variables and variable cost. I only adjusted for average stage length.

[64] the low standard error and (hence) high t-ratio and p-value of even the capital stock variable do not suggest multicollinearity problems in the model.

4. Total Variable Cost Equation Estimation Results

Tables 2a and 2b show the total variable cost equation estimation results when the calculated "residual" TFP index is omitted and included. respectively[65].

Table 2a
Total Variable Cost Function Estimation Results:
"Residual" TFP Index Omitted

Dependent Variable: **total variable cost**

	coefficient	standard error	t-ratio (691df)	p-value
constant	4.3001	0.27977	15.37	0.0000
output	0.58265	0.019785	29.449	0.0000
average stage length	-0.15248	0.027124	-5.6216	0.0000
average load factor	-0.30277	0.067184	-4.5066	0.0000
capital stock	0.23872	0.012643	18.882	0.0000
working capital	0.067547	0.0062272	10.847	0.0000
price of labour	0.048969	0.011551	4.2393	0.0000
price of fuel	0.25284	0.017071	14.811	0.0000
price of other	0.2778	0.029632	9.3747	0.0000

Number of Observations:	700
R-Squared:	0.7302
Log-Likelihood Function:	419.886

---

[65] usually the total variable cost equation is estimated together with the associated factor cost share equations in order to improve efficiency.
In the Cobb-Douglas case.
∂ ln total variable cost = β_k
∂ ln price input k
but we know the LHS = ∂ total variable cost . price of input k . which in equilibrium___
$\qquad$ ∂ price input k $\qquad$ total variable cost
$\qquad$ = quantity input k . price input k
$\qquad$ total variable cost
$\qquad$ = cost share of input k:
hence we restrict the coefficients of the (logged) factor price variables to be equal to their factor cost shares
(these are equations 2. 3. and 4 (although capital stock is fixed in the short-run. carriers still make rental payments on flight equipment and incur capital stock depreciation costs: however this cost-share equation is dropped to avoid singularity of the variance-covariance matrix)).
Given that in the frontier cost equation estimation packages that the author is aware of system estimation is not possible. only the single equation estimation results are reported in this paper to facilitate comparison (system estimation results are available. however. upon request).

Table 2b
Total Variable Cost Function Estimation Results:
"Residual" TFP Index Included

Dependent Variable: **total variable cost**

	coefficient	standard error	t-ratio (690 df)	p-value
constant	4.3161	0.23895	18.062	0.0000
output	0.70732	0.01702	41.558	0.0000
average stage length	-0.19985	0.020723	-9.644	0.0000
average load factor	-0.24722	0.062888	-3.9311	0.0001
capital stock	0.17692	0.010491	16.863	0.0000
working capital	0.067553	0.0058236	11.6	0.0000
price of labour	0.040325	0.011023	3.6582	0.0003
price of fuel	0.32888	0.016774	19.607	0.0000
price of other	0.25957	0.026592	9.7612	0.0000
"residual" TFP	-0.047595	0.0044841	-10.614	0.0000

Number of Observations:	700
R-Squared:	0.7843
Log-Likelihood Function:	446.687

The tables show that in both equations the coefficients of all variables have their expected sign, including the "characteristic variables" average stage length and average load factor, and the coefficients of the variables are all individually statistically significant at even the 1% level[66]. The fact that the coefficient of the "residual" TFP index is highly significant suggests that there is little relationship between this variable and the error term and hence that multicollinearity is not a problem in this model. The coefficient of the "residual" TFP index indicates that, ceteris paribus. a one percent increase in the value of this index (either due to technological progress or an increase in technical efficiency (or both)) would have decreased carrier total variable cost by approximately 0.04760% on average for the carriers in my sample over the time period considered.

The main quantitative difference between the two estimated equations is perhaps the magnitude of the coefficient of the output variable. In Table 2a this is estimated to be approximately 0.5827, suggesting, contrary to literature on the aviation industry. that there are huge economies of scale inherent in the provision of air transport services. When the "residual" TFP index is included in the total variable cost equation, however, this coefficient is estimated to be approximately 0.7073. which, although still lower than expected, is significantly higher than when this index is omitted.

These results suggest that the inclusion of the "residual" TFP index may have improved the equation. Given the (individual) statistical significance of the coefficient of this index, at the very least this has not detracted from the equation. I thus decided to use the results in Table 2b in my initial DWL calculations.

In 1995. JAL supplied 8 894 946 650 units of output[67], and its total variable costs were $US 11 631 449 024[68] [69]. Given assumption 1).

Pjal = <u>11 631 449 024</u>

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[66] of course given that we are estimating the total variable cost equation without the associated factor cost share equations. the coefficients of the (logged) factor price variables do not reflect their actual share of total variable costs: for the carriers in my sample over the time period under consideration. the actual average shares of labour, fuel and "other" inputs were approximately 22.7%. 17.6% and 48% respectively.

[67] given that flight output is measured in TKP and the quantity of incidental services produced is proxied by a quantity index. total airline output must be measured in "units".

[68] given that all "values" are measured in $US. "US" will be omitted from here on.

[69] all values are measured in $1990. given that the base years of the WPI and CPI indices is 1990. $1995 values can be obtained by multiplying the calculated values by the 1995 values of the WPI and CPI.

8 894 946 650

= $1.3076[70]; that is. the average price at which JAL provided its services was $1.3076 per unit of output.

In 1995 the average value of the TFP index among the 50 carriers in my sample was 1.7923. higher than the value for JAL (1.6702). Substituting this into the estimated equation:

In total variable cost = 4.3161 + 0.7073 ln(8894946.6498) -0.1999 ln(2325.6111)
      -0.2472 ln(0.6518) + 0.1770 ln(10122524.9458) + 0.06755 ln(873459.8698)
      + 0.04033 ln(102711.2027) + 0.3289 ln(0.0005141) + 0.2596 ln(1.4055)
      -0.04760 ln(1.6703)

      = 16.003745

∴ total variable cost = 8 919 451.7992

      = $ 8 919 451 799

Thus if an average carrier (with average TFP) had provided JAL's output in 1995 given JAL's output characteristics. with JAL's capital stock and faced JAL factor prices. its total variable cost would have only been $ 8 919 451 799, approximately 76.68% of JAL's total variable costs.

Given assumption 2),

Pav = $\frac{8\ 919\ 451\ 799}{8\ 894\ 946\ 650}$

   = $1.002755

The average carrier would have provided its output at only $1.002755 per unit, which is approximately 76.69% of JAL's price. At this price. however. it would have been able to sell more output than JAL.

Using the formula $\eta_A = \frac{dQ}{dP} \cdot \frac{P}{Q}$.

our assumed value of the price elasticity of demand for all air transport services provided by JAL (-1.16), and assumptions 3) and 4),

$\frac{dQ}{dP}$ = -1.16 $\frac{(8\ 894\ 946\ 650)}{(1.3076)}$

   = -7 890 897 915

∴ $\frac{dP}{dQ}$ = -1.2673E-10. which is the slope of the demand curve for JAL output.

Hence dQ = $\frac{(1.002755-1.3076)}{-1.2673E-10}$

      = 2 405 500 774. given assumption 2).

∴ Qav = 8 894 946 650 + 2 405 500 774

      = 11 300 447 424

---

[70] for consistency. all prices are reported to four decimal places.

Hence the carrier with average TFP would have provided 11 300 447 424 units of output at Pav. 2 405 400 774 more than JAL: that is, output would increase by approximately 27.04%. Given assumption 4), we can then calculate the DWL ABC from the formula of a triangle:

$$\text{area triangle ABC} = \frac{1}{2}(11\ 300\ 447\ 424 - 8\ 894\ 946\ 650) \cdot (1.3076 - 1.002755)$$

$$= 366\ 652\ 442$$

Hence the DWL to consumers of JAL output in 1995 from having JAL providing this output rather than a carrier with average TFP was approximately $ 366 652 442.

If factors were also freely tradable in 1995, and given assumption 6), my sample indicates that the carrier with average TFP would have sourced all of its labour and fuel from Egypt, and all of its "other" inputs from Malaysia. Substituting the prices of these inputs into the total variable cost equation:

$$\ln \text{total variable cost} = 4.3161 + 0.7073 \ln(8894946.6498) - 0.1999 \ln(2325.6111)$$
$$-0.2472 \ln(0.6518) + 0.1770 \ln(10122524.9458) + 0.06755 \ln(873459.8698)$$
$$+ 0.04033 \ln(1255.1106) + 0.3289 \ln(0.0001570) + 0.2596 \ln(0.3884)$$
$$-0.04760 \ln(1.6703)$$

$$= 15.1022$$

$$\therefore \text{total variable cost} = 3\ 620\ 610.9365$$

$$= \$ 3\ 620\ 610\ 937$$

Thus if the "average" carrier had provided JAL's output in 1995 given JAL's output characteristics and with JAL's capital stock but could source all of its inputs globally, its total variable cost would have been $ 3 620 610 937, which is only approximately 31.13% of the total variable cost of JAL.

$$\text{Hence Pav.ftf} = \frac{3\ 620\ 610\ 937}{8\ 894\ 946\ 650}$$

$$= \$ 0.4070$$

It would have supplied its output at only $ 0.4070 per unit; hence consumers of air transport services would have saved on average 0.9006 cents per unit of output.

$$dQ = \frac{(0.4070 - 1.3076)}{-1.2673\text{E-}10}$$

$$= 7\ 106\ 606\ 275$$

$$\therefore \text{Qav. ftf} = 8\ 894\ 946\ 650 + 7\ 106\ 606\ 275$$

$$= 16\ 001\ 552\ 925$$

At this price, it would have produced 16 001 552 925 units of output, 7 106 606 275 units more than JAL.

$$\text{area triangle ADE} = \frac{1}{2}(16\ 001\ 552\ 925 - 8\ 894\ 946\ 650) \cdot (1.3076 - 0.4070)$$

$$= 3\ 200\ 104\ 806$$

Hence the DWL from having JAL provide its output level at JAL factor prices rather than a carrier with average TFP which sources its factors globally providing its output level at its per unit average price was approximately $ 3 200 104 806.

5. Frontier Total Variable Cost Equation Estimation Results

Tables 3a and 3b show the frontier total variable cost equation estimation results calculated using the adjusted coefficients method when the "residual" TFP index is omitted and included. respectively[71].

In both equations the coefficients of all variables have their expected sign. and the coefficients of the variables are all individually statistically significant at even the 1% level[72,73]. Once again the "residual" TFP index is highly significant. suggesting that there is no multicollinearity problem in this model, and hence that there is little relationship between the TFP index and the error term. The coefficient of the TFP index indicates that, ceteris paribus, a one percent increase in TFP would have decreased carrier total variable cost by approximately 0.07996% on average for the carriers in my sample over the time period considered. As for the standard total variable cost equation, the coefficient of the output variable increases in magnitude when the "residual" TFP index is included in the equation (but is still lower than expected). Given these results, I decided to again use the equation which includes the "residual" TFP index in my DWL calculations.

Table 3a
Frontier Total Variable Cost Function Estimation Results:
"Residual" TFP Index Omitted

Dependent Variable: **total variable cost**

	coefficient	standard error	t-ratio
constant	3.8515798	0.39909158	9.650867
output	0.637413	0.024192236	26.347831
average stage length	-0.09444	0.038593999	-2.4470153
average load factor	-0.439536	0.097708257	-4.4984491
capital stock	0.2304578	0.015609523	14.763926
working capital	0.0911834	0.009089003	10.032283
price of labour	0.104662	0.017616838	5.9410192
price of fuel	0.5371403	0.019601276	27.403334
price of other	0.2288592	0.047439763	4.8242065

Number of Observations: 700

Table 3b
Frontier Total Variable Cost Function Estimation Results:
"Residual" TFP Index Included

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[71] the results presented in this section were calculated using Coelli's FRONTIER Program (Version 4.1).

[72] except for the coefficient of the average stage length variable in the first equation. which is significant at the 5% level.

[73] note that the coefficients of the variables in Tables 3a and 3b are different from those in Tables 2a and 2b respectively.

Dependent Variable: total variable cost

	coefficient	standard error	t-ratio
constant	3.8474956	0.38975751	9.8715112
output	0.6709345	0.02411864	27.818089
average stage length	-0.114269	0.037783136	-3.0243339
average load factor	-0.383421	0.097034123	-3.9514018
capital stock	0.2235981	0.015836613	14.119061
working capital	0.0870781	0.008825211	9.8669749
price of labour	0.0988533	0.017277536	5.7214911
price of fuel	0.549247	0.020301733	27.054194
price of other	0.2425803	0.046278661	5.2417307
"residual" TFP	-0.079955	0.014452031	-5.5324526

Number of Observations: 700

If ASAs were abolished and hence there were no restrictions on international carrier operations, not only would the carrier with the highest "residual" TFP index be able to operate in city-pair markets served by JAL, it would also be able to serve these markets at its minimum cost as it would be able to achieve the maximum cost-savings available to it by being able to fully exploit the economies of traffic density inherent in the provision of its services[74].

My sample indicates that in 1995 the carrier with the highest TFP index was British Airways (3.7539). Substituting this into the frontier variable cost equation:

ln total variable cost = 3.8475 + 0.6709 ln(8894946.6498) -0.1143 ln(2325.6111)
-0.3834 ln(0.6518) + 0.2236 ln(10122524.9458) + 0.08708 ln(873459.8698)
+ 0.09885 ln(102711.2027) + 0.5492 ln(0.0005141) + 0.2426 ln(1.4055)
-0.07996 ln(3.7539)

= 15.6174

∴ total variable cost = 6 061 286.2297

= $ 6 061 286 230

Thus if British Airways had provided JAL's output in 1995 given JAL's output characteristics with JAL's capital stock and faced JAL factor prices, its total variable cost would have been $ 6 061 286 230, which is approximately half (52.11%) the total variable cost of JAL.

Hence Pm = $\frac{6\ 061\ 286\ 230}{8\ 894\ 946\ 650}$

= $ 0.68143

British Airways would have provided output at an average price of only $ 0.68143 per unit of output. This is lower than the price at which the average carrier subject to JAL factor prices would have supplied this output level, but higher than the price at which the average carrier would have provided it given that factors of production are freely tradable.

dQ = $\frac{(0.68143-1.3076)}{-1.2673E-10}$

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[74] obviously its ability to fully exploit economies of traffic density and hence achieve the maximum cost-savings possible will depend also on airport infrastructure, international competition policy, foreign ownership rules, the level of government financial assistance to carriers, and airline access to a dispute settlement mechanism. This point is discussed further in Section 6.

= 4 940 976 880

$\therefore$ Qm = 8 894 946 650 + 4 940 976 880

= 13 835 923 530   .

Hence the minimum cost carrier would have provided 13 835 923 530 units of output, more than the carrier with average TFP when it is subject to JAL factor prices, but less than this carrier when factors are fully tradable.

area triangle AFG = $\frac{1}{2}$ (13 835 923 530 - 8 894 946 650) . (1.3076 - 0.68143)

= 1 546 945 746

Hence the DWL from having JAL rather than British Airways providing JAL's output in 1995 was approximately $ 1 546 945 746.

If we again make the assumption that factors of production are freely tradable, using our frontier total variable cost equation:

In total variable cost = 3.8475 + 0.6709 ln(8894946.6498) -0.1143 ln(2325.6111)
    -0.3834 ln(0.6518) + 0.2236 ln(10122524.9458) + 0.08708 ln(873459.8698)
    + 0.09885 ln(1255.1106) + 0.5492 ln(0.0001570) + 0.2426 ln(0.3884)
    -0.07996 ln(3.7539)

= 14.2185

$\therefore$ total variable cost = 1 496 322.2509

= $ 1 496 322 251

Thus if British Airways had provided JAL's output in 1995 given JAL's output characteristics, and with JAL's capital stock but could source all of its inputs globally, its total variable cost would have only been approximately $ 1 496 322 251, which is only approximately 12.86% of the total variable costs of JAL.

Pm, ftf = $\frac{1\,496\,322\,251}{8\,894\,946\,650}$

= $ 0.1682

Hence British Airways would have provided output at an average price of $ 0.1682,
which is lower than even the price at which the average carrier given free trade in factors of production would have supplied it.

Thus dQ = $\frac{(0.1682-1.3076)}{-1.2673E-10}$

= 8 990 594 177

$\therefore$ Qm, ftf = 8 894 946 650 + 8 990 594 177

= 17 885 540 827

Hence the minimum cost carrier would have supplied 17 885 540 827 units of output, more than double that supplied by JAL, and more than that supplied by the average carrier also given free trade in factors.

area triangle AHI = $\frac{1}{2}$ (17 885 540 827 - 8 894 946 650) . (1.3076 - 0.1682)

Hence the DWL to consumers of JAL output in 1995 from having JAL provide this output at JAL factor prices rather than the carrier with the highest TFP in that year which sources its factors globally was approximately $ 5 121 941 503.

Table 4 shows the cost efficiency indices of the carriers in my sample over the period 1982-1995, which, given our assumption that the TFP index fully captures the effects of carrier technical efficiency (as well as technological progress), are actually indices of relative allocative efficiency. The table shows that over this period none of the carriers were allocatively efficient (as all the values are significantly greater than one), and hence the common assumption that they are is misleading. The table indicates that on average Asian and Australasian carriers tended to have (relatively) the highest levels of allocative efficiency, particularly non-Japanese East Asian carriers and Qantas Airways (South Asian carriers tended to be somewhat less allocatively efficient). North American carriers also tended to have high levels of allocative efficiency, particularly carriers based in Canada. It is difficult to conclusively determine the relative allocative efficiency of Central and South American and African carriers given that there are only three airlines of each type in my sample, and the values vary significantly across these carriers. UK and Western European carriers, however, seem to have much lower levels of allocative efficiency on average than either their Asian and Australasian or North American counterparts. As in the case of the other groups, values vary significantly across the carriers in this group. Perhaps the most interesting thing to notice about Table 4, however, is the fact that the indices increase over time for all carriers, suggesting that either carriers are becoming less allocatively efficient over time, or, more plausibly, that the cost frontier is shifting down over time. The exact determinants of the rise in these indices over time is a topic for further investigation.

Table 4
Estimated (Allocative) Efficiency Indices

	1982	1985	1988	1991	1995	Average 82-95
North America						
American Airlines	1.48	1.58	1.70	1.86	2.13	**1.76**
America West Airlines	1.22	1.26	1.31	1.37	1.47	**1.33**
Continental Airlines	1.47	1.57	1.68	1.83	2.10	**1.74**
Delta Air Lines	1.50	1.61	1.73	1.90	2.19	**1.79**
Federal Express	1.87	2.07	2.32	2.67	3.32	**2.46**
Hawaiian Airlines	1.39	1.47	1.56	1.68	1.89	**1.61**
Northwest Airlines	1.36	1.44	1.52	1.63	1.82	**1.56**
Tower Air	1.57	1.68	1.83	2.02	2.37	**1.90**
Trans World Airlines	1.64	1.78	1.95	2.18	2.59	**2.03**
United Air Lines	1.57	1.69	1.84	2.04	2.39	**1.91**
US Airways	1.53	1.64	1.78	1.95	2.27	**1.84**
Air Canada	1.36	1.42	1.51	1.61	1.80	**1.55**
Canadian Airlines	1.40	1.48	1.58	1.70	1.91	**1.62**
UK and Western Europe						
Britannia Airways	1.48	1.58	1.70	1.85	2.13	**1.75**
British Airways	1.45	1.54	1.65	1.79	2.04	**1.70**
British Euro Airways	1.86	2.05	2.31	2.65	3.29	**2.44**
British Midland Airways	2.04	2.30	2.63	3.08	3.96	**2.81**
Hunting Cargo Airlines	2.32	2.66	3.12	3.76	5.05	**3.39**
Monarch Airlines	1.17	1.20	1.24	1.29	1.36	**1.25**
Virgin Atlantic Airways	1.22	1.26	1.31	1.37	1.48	**1.33**
KLM uk	2.35	2.70	3.17	3.83	5.17	**3.45**
Austrian Airlines (AUA)	1.90	2.11	2.38	2.75	3.44	**2.53**
Finnair	1.38	1.46	1.55	1.67	1.87	**1.59**
Air France	1.48	1.57	1.69	1.85	2.12	**1.75**
Lufthansa	1.62	1.76	1.92	2.14	2.54	**2.00**
Alitalia	1.51	1.61	1.74	1.91	2.20	**1.80**
KLM Royal Dutch Airlines	1.43	1.52	1.63	1.76	2.00	**1.67**
TAP Air Portugal	1.89	2.09	2.36	2.72	3.40	**2.50**
Scandinavian Airlines System (SAS)	1.87	2.07	2.33	2.67	3.32	**2.46**
Aviaco	1.71	1.87	2.07	2.32	2.81	**2.16**
Iberia Airlines	1.54	1.65	1.79	1.97	2.29	**1.85**
Swissair	1.72	1.88	2.09	2.36	2.86	**2.19**

Asia and Australasia

Air India	1.54	1.65	1.79	1.96	2.28	1.85
Indian Airlines	1.63	1.77	1.94	2.17	2.58	2.03
All Nippon Airways (ANA)	1.59	1.71	1.87	2.07	2.44	1.94
Japan Air Lines (JAL)	1.39	1.46	1.55	1.67	1.87	1.59
Japan Asia Airways (JAA)	1.97	2.20	2.51	2.91	3.70	2.67
Malaysian Airlines	1.30	1.35	1.42	1.51	1.65	1.45
Pakistan International Airlines (PIA)	1.68	1.82	2.01	2.25	2.70	2.10
Philippine Air Lines (PAL)	1.42	1.50	1.61	1.74	1.96	1.65
Singapore Airlines	1.28	1.33	1.39	1.47	1.61	1.42
Thai International Airways	1.36	1.43	1.52	1.63	1.82	1.56
Cathay Pacific Airways	1.14	1.16	1.19	1.23	1.28	1.20
Qantas Airways	1.28	1.33	1.40	1.48	1.61	1.42

Central and South America

Mexicana Airlines	1.32	1.38	1.46	1.55	1.71	1.49
VARIG Brazilian Airlines	1.46	1.55	1.66	1.81	2.06	1.71
LACSA Airlines	1.75	1.91	2.13	2.41	2.93	2.23

Africa

EgyptAir	1.40	1.48	1.58	1.70	1.92	1.62
Air Madagascar	1.82	2.00	2.24	2.56	3.15	2.36
Tunis Air	1.81	2.00	2.23	2.55	3.14	2.35
Year Average	**1.57**	**1.69**	**1.85**	**2.06**	**2.44**	**1.93**

6. Summary of Results and Complementary Issues

In summary, the results in Sections 4 and 5 show that, given our seven assumptions, the DWLs arising from the fact that ASAs prevent not only higher productivity, lower-cost carriers from providing services in particular city-pair markets, but also prevent these carriers from fully exploiting the economies of traffic density inherent in the provision of such services (and hence maximising their cost-savings) are not negligible, particularly when combined with current restrictions on international factor flows. This suggests that apart from the usual transfers[75]the gains to society (from not incurring the DWLs) from relaxing the current restrictions on trade in air transport services imposed by ASAs would be significant, and would be greater the greater the extent to which both they and current restrictions on international factor flows are relaxed.

Obviously the magnitude of the calculated gains may change somewhat if we use less restrictive assumptions in our calculations, but the relative sizes of the gains under partial and full liberalisation will not change, with and without full liberalisation of international factor flows. The magnitude of the gains will also be determined, however, by five other factors.

The first of these is carrier subsidies. Despite the reduction in direct subsidies over the past decade or so, governments still provide indirect subsidies to carriers in many countries[76]. These provide carriers with "soft" budget constraints, enabling them to provide services in markets with relatively low TFP and high unit costs. These cost of these subsidies to the government must obviously covered by tax revenue, imposing costs on all tax-payers (not just consumers of air transport services). The second of these factors is foreign ownership rules. Currently foreign ownership in airlines based in a particular country is restricted to a maximum of 50% of total equity (often foreign carriers are only allowed to own substantially less than 50%), in order to ensure that carriers are covered by the terms of the ASAs which its base country is a signatory to (that is, that they are deemed "national carriers"). These rules,

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[75] the relative magnitudes of the transfers to consumers and producers respectively, as already discussed, will be determined by the position and slope of the supply curve and the extent to which consumers of air transport services also are holders of carrier equity.

[76] it can be argued, for example, that the US Chapter 11 Bankruptcy Code acts as an indirect subsidy to US carriers

however, prevent lower-cost foreign carriers from providing services in particular city-pair markets, either by setting up their own operations. or by taking over and rationalising the operations of carriers already serving these markets. Over the past decade or so. many carriers have engaged in practices such as (less than 50%) equity purchases. minor equity swaps. block-purchasing and code-sharing agreements, and marketing alliances, which have enabled them to circumvent foreign ownership restrictions and (indirectly) provide services in city-pair markets which they are prevented from (directly) serving by the terms of the ASAs which they are subject to[77].

The third of these factors is infrastructure shortages at airports. Currently many of the world's major airports have severe capacity constraints. due to the rapid increase in the demand for air transport services over the past decade or so. These constraints not only hinder the ability of carriers currently serving these airports to maximise their cost-savings (by capturing economies of traffic density), but also prevent (possibly lower-cost) other carriers from serving these markets (which in turn provides carriers already serving these markets with a certain degree of protection). The fourth factor is dispute settlement. Civil aviation is not covered by the General Agreement on Trade in Services (GATS) dispute settlement mechanism, and hence there is currently no multilateral forum for resolving disputes over trade in aviation services between countries. ASAs have arbitration clauses. but these are non-binding. It is highly likely that disputes will be more frequent (as well as longer-lasting) should further liberalisation take place. particularly between those groups which stand to benefit from a more liberal market. and those who will incur substantial losses. Without an impartial body to resolve them. these could lead to vast amounts of carrier resources wasted on resolving them themselves.

The last factor is international competition policy. Currently there is no multilateral body which monitors competition. and many developing countries do not even have national competition policies[78]. Most developed countries have national competition policies[79] which are monitored by government-mandated regulatory authorities; however. typically these bodies are only legislated with the authority to control actions undertaken by carriers which occur in and affect the domestic economy: they have no jurisdiction over actions undertaken by either local or foreign carriers either in overseas markets (even though these actions might affect the domestic economy), or in local markets which affect foreigners[80]. Hence currently not only are a significant proportion of the actions undertaken by carriers in their provision of air transport services not subject to competition policy rules. but also those services which are governed by such rules are often subject to different rules, depending on the country in which they are undertaken. This would again prevent carriers from minimising their costs by restricting their ability to fully exploit economies of traffic density inherent in the provision of air transport services.

Hence any further moves towards liberalisation (either partial or total) would need to be accompanied by total abolishment of indirect carrier subsidies and foreign ownership restrictions. efforts to relieve current infrastructure shortages at major airports. and the establishment of bodies at the global level mandated with the authority to resolve disputes and monitor competition respectively. to ensure that the full benefits from such moves are realised.

The Section 4 and 5 results also show (given that its coefficient was (individually) statistically significant) that by including an index of "residual" TFP as an exogenous variable in our equation, we can determine not only the approximate contribution of TFP to carrier total variable cost among the carriers in our sample. but also whether or not these carriers were allocatively efficient over the time period considered (rather than simply assuming that they were). Obviously. however. we are still unable to analyse carrier technical efficiency, given that the estimated TFP indices will also contain the effects of (given) technological progress.

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[77] these actions have meant that carriers from third countries have been gaining some protection from ASAs. distorting the purely reciprocal nature of these agreements.

[78] in the East Asia region. for example. China. Indonesia. Malaysia and Thailand have no national competition policy (Lloyd (1996); 20).

[79] with the notable exceptions of Hong Kong and Singapore. which argue that they do not need them given their liberal policies on international trade.

[80] even among those bodies which do have authority over their national carriers' actions abroad. most tend to take a more lenient view of those actions which harm residents of other countries (ibid: 13)

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A fuzzy approach to Overbooking in Air Transportation

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1. Introduction

A flight, like most services, is produced by an airline company while supplying and cannot therefore be stored. If an aircraft takes off with some empty seats there is a lost revenue that cannot be recaptured.

The marginal revenue of an extra passenger occupying a seat which otherwise would have not been sold, is very large, while the additional supported costs are very small. For this reason it is very important for the airlines to reach a high load factor of the aircraft.

The problem is that even if a flight is sold out, i.e. the aircraft capacity matches exactly the number of booked seats, it is almost sure that the aircraft will leave the gate with some empty seats. This happens because some passengers don't appear to claim their seats the day of the departure and some cancel their reservation too late to allow the company to sell the seats again.

To reduce these effects most airlines overbook their scheduled flights to a certain extent in order to compensate for "no-shows". As a consequence, some passengers are sometimes left behind or "bumped" as a result. By bumping passengers from an oversold aircraft, an airline can incur costs ranging from nothing, if the excess passengers can be rebooked with the same airline on a later flight that day, to meals, hotel rooms, vouchers for free flights, and the cost of transportation on another airline, not considering the potential loss of customer goodwill.

Overbooking and automated reservation systems are today an important chapter of the *yield management*, which has become a basic tool for the survival of the airlines in the air transport market, increasing today more and more in competitiveness and complexity. It has been evaluated that in the period from 1989 to 1992 American Airlines have saved through yield management about 50% more than its net profit for the same period.

Generally airline accept reservation requests up to a booking limit, if the number of initial reservations is less than the booking limit, and decline the reservation requests otherwise.

As the number of no-show is a stochastic variable, it is possible that the passengers that show up are more than the available seats for the flight, thus producing the opposite problem of the seat spoilage, i.e. a number of denied boarding. These may be voluntary, if a passenger with a confirmed reservation accepts some kind of refund to abdicate the flight (money, hotel accommodation, meals, etc), otherwise is an involuntary denied boarding, causing damages to the company image and additional costs.

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Airline Overbooking at Aer Lingus

This paper presents a model of airline overbooking at class level. A level control model, based on revenue maximisation, is compared with the model used by Aer Lingus, Ireland's national airline. Solution methods are described and conclusions are presented.

Keywords: Air Transport, Yield Management

Introduction

Most airlines operate their passenger services on the basis of advance reservations. The new electronic methods of booking through the Internet mean that individuals no longer have to go through intermediaries to book seats, and so book on a number of flights in order to ensure that they get to their destination.

With intensified competition, this is causing problems for the airlines. They find that they are flying with empty seats, which if full would represent almost pure profit. The solution to this problem is to overbook; that is to allow more bookings than there are seats. This however is fraught with the possibility that should all these people show up, some will not get on the flight. This in turn may oblige the airline to pay standard compensation to the passenger who is denied boarding. There is also the not inconsiderable cost of customer dissatisfaction.

Initial studies of overbooking were hampered by the fact that airlines did not admit that they engaged in this practice. The first reported models [1,2] sought to determine booking levels by minimising the lost revenue from flying with empty seats plus the cost of denied boardings. These models were not widely implemented because they required the probability distributions of passenger demand and no shows. Estimating demand remains a problem today, but most airlines use large amounts of recorded data to estimate it to within acceptable levels.

Thompson's [3] model, which was the next major advance in the area, concentrated on the cancellation process and looked at the probability of there being denied boardings for any given booking level. The basic idea was that the number of cancellations, including no shows could be estimated using the standard binomial distribution. Thompson's work contained two major assumptions about groups and cancellations which will be discussed later in the development of the model which is the focus of this paper. Other researchers were to build on Thompson's work. These included Taylor [4], who incorporated a consideration of group sizes, Deetman [5], who studied the implementation of Taylor's ideas, and Rothstein and Stone [6] who implemented a related model for American Airlines in 1967. Rothstein [7] completed his doctoral thesis in 1968, and produced an overbooking model. This model moved away from Thompson's work and sought to maximise revenue subject to a constraint on the proportion of denied boardings, based on the theory of Markovian sequential decision processes. He used a dynamic programming approach to solve his model for one class of passenger only. For multiple classes, he treated each class as a separate flight.

Alstrup et. al. [8,9] published an overbooking model for flights with two types of passenger. This was described as a generalisation of Rothstein's model. The limitations of the dynamic programming solution approach became apparent when it was estimated that it would take 100 hours to solve the model for two classes on a 110 seater plane. Through the use of various heuristics, the solution time was reduced to under a minute.

Most models mentioned so far have been incremental control systems in which a maximum additional number of reservations can be accepted in a period. However, several airlines use a level control system in which reservations are accepted until the total number of reservations reaches a specified level. This approach requires more detailed information than the incremental approach. When dealing with a large number of classes the information requirements become prohibitive. The best known level control model was published by Eriksson [10] in 1992, in which demand and no shows were modelled as continuous distributions. This model was solved optimally for flights of two classes.

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9. Appendix

```
% function overb(dati,numMf,epochs,outputfile)
%
% dati = input matrix + output (last column)
% numMf = number di membership functions for the input (i.e. [3 2 4])
% epochs = number of iterations
% outputfile = name of the output file with .fis extension
%
function overb(dati,numMf,epochs,outputfile)
        data=dati;
        y=data(:,size(data,2));
        NumInput = size(data,2) - 1;
        TrainData = data;
        NumMfs = numMf;
        MfType = str2mat('trapmf');
        for i=1:NumInput-1,
                MfType = [MfType' str2mat('trapmf')']';
        end
        NumEpochs = epochs;
        StepSize = 0.1;
        InputFismat = genfis1(TrainData, NumMfs, MfType);
        close all;
        for i = 1:NumInput;
                subplot(NumInput, 1, i);
                plotmf(InputFismat, 'input', i);
                xlabel(['input ' num2str(i) ' (' MfType(i, :) ')']);
        end
        title('Initial fuzzy sets');
        OutputFismat = anfis(TrainData, InputFismat, [NumEpochs nan StepSize]);
        yy = evalfis(data(:,1:NumInput), OutputFismat);
        figure;
        plot(1:size(y,1),y,'o',1:size(y,1),yy,'x');
        legend('real','simulated');
        title('Real system vs. simulated system');
        figure;
        for i = 1:NumInput;
                subplot(NumInput, 1, i);
                plotmf(OutputFismat, 'input', i);
                xlabel(['input ' num2str(i) ' (' MfType(i, :) ')']);
        end
        title('Final fuzzy sets');
        writefis(OutputFismat,outputfile);
end
```

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- it is a good approximation of the intrinsic complexity of the problem.
  The program is reported in the Appendix.
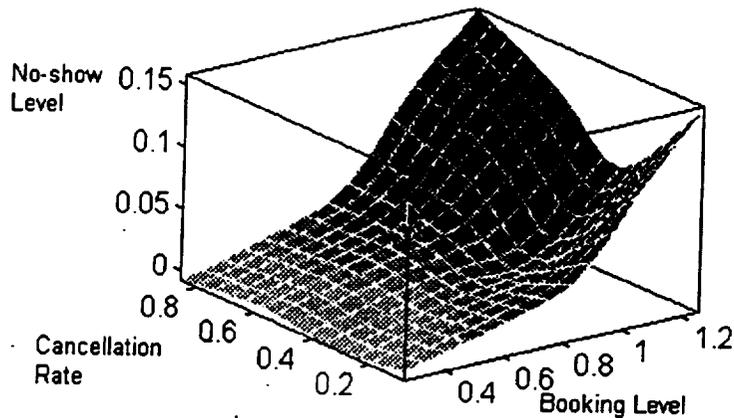
Figure 11 – Fuzzy Model Surface

As it can be seen in Figure 11, using a set of training data, ANFIS is able to approximate the booking process, showing a clear growth in the No-Show Level for increasing values of the Booking Level and of the Cancellation Rate.

8. Conclusions

A fuzzy approach to the overbooking problem in air transportation has been presented.

The aim is to show that a complex system, such as the booking process, can be better controlled in terms of fuzzy sets than crisp numbers and mathematical models.

The underlying idea is that the notion of high booking level or low no-show level may change form day to day, flight to flight, airlines to airlines, season to season, but the logic is always the same and is contained in the inference rules. Therefore the method can be easily tuned just shifting the fuzzy sets averages or the intervals of confidence.

It has been shown the capability of the function ANFIS, contained in the Fuzzy Logic Toolbox of Matlab, as a simple instrument to build an adaptive fuzzy inference system. When you try to approximate a function with an adaptive fuzzy inference system, there are several parameters that you can choose to vary, some relevant to the fuzzy system, such as number and shape of the membership functions, or the method of inference and defuzzification, some relevant to the training method, such as the number or the sequence of the training data. It would be worthwhile to carry out some analysis to find out which is the best configuration of these parameters to obtain the best approximation.

The model has been built considering only a fare class of passengers, while in reality it would be better to extend the forecast of total bookings for each fare class.

A problem that should be investigated with more detail is about the consequence of the limits settled on the number of seats that can be sold. By this way, in fact, the airline companies can only evaluate the accepted demand, while no observation can be done on

the demand that was turned away.

Finally Figure 10 shows the surface representing a 3D view of the overbooking model. It represents the outcome of the application of the FIS rules for each combination of the input variables.
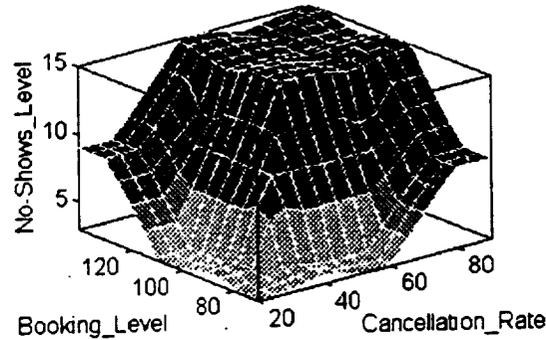
Figure 10 – 3D view

The model has been constructed using the software "Fuzzy Logic Toolbox", which is an extension of the MATLAB software application.

Using this fuzzy model an optimal booking policy can be adopted, by dynamically modifying the booking limit for the reservations that can be authorised in each time interval of the booking process. The authorisation level to be adopted for each picture is the sum of the cabin capacity and the number of no-show as calculated by the fuzzy model.

7. Neuro-Adaptive Fuzzy Inference Systems

As already said, the fuzzy sets (number, shape, range and overlapping) and the fuzzy rules are built by the co-operation of an expert and a fuzzy engineer, which traduces the experience into the fuzzy model. Otherwise it is possible to automate the process using a procedure based on the neural networks, such as the ANFIS function, contained in the Fuzzy Logic Toolbox of Matlab. This is a Neuro-Adaptive Fuzzy Inference System essentially constituted of a fuzzy inference system, whose rules and membership functions are derived by a back-propagation algorithm based on some collection of input-output data. By this way the fuzzy system is able to learn from the example data, applying some optimisation routines to reduce the error between the data and the fuzzy system output.

To carry out this learning procedure a fuzzy inference system has to be specified, or alternatively, if no supposition can be made on how the initial membership functions should be, it is possible to use the command *genfis1*, which will examine the training data set and then generate a FIS matrix based on the given numbers and types of membership functions. The membership functions of the input variables are uniformly distributed in the range of the training data. Of course this procedure requires that a large amount of historical data are available.

A Neuro Adaptive Fuzzy Inference System has been built using the Alitalia reservation database for the flight Rome-New York of the 1993. A simple program has been written in the internal Matlab language to demonstrate that a fuzzy inference system can be adopted to simulate the booking process of a flight and that two main aspecys can be pointed out:

- it can be easily and rapidly built;
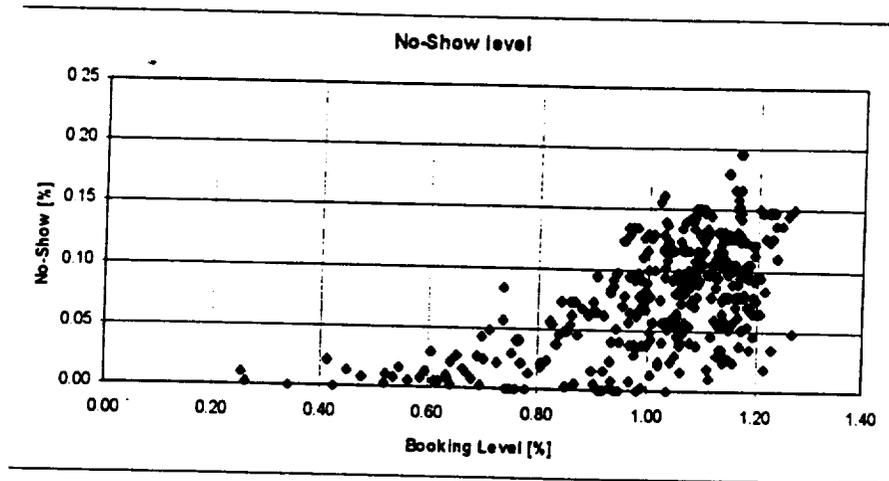
No-Show level

Figure 8 - No-Show Level as a function of the Booking Level

For the modelling of the system the following input control variables has been chosen:

- the booking level (BL) at any time before departure, as the total reservations made up to that time minus the total cancellations (in percent of the aircraft capacity);

- the cancellation rate (CR) at any time before departure, as the ratio of the number of people who had cancelled their reservation to those who had booked (C/B for each picture).

The number of no-show passenger (NS) in percent of the aircraft capacity is the solution variable (output).

In Figure 9 the input and output fuzzy activated by the parallel action of each rule with the corresponding aggregated fuzzy regions are shown, while the final solution is obtained as defuzzification with the centroid method.
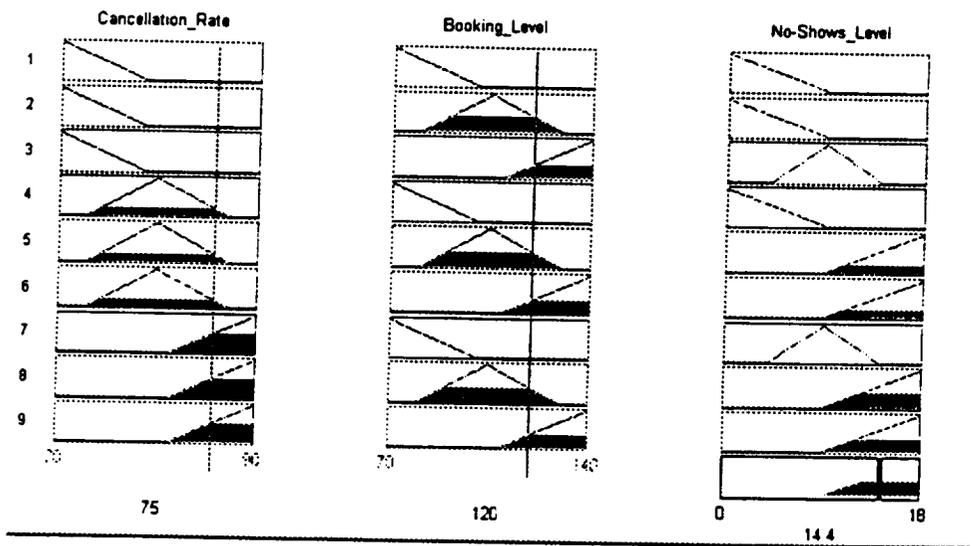
Figure 9 – Application of the FIS rules

consequence of discouraging penalty for lower fare classes, or as a consequence of the high cancellation rates and no-show rates observed for the higher fares.

The slope of the curve is steeper near a restriction expire for lower fares and near the very last few days for higher fares. The booking limits tend to flatten the curve and the airline loses information about the shape of the real curve of an unconstrained demand

The fact that, occasionally in the example shown, the average overbooked seats are coincident with the average no-show level is scarcely meaningful, as it might be the average result of flights with many denied boardings and flights with many empty seats. The goal for a effective forecasting policy is to get the "perfect hit" for each flight.

6. The Fuzzy Inference Overbooking Model

Following the concepts shown in paragraph 4, a Fuzzy Inference Overbooking Model has been built. The experience coming from the historical data of a flight reservation process has been incorporated to construct the membership functions as described in paragraph 4.2.2 and writing the rules as indicated in paragraph 4.2.3. The No-Show Level as a function of the Cancellation Rate and as a function of the Booking Level are plotted respectively in Figure 7 and in Figure 8, for a set of historical data of a typical booking process.
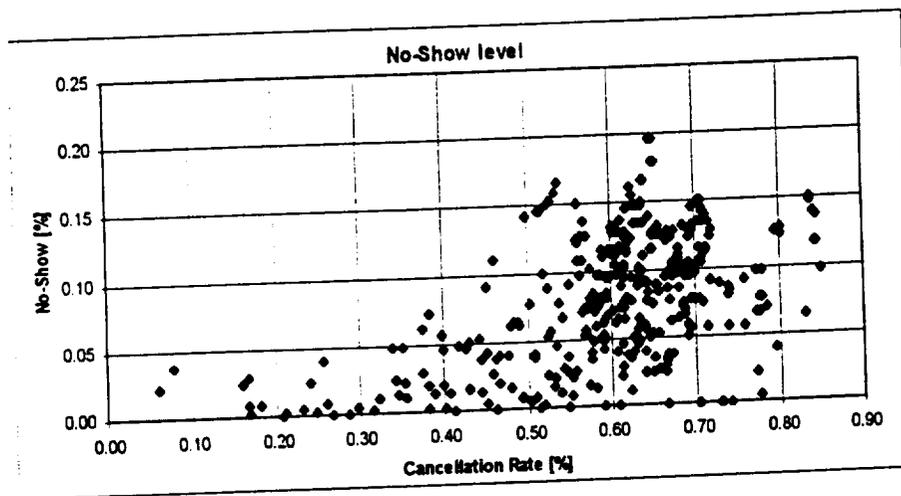
Figure 7 – No-Show Level as a function of the Cancellation Rate

As shown by these charts, there is a substantial trend to the growth of the No-Show Level both with the Booking Level and with the Cancellation Rate. The number of no-show, as percentage of the cabin capacity, seem to be a function of how much the cabin is engaged and how much passengers tend to reject their reservation. This means that the evolution of the booking process depends fundamentally on the state of the process, described by the Booking Level and by the Cancellation Rate, while the dependency from the time is weak.

- booking class
- picture number (from 1 to 13)
- event code (E, C, N, G)
- date of departure
- value of the event.

Pictures with their relevant time intervals are indicated in Table 1.

Picture	Days to departure
1	342-90
2	89-60
3	59-43
4	42-23
5	22-13
6	12-7
7	6-5
8	4-4
9	3-3
10	2-2
11	1-1
12	0-0
13	check in

Table 1 – Pictures of the flight

The event recorded for each picture are:
- B =actual booked passengers, i.e. the difference between reservations and cancellations;
- C = cancelled passengers;
- N = No-Show at departure, booked at the relevant picture;
- G = Go-Show are the total passengers appearing at the departure (picture 13) without reservation.

The effective number of boarded passengers is the minimum between the physical compartment capacity and the term (B+G-N).

In Figure 6 a typical example of average historical booking flight data are shown.

The Booking Level is the cumulative sum of B relevant for each picture. The Cancellation Rate is the ratio of the cumulative sum of the total cancelled seats to the reserved ones.
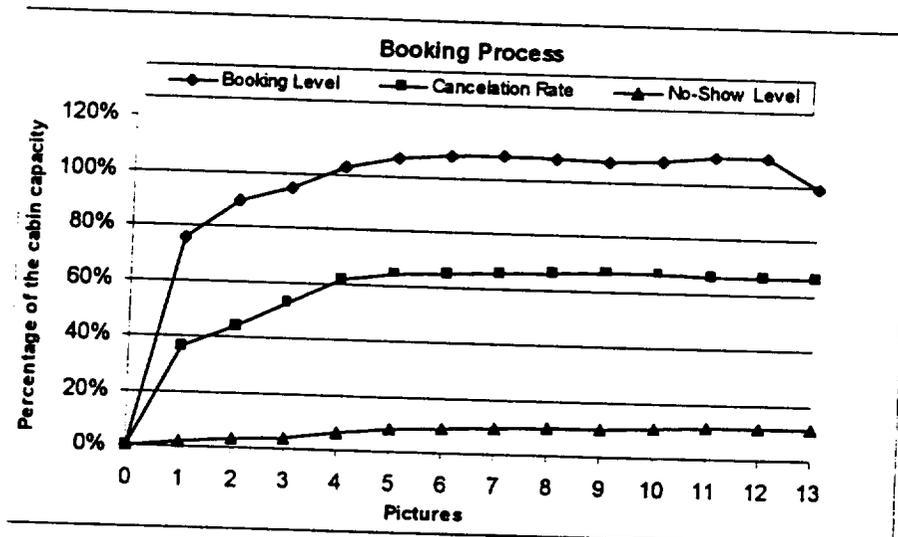
Figure 6 – Average of historical booking database

The falling down of the booking curve at the 13th picture is the effect of passengers who don't show up at the day of departure.

The shape of the booking curve for a specific class on a given flight depends on several factors. In fact it is important how early before take-off the reservations are made and besides it is usually found that leisure travellers usually book early, while business men late. Furthermore it is important that a large amount of cancellations occurs, as a
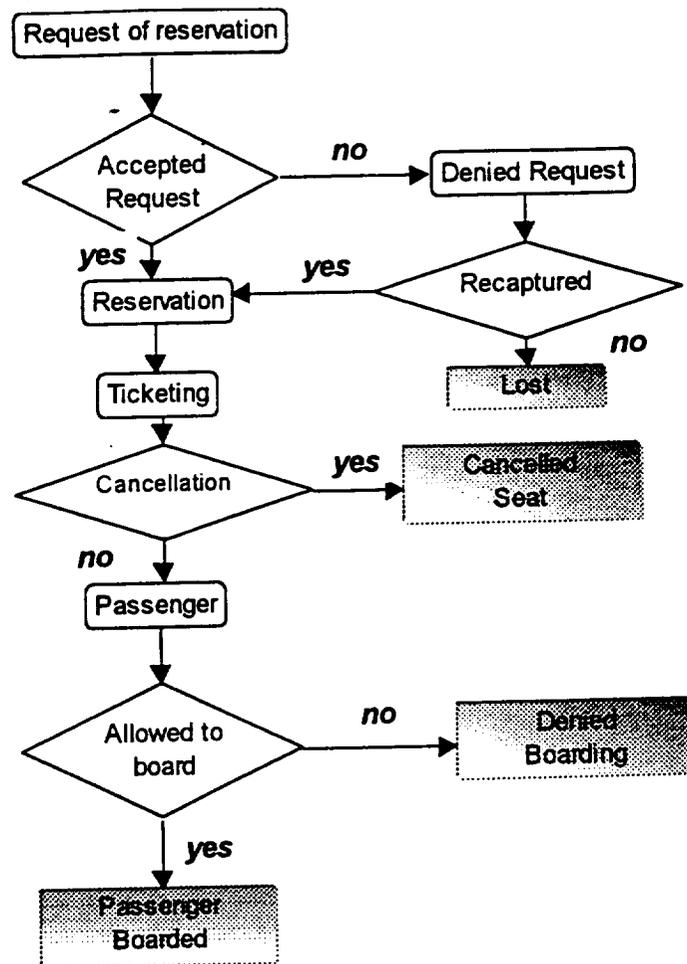
Figure 5 – The Booking Process

The result of the economic interaction between potential customers and the airline is a certain number of reservations and cancellations in each class on each flight.

Without any specific mathematical effort, a Fuzzy Inference System is able to incorporate all these factors, affecting the problem, as they are perceived by an expert (marketing specialist).

The booking process is divided into N time intervals of unequal length, i.e. the duration of each interval decreases as the departure date approaches.

Most airlines keep a record of some data describing the evolution of this process. A large number of such intervals is computationally impractical, while a small number allows no adjustment for differences between forecast and actual bookings as the booking history for each flight develops. Usually airlines hold an historical flight database where the booking process is photographed by 13 pictures. In details these reservation data contain:

- company
- flight number
- origin and destination
- day of the week
- type of aircraft
- compartment (i.e. top, business, economy)
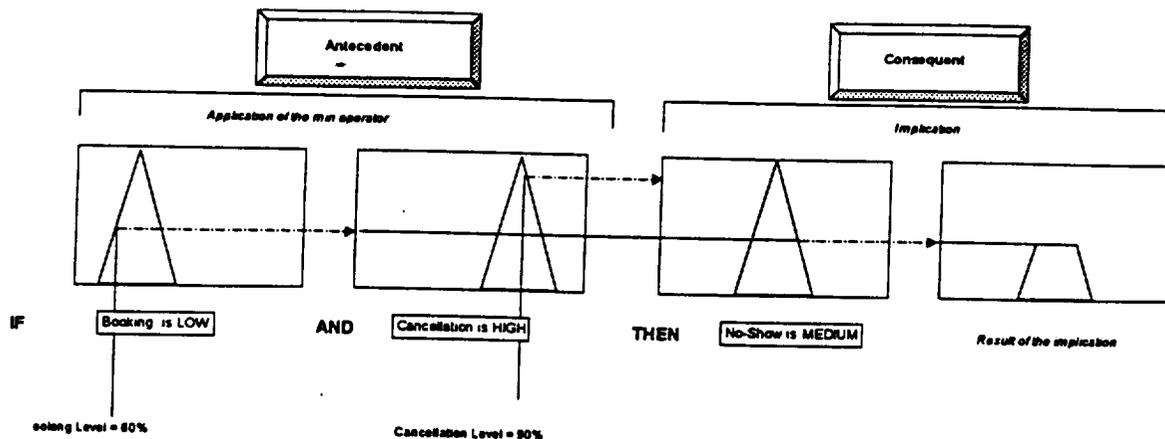
Figure 4 – Application of an inference rule

4.2.4 Aggregation of the Rules

The application of each rule determines an adjusted fuzzy set of the consequent part. The final conclusion is then derived summing the fuzzy sets of the conclusion of each rule, by a process called "determining MAX" (maximum) deriving from the application of the inference rules

4.2.5 Defuzzification

This step selects the expected crisp value of the solution (output) from the fuzzy region resulting from the aggregation of the fuzzy sets each activated by all the rules applied in parallel.

There are several methods of defuzzification, but the most widely used is the method of the centroid, where the abscissa of the centre of gravity of the output fuzzy set region represents the "balance" point of the solution.

5. The Airline Booking Process

The booking process, from an airline company point of view, is rather complex. From a microeconomic point of view it is an economic interaction between the consumer (the potential air traveller) who tries to maximise his utility function under some given factors (travel dates, price, service and restrictions) and the airline trying to maximise its profit.

In the weeks before the departure many reservations are made for each type of fare. As the time of departure approaches some cancellations are added to the new reservations. Moreover at the day of departure there are additional complications due to travellers who show up without a reservation (go-show), travellers who fail to show-up (no-show) and travellers who are inserted in a waiting list. Furthermore there are many external factors which affect the booking process, such as different fare levels for each class, flight frequency, season or type of aircraft.

When the spaces corresponding to a certain fare class are filled, the request of travel is denied, but the airline (or the reservation agent) can try to recapture the traveller on a different class or on a different flight in the requested fare class. Nevertheless the actual number of boarded people depends also on the level of authorisation which has been adopted during the booking process.

A typical flow chart of a booking process is shown in Figure 5.

4.2.1 Choose the system variables

One of the most difficult parts to achieve a good formulation of the problem is to identify the data which influence the operation of the system and those which represent the output value of the model.

In this paper an overbooking fuzzy model has been constructed by selecting as control variables (input):

• the booking level (BL) at a given time, i.e. the difference between the total number of people who had booked a seat from the opening of the reservation period and the one who had cancelled it (in percent of the aircraft capacity);

• the rate of cancellation (CR) at a given time, i.e. the ratio between the number of people who had cancelled their reservation and those who had booked.

The number of no-show passenger (NS) in percent of the aircraft capacity is assumed as the solution variable (output).

A scheme of the proposed model is shown in Figure 3.
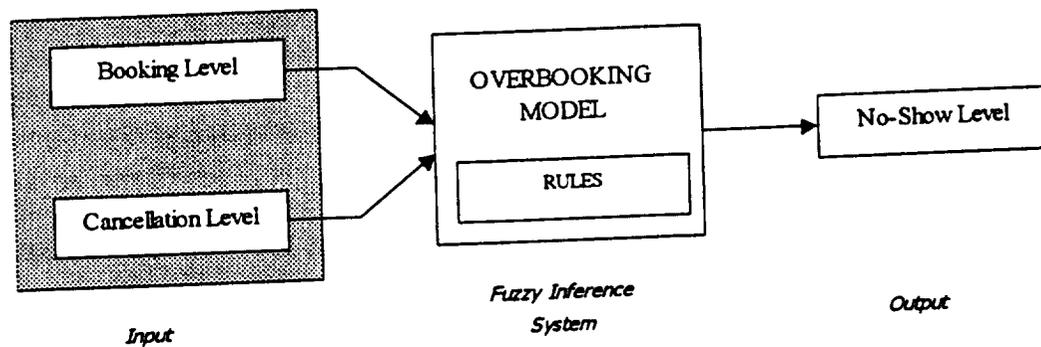
Figure 3 – Fuzzy Inference System

4.2.2 Define the Fuzzy Sets

The shape of the fuzzy set is quite important, but most models don't show a very wide sensitiveness to it. Triangular, trapezoid or bell curves are often used. Neural networks models have been used to find natural membership functions in the data and thus automatically creating fuzzy surfaces.

It is convenient to use a wide and elastic domain rather than a restrictive one.

To obtain a smooth and continuous control of the output variable a suitable degree of overlap of each fuzzy set should be assured.

4.2.3 Write the Inference Rules

The rules are written in the form described at paragraph 3.2. The rules that activate the same solution fuzzy set are grouped together. The application of a rule of inference that gets the shape of the consequent (output fuzzy set) as a result of the implication of the antecedent is reported in Figure 4. The implication form used is a minimum function , called as implication of Mamdani.

There are different defuzzification functions, some computing the centroid of the output sets, some averaging the maximum points of the output sets. However, each of them inevitably results a compromise between the need to find a single point outcome and the loss of information that such process produces, by reducing to a single dimension the output region solution.

4. Fuzzy Inference System

4.1 Introduction

Why should the fuzzy logic be applied to perform an optimal booking policy for a flight?

If we ask to a revenue management analyst how he settles the level of booking authorisation to be adopted in the days before the aircraft take-off, he probably would say that if he finds a low booking level reached in that moment, he takes the decision to authorise a level of reservations which is more than the aircraft's capacity to compensate the expected no-show passenger. If we ask him what does he mean for low booking level, he could say that this depends on many factors, such as the type of flight, the season, the ratio between business passenger and leisure ones, but anyway, less than 50% of the aircraft capacity ten days before departure might be seen as a low booking level. The question is if he will use a different overbooking policy with a booking level of 51%. Actually he thinks that 50% is a limit for unequivocally saying that an over-sale of seats must be done, but to lower level, also for higher booking level an overbooking of seats must be accepted.

In other words we see how this kind of problem requires that the variables controlling the system must shift from a mathematical and deterministic formalism to a linguistic representation based on fuzzy sets.

Actually fuzzy systems suit very well in modelling non-linear systems. The nature of fuzzy rules and the relationship between fuzzy sets of different shapes provides a powerful capability for the description of a system whose complexity makes traditional expert system, mathematical, and statistical approach very difficult.

The problem is now to manage the experience of the expert and to transform it in a set of inference fuzzy rules expressing the dynamics of the system we want to model.

4.2 Building a Fuzzy Inference System

There are five main steps that must to be carried out to build a Fuzzy Inference System (FIS):

- to choose the system variables (control variables for the input and solution variable for the output);
- to define the fuzzy sets (number, shape and confidence intervals of the membership functions);
- to write the relationships between the input and the output (inference rules);
- to defuzzify to get the value of the solution;
- to run a simulation of the model.

The meaning of the statement is that,

x is a member of (the fuzzy set) Y to the degree that w is a member of (the fuzzy set) Z

The final solution fuzzy space is created by the collection of correlated fuzzy propositions, called rules of inference, each contributing with its degree of truth.

The main methods of inference used in fuzzy systems are the *min-max method* and the *fuzzy additive method*.

3.2.1 The min-max rules of implication

By this method the contribution of the antecedent part to the consequent fuzzy region is restricted to the minimum, i.e. to the smaller value of the grades of inputs, while the final output region is obtained as a maximum, i.e. by summing the fuzzy sets region corresponding to each rule.

3.2.2 The fuzzy additive rules of implication

The fuzzy additive compositional operation is a slightly different approach as the output fuzzy region is bounded by [1,0], so that the result of any addition cannot exceed the maximum truth value of a fuzzy set.

Both methods reduce the level of truth of the output fuzzy region activated by the relevant rule of inference

3.2.3 Methods of decomposition and defuzzification

Using the general rules of inference, the evaluation of a proposition produces one fuzzy set associated with each model solution variable. To find the actual scalar value representing the solution the method of defuzzification is used. It is the final step of the fuzzy reasoning. As shown in Figure 2, this is obtained through an aggregation process that produces the final fuzzy regions, which have to be decomposed using one of the defuzzification methods.
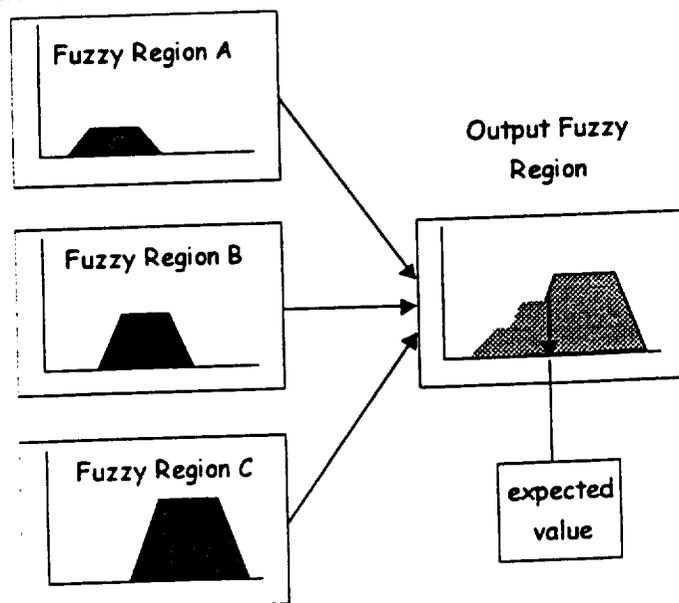
Figure 2 – The Aggregation and Defuzzification Process

function maps to what degree of confidence each value belongs to the fuzzy set. It is important to outline that the "degree of confidence" we are talking about has not to be interpreted as a probability but as a degree of truth, i.e. a measure of compatibility of the value of a variable with an approximate set, and not the occurring frequency of that value.

Formally, if X is a set of elements indicated as x, a fuzzy set $\mathcal{D}$ of X is a set of paired values as shown below:

$$\mathcal{D}=[(x,\mu_{\mathcal{D}}(x) : x \in X]$$

$\mu_{\mathcal{D}}(x)$ **is called membership function and it associates a degree of confidence** μ **to each value of** x **in** $\mathcal{D}$**. For instance the curve of Figure 1 – Fuzzy set of the booking level as % of the aircraft capacity**

can be seen as the degree of membership of each value of the booked seats of an aircraft to the set "High booking level". In this example, 50% and 150% are the limits of the so called interval of confidence.

Using the Fuzzy Set Theory it is possible to approximate the behaviour of complex and non linear systems, which otherwise would require a high level of computational resources. At the same time it is possible to have a model of the system very close to the human way of reasoning and to the way experts themselves think about the decision process, while many traditional expert and decision support systems lose fast comprehension as the complexity of the system increases because they persist in applying dichotomised rules with artificial and crisp boundaries.

We are talking of *approximate* (or *possibilistic*) *reasoning*, that is the way the experts think. So trying to perform an optimal booking policy during the period elapsing from the opening of the reservations of a flight till the departure day, a revenue management analyst would give us suggestions such as: "if the booking level is low, and the rate of cancellation is high, then the number of no-show passenger will be quite high". Actually, the expert of the problem shows a knowledge of the system through concepts without a well defined pattern, based on his sensations, experience and intuitions, more than on precise data. Now the fact is that fuzzy systems are able to directly manage these kind of imprecise recommendations, reducing the distance that lies between the idea expressed by an expert and the one coded in a conventional model.

Another basic difference between a conventional expert system and a fuzzy system is that the former has a series of statements which are executed serially and is carried out with algorithms that reduce the number of rules examined, while the second has a parallel processing and activates all the rules at same time.

3.2 Fuzzy Rules

The fuzzy rules are the building blocks of a fuzzy system. A fuzzy rule is a conditional proposition that settles a link between the fuzzy sets. Each rule is appraised for its degree of truth and shares to the final output set.

The proposition has the general form,

if w is Z then x is Y

where w and x are scalar values and Z and Y are linguistic variables, i.e. fuzzy sets.
In this example w is the "process state", while x is the "control action".

However the most part of the proposed models are focused to the determination of the expected number of no-shows in terms of probability distributions.

The aim of this paper is to propose a method, which minimises the spoiled seats and the denied boarding at the same time for every single flight. This can be achieved by monitoring the booking process during the days before the departure and using an Inference Fuzzy System as an easy decision support system to assist the revenue management analysts. This allows to undestrand any unusual event or action taken by competitors for each flight from the opening of the reservations to the take-off.

3. The Fuzzy Logic

As Lotfi Zadeh said, "when the complexity of a system increases, our ability to make precise and yet significant statements about its behaviour diminishes until a threshold is reached beyond which precision and significance become almost mutually exclusive characteristics". The basic idea underlying the Fuzzy Logic is that when we try to describe a system by a traditional model we use mathematical variables, which represent the state of the system as existing or not existing. If we represent the state of the system in terms of *fuzzy sets*, and not in terms of discrete symbols and numbers, we can obtain a representation of the system more close to human reasoning and the transition from a system state to the next is more gradual.

3.1 Fuzzy Sets and Membership Functions

According to Fuzzy Logic, when a system is characterised by an incomplete knowledge, the hypothesis are not only true or false, but are true or false by a certainty factor.
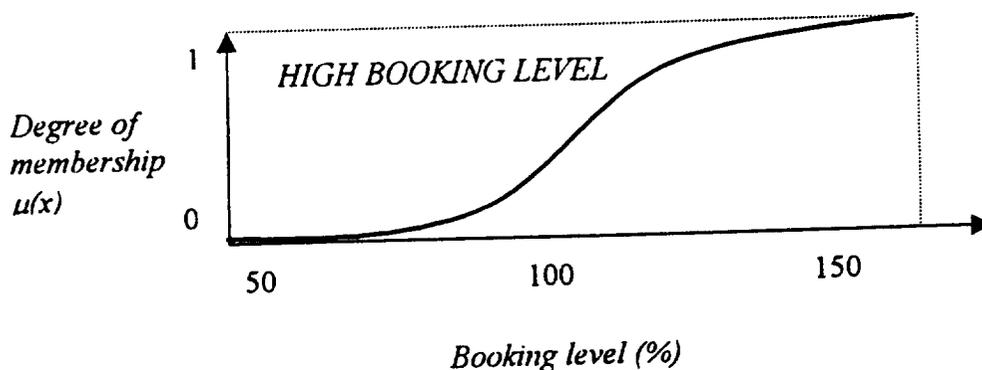
Booking level (%)

Figure 1 – Fuzzy set of the booking level as % of the aircraft capacity

The Fuzzy Set is a function indicating to what degree (between 0 and 1) the value of a variable belongs to the set. A degree of zero means that he value is not in the set, while a degree of one means that the value is completely representative of the set. A membership

The problem we want to face in this paper is what kind of *booking policy* should an airline adopt in the days before the departure in order to reduce the double risk of empty seats and denied boarding. In other words the company should establish what is the optimal *authorisation level* at any given time before the take-off, i.e., the optimum number of reservation to be accepted.

Selling more seats than the aircraft's capacity might be seen as an incorrect behaviour, but the airlines sustain that without the balancing factor of an overbooking policy, the load factors of the flight would be lower than the actual one, thus producing an inevitable increase in the average fares.

At the present, the overbooking level limits to be accepted during the reservation process to meet the airline objectives are the outcome of mathematical models based on historical data about the behaviour of the seat bookings and cancellations, otherwise they are fixed by a revenue management analyst, i.e. a specialist who takes the most suitable decision based on his own sense and experience.

Whatever is the method adopted, we believe that for a given flight the limits of the authorisation level cannot be evaluated through static considerations owing to the tightly dynamic nature of the booking process, which requires a continuos check and change of these limits, in order to suit the unpredictable passenger behaviour, which becomes more and more changeable as the day of the take-off approaches.

2. Review of the existing models

Several models had been proposed in these last four decades based on different approaches to match the objectives of the airline companies.

The *cost minimisation model* (Beckmann, 1958; Kosten 1960) finds the optimal authorisation level as the one which determines the minimum expected total cost of overbooking, calculated as sum of the cost due to denied boarding (that increase with the number of accepted booking) and the spoilage due to empty seats (that is reduced instead).

Thompson (1961) proposed a model to limit the probability of denied boarding calculated as the area of a standard normal distribution of the number of show-up passengers exceeding the aircraft capacity.

A similar approach was used by Taylor (1962), which takes into account the ratio of denied boarding over the number of booked passengers as a constraint not to be overcome, while Rothstein (1967) maximises the expected revenue of the flight under the limit of an acceptable pre-set risk of denied boarding.

The model made by Gerbracht (1979) for the Continental Airlines selects the optimum level of booking to maximise the expected net revenue as a result of the revenue obtained from the passengers actually carried, and also the penalty arising from the number of passengers with denied boarding. Since the number of no-shows varies randomly for each flight, if the probability distribution of no-shows is given, the statistical expected net revenue can be maximised. As it is much more expensive to have a denied boarding than to spoil an empty seat, the optimum booking levels are always shifted toward low overbooking values with regard of the average no-shows.

The most advanced researches try to arrange a compromise between the aim of maximising the net revenues with the need of assuring a more competitive level of service, avoiding the denied boarding as much as possible.

In this paper, a new level control model will be presented and solved using multidimensional search routines. In the first section the model will be given. Then the solution methods will be outlined and results will be presented. Finally, the concluding remarks and further research directions will be discussed.

The Overbooking Model

Much of the research in the overbooking area concentrates on a dynamic programming approach. The number of transition probabilities and recursion equations grows very large in the multi-class case and the computation time is adversely affected. A level-control approach rather than an incremental approach became the feasible option. The drawback of this model is that it requires more information. This information was sourced from Aer Lingus, Irelands national airline, which was the basis for the study.

In developing a model for expected revenue the main requirement is to estimate the level of No Shows. A No Show is defined as a person who has made a booking but has not turned up for the flight, while a Go Show is a person without a booking who has turned up looking for a seat on a flight (e.g. a person with an open ticket). Making a number of assumptions about the random distributions of how customers book and show up, we can calculate expected Show Up levels mathematically at class level. As Denied Boardings and Boarded Go Shows occur only at cabin level, the contributions from these are calculated at that level and so class level information is not captured. However, as the main contribution is from the Show Ups and No Shows the level of error introduced should be small.

Assumptions of the Model

1. The probability of a booking resulting in a No Show is independent of whether that booking is part of a group.

    This assumption is validated by the work of Thompson [3] and by O'Connor [11]. O'Connor makes the following observation, 'group bookings in many cases will come not from actual groups, but from a collection of individuals booked by an agent'. This means that group identification is in itself a major issue.

2. The probability of any booking resulting in a No Show at flight time is independent of when that booking was made.

    The justification for this assumption is based on the work carried out on cancellations by Martinez and Sanchez [12] at American Airlines. Their conclusions were based on an examination of a large amount of historical data.

3. The different classes all book over the same period.

    This is a simplification. The model could be extended so that classes book in order as this represents how some classes book in reality.

4. The number of passenger seeking tickets is assumed to be a normally distributed random variable.

    It is reasonable to assume that the receipt of requests for tickets over any given period will follow a Poisson distribution. In such a case it is reasonable to approximate the number of requests for tickets by a Normal distribution.

5. The number of No Shows from any given booking level is binomially distributed.

    The probability of x No Shows, out of b bookings, is assumed to be binomial. That is,

$$P(X = x) = \binom{b}{x} p^x (1-p)^{b-x}$$

    where p is the probability that any given booking will result in a No Show i.e. the No Show Rate. In most cases the No Show rate is estimated from historical data, and is assumed to be normally distributed. Alstrup et al [9] argue that these assumptions are reasonable.

6. The flight has one service compartment, with up to five classes of passenger who pay different fares and have different booking patterns.

    In order to simplify the problem and reduce computation time, the limitation to five classes was chosen. This can be extended in the model.

7. The No Show rate does not vary with time and is independent of the number of bookings in that class.

The No Show rate for those passengers who book in the last few days of the booking period is assumed to be equal to the No Show rate for those who book at the start of the booking period. This is termed the forgetfulness property and was first found by Thompson [3].

8. The number of Go Shows in any class is independent of the number of Show Ups in any class. This assumption is based on the independence of Go Shows and booking demand. It can be argued that the two are dependent, but in general it appears that the assumption of independence is reasonable.

Notation

N = Number of classes
c = Capacity of Plane
ms = Mean Show Up
ss = Std. Dev. Show Up
mg = Mean Go Show
sg = Std. Dev. Go Show
au = Authorisation
f = Fare
s = Number of Show Ups
bgs = Number of Boarded Go Shows
$wavfare$ = Average Fare weighted by Show Ups
$brdfare$ = Average Fare weighted by Go Shows

es = Number of Empty Seats
b = Bookings
md = Mean Demand
sd = Std. Dev. Demand
db = Number Denied Boarding
$dbcost$ = Denied Boarding Cost
mn = Mean No Show Rate
sn = Std. Dev. No Show Rate
cab = Cabin

Subscripts are used to indicate the level to which these apply. The convention used is that the subscript i refers to data at class level.

The Probability of a booking, $P(b)$, is normally distributed with mean md and standard deviation sd.
The Probability of a Go Show, $Q(g)$, is normally distributed with mean mg and standard deviation sg.
The Probability of a Show Up, $R(s)$, is normally distributed with mean ms and standard deviation ss.
The following are also used. If the number of Show Ups and the number of Go Shows in any class is independent of the number in any other class then,

$$ms_{cab} = \sum_{i=1}^{N} ms_i \qquad ss_{cab} = \sqrt{\sum_{i=1}^{N} ss_i^2} \qquad au_{cab} = \sum_{i=1}^{N} au_i$$

$$mg_{cab} = \sum_{i=1}^{N} mg_i \qquad sg_{cab} = \sqrt{\sum_{i=1}^{N} sg_i^2}$$

Development of the Revenue Function

The main revenue is generated from the number of expected Show Ups in each class and multiplied by the fare in that class. The resulting figure has to be modified to take account of the denied boardings and the boarded Go Shows.

If there are expected denied boardings then two adjustments have to be made to the expected revenue. First of all, those passengers who were denied boarding were included in the first term of the function, thus requiring that this amount must be subtracted from the expected revenue and also they are entitled to compensation because they were denied boarding.

Because denied boarding occurs at cabin level, and passengers pay different amounts for seats in different classes, the calculation of the amount to be subtracted cannot be calculated exactly without a simulation. Because of this, it was decided that an average fare *wavfare* weighted by the Show Ups in each class would be used. The same problem arose with the Go Shows in that these occur at cabin level and not at class level. An average fare *brdfare* was used to counteract this problem.

The expected revenue function can now be written as,

$$\overline{rev} = \sum_{i=1}^{N} (ms_i \times f_i) - \left(\overline{db} \times (db\cos t + wavfare)\ \right) + \left(\overline{bgs} \times brdfare\right)$$

Mathematical Development

In order to calculate Show Ups, booking levels for each of the classes must be known. In any class,

Let X_i = Number of tickets for which there is demand in class i

      au_i = Number of tickets available for sale in class i

      b_i = Number of tickets booked in class i

From this it follows that,

$$b_i = \begin{cases} X_i & if\, 0 \le X_i \le au_i \\ au_i & if\, X_i > au_i \\ 0 & otherwise \end{cases}$$

If $E(b_i)$ represents the expected bookings in class i , then in calculating it, both cases have to be considered.

$$E(b_i) = \int_0^{au_i} xP_i(x)dx + au_i \int_{au_i}^{\infty} P_i(x)dx$$

It is important to note that in many of these cases where the values cannot be less than 0, a truncated gaussian normal distribution is used in the calculation. By truncated it is meant that the area under the curve between 0 and ∞ is equal to 1.

Having now calculated the expected bookings in class i, $E(b_i)$, an expression was developed for Show Ups. Let,

      S_i = Number of Show Ups in class i

      T_i = No Show Rate in class i

Using Assumption 7, that the No Show rate does not vary with time and is independent of the number of bookings in that class, we can say that, given Ti constant over the time of the booking period,

$$S_i = b_i(1.0 - T_i)$$

$$E(S_i) = E(b_i)(1.0 - T_i)$$

and given b_i and T_i are independent,

$$E(S_i) = E(b_i)(1.0 - E(T_i))$$

which is equal to,

$$ms_i = E(b_i)(1.0 - ns_i)$$

Denied Boardings

The number of Denied Boardings will depend on the number of Show Ups per class. Integration over all possible cases is required in order to calculate the expected Denied Boardings. If there are a large number of Show Ups in a particular class, then any Denied Boarding has a greater probability of being from that class than from one with a low number of Show Ups. To give an indication of the complexity involved, Eriksson [10] assumes for simplification purposes that all classes have the same No Show distribution and using this completely integrates across classes for an estimate of expected Denied Boardings. To calculate this he has to work with an expression containing 2^N terms, each of which is a nesting of integrals across the N classes. This leads to excessive computation in the multi-class case. To overcome this, the assumption of independence between the number of Show Ups in any class and the allowance for the difference in the average fare used by the Show Ups were used. This achieves essentially the same purpose as Eriksson but with simpler calculations. Therefore, Denied Boardings are calculated at cabin level.

We are interested in the total number of Show Ups in the cabin, s_{cab}. If c is the capacity and $S_{cab} \leq au_{cab}$, then,

$$db = \begin{cases} s_{cab} - c & \text{if } s_{cab} > c \\ 0 & \text{if } s_{cab} \leq c \end{cases}$$

and consequently

$$E(db) = \int_{c}^{au_{cab}} (s-c)R_{cab}(s)ds$$

Go Shows

The main interest is not the number of Go Shows but rather the number of those that get seats, that is the Boarded Go Shows. There is no penalty cost for refusing a passenger. The calculation of Boarded Go Shows is more complex in that it depends on the number of Show Ups and the number of Go Shows. As with Denied Boardings, Go Shows are dealt with at cabin level. Fare becomes an issue again, as we do not know from which class the Go Shows will come. Therefore an average fare is calculated based on the number of Show Ups per class.

The calculation is as follows:

Integrating over the range of possible show up values, an expected number of Boarded Go Shows for each Show Up value is calculated. Let,

G = Number of Boarded Go Shows

g = Number of Go Shows

then,

$$G = \begin{cases} f(g) & \text{if } c - s_{cab} > 0 \\ 0 & \text{otherwise} \end{cases}$$

where,

$$f(g) = \begin{cases} g & \text{if } 0 \leq g \leq c - s_{cab} \\ c - s_{cab} & \text{if } g > c - s_{cab} \\ 0 & \text{otherwise} \end{cases}$$

In the case of $f(g)$ and dealing with both possibilities of the function, the expected number of Boarded Go Shows for a given number of Show Ups can be calculated as follows

$$E(g) = \int_{0}^{c-s_{cab}} gQ_{cab}(g)dg + (c - s_{cab}) \int_{c-s_{cab}} Q_{cab}(g)dg$$

This must be integrated over all possible Show Ups to calculate the expected Boarded Go Shows for the flight.

$$\overline{bgs} = \int_{0}^{c} \left(\int_{0}^{c-s_{cab}} gQ_{cab}(g)dg + (c - s_{cab}) \int_{c-s_{cab}} Q_{cab}(g)dg \right) R_{cab}(s)ds$$

Expected Revenue Function

Having carried out these preliminaries, the complete expected revenue function can now be written.

$$\overline{rev} = \sum_{i=1}^{N} \left[\left(\int_{0}^{au_i} bP_i(b)db + au_i \int_{au_i}^{\infty} P_i(b)db \right) \times (1.0 - ns_i) \times f_i \right]$$

$$- \left(\int_{c}^{uu_{cab}} (s-c)R_{cab}(s)ds \times (db\cos t + wavfare) \right)$$

$$+ \left[\int_{0}^{c} \left(\int_{0}^{c-s_{cab}} gQ_{cab}(g)dg + (c - s_{cab}) \int_{c-s_{cab}}^{\infty} Q_{cab}(g)dg \right) R_{cab}(s)ds \right] \times brdfare$$

Limitations of the Model

The aim in the development of the model was to capture information at class level as far as possible. However, this has not been fully realised. The assumption relating to the No Show rate being constant over the time period of the booking process can be questioned. This could be varied to take account of the time when the passenger booked. The main problem would be access to data. The estimation of Denied Boardings and Boarded Go Shows cannot completely capture information at class level. This has been mitigated by using weighted average fares. The final limitation is the form of the model. It is a 'box' model i.e. each class is given a booking authorisation and even if that booking level is not met those bookings are not offered to other classes. The alternative would be a form of nesting. This would entail some form of nesting hierarchy in which one class, or several classes, would have a higher priority than others. Such a model would take a different form.

Solution Methods

Having developed the revenue function, a number of solution techniques were available. Derivatives could be sought and solved, either by developing a solution procedure iteratively, or by using a package. Erikkson at Scandinavian Airlines [10] with a similar function has used this approach. However the calculation of derivatives in this case is quite complicated. A simpler approach was sought.

Direct search methods were investigated. Two methods in particular were looked at which did not require derivatives. There were the Downhill Simplex Method of Nelder and Mead [13] and the Pattern Search Method of Hooke and Jeeves [13]. Although these are designed as minimum seeking procedures, they can be easily used to find maxima.

Starting Heuristic

A number of different techniques were used in order to find a starting point for the search routines. The initial supposition was that there were a lot of local maxima however this was not borne out. Further analysis indicated that there were large flat areas which were causing problems for the search methods. In order to find the maximum of the function a starting heuristic was developed to give reasonable starting points.

The heuristic involves setting an initial overbooking level for each class as follows,
i) Calculate a cabin level default overbooking rate
ii) Use this to deterministically overbook the cabin
iii) Allocate those bookings amongst the classes.

The default overbooking rate was calculated as follows:

$$DefOBRt = \frac{\sum_{i=1}^{n} \mu_i \times (1.0 + nsr_i)}{\sum_{i=1}^{n} \mu_i}$$

where μ_i is mean demand in class i and nsr_i is the mean No Show rate in class i. Using this method, a class with large demand but a low No Show rate will not dominate and neither will a class with low demand but a large No Show rate.

To deterministically overbook the cabin, the capacity is multiplied by the default overbooking rate found in step 1.

$$Level = Capacity \times DefOBRt$$

The next question was how to allocate this level across classes. An examination of the literature showed that an allocation procedure based on Expected Marginal Seat Revenue was available [14]. The Fare Mix Algorithm allocates seats based on the Expected Marginal Seat Revenue (EMSR) to be gained from allocating a seat to one class rather than another. This algorithm is based on the principle that since $EMSR_i(s)$ is the additional revenue that is expected to accrue when the sth seat is allocated to fare class i then

$$EMSR_i(s) = f_i \times P(r_i > s)$$

where f_i is the fare in class i. This means that the expected marginal seat revenue of the sth seat in the ith fare class is the price of that seat multiplied by the probability of there being more than s requests for seats in that fare class. The algorithm iteratively goes through the plane capacity and at each stage allocates the seat to the class which shows the greatest expected marginal seat revenue.

This algorithm was used, setting the capacity to the value of level rather than capacity. This procedure would ensure that the level was allocated across classes in a way that reflected the demand and fare information available.

The above three steps give a starting point from which to begin searching. Computationally it is quick, and the levels it produces have proved on investigation to be quite close to the optimum levels.

The Aer Lingus Model

At the time of this analysis, Aer Lingus were using the following heuristic model for overbooking. Their approach was based on a single cabin single class overbooking strategy. It was a three step process which can be described as follows.

i) Staring with a booking level at plane capacity, c, expected Show Ups, expected Empty Seats and expected Denied Boardings were calculated in the same way outlined above.

ii) From these values, the total cost of flying with this booking level was calculated. The resulting cost comprised of the opportunity cost of flying with an empty seat and the denied boarding cost.

iii) The booking level was incremented and steps one and two were repeated until the difference between the new and the old cost was less than a specified tolerance.

An important difference between this model and the model developed in this paper is that the Aer Lingus model is cost based. Their aim was to minimise costs dependent upon the empty seat cost and the denied boarding cost.

Analysis of Results

Testing was carried out in two main phases: first to ensure that the solution strategies were in fact optimising the functions, and second to see if the results achieved were reasonable.

In order to test for optimisation, a number of examples were completely enumerated. One conclusion from complete enumeration was that this was not a feasible option due to the number of calculations

involved and the consequent time delay. From the results of complete enumeration, it was found that the search routines were not always finding the optimum.

This led to the development of the starting heuristic which was outlined in the previous section. However, even with good starting values it was found that although the Nelder and Mead [13] method was always in the vicinity of the optimum, it did not always reach that optimum. This led to the use of the Hooke Jeeves Pattern Search [13]. Initially, the Hooke Jeeves method was used in conjunction with the Nelder and Mead method, however this increased computation time and did not bring about much of an improvement. This led to further exploration in the area and from complete enumeration it was found that there were large flat spaces and this is what had caused the methods to terminate in the vicinity of the optimum rather than at the optimum.

A simulation model was built to test the authorisations that would come from the model. In order to test the expected revenue model, the model used by Aer Lingus was used. This provided a useful benchmark to test against. The data for testing was sourced from Aer Lingus.

Strategy	Authorisations	Show Ups	Expected Revenue
Exp. Rev. Model N & M Search	80/60	120	15120.00
Exp. Rev. Model H & J Search	80/59	119	15024.00
Starting Heuristic	79/59	118	14907.00
Aer Lingus	78/58	116	14811.00

Table 1. Deterministic Testing in the Two Class Case, Capacity 120

The next series of tests carried out were deterministic Table 1. These are tests where there is no standard deviations for the demand and no shows. It was found that of the models, the Aer Lingus model was the most conservative. It is interesting to note that the starting heuristic gives results that are close to the optimum.

Strategy	Authorisations	Show Ups	Expected Revenue
Exp. Rev. Model N & M Search	162/72/75/82/125	516	57.257.71
Exp. Rev. Model H & J Search	151/83/67/90/180	571	57,326.16
Starting Heuristic	140/58/113/75/126	512	56,900.81
Aer Lingus	140/58/113/75/126	512	56,900.81

Table 2. Non-Deterministic Testing in the Five Class Case, Capacity 420

The results from the non-deterministic testing bore out these results, Table 2. It was interesting however to note that this starting heuristic gave the same authorisations as the Aer Lingus model in this case. Further testing in the five class case and using other data bore out this observation. In general the results show that the expected revenue function solved with either of the search routines improves on the Aer Lingus model.

Conclusion

The expected revenue approach based on the model developed outperformed the Aer Lingus model in all test cases. The Aer Lingus model was found to be quite conservative in its authorisations. The expected revenue model requires less data than the Aer Lingus model due to it being a revenue maximisation approach rather than a cost minimisation approach.

The solution procedures employed do not guarantee optimality, an area which future research will address. The model uses cabin level data for the Boarded Go Shows and the Denied Boardings. Further research will look at the feasibility of capturing and using this information at class level. The model, as mentioned earlier, is a 'box' model. Future research will concentrate on overbooking while 'nesting' the authorisations.

In conclusion the expected revenue model is currently in use by Aer Lingus for overbooking. The expected revenue model achieves increases of revenue of the order of two to three per cent on average over the Aer Lingus model

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Air transport in the new millenium:
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Hard choices and low prices:

positioning for sustainable advantage

in the airline industry (the case of Ryanair)

Session 4A: Airline networks and airline alliances II

Tuesday, 2.15-3.45pm

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Abstract

This paper examines the limitations of needs-based positioning strategy, premised on low cost, for airline companies seeking to establish themselves as long-term market competitors. In conducting such an analysis, we look at the emergence of low fare airlines in Europe and critique the most successful of these, the Irish operator, Ryanair. A critique of strategies for sustainable advantage leads into an analysis of low price strategy. This is followed by a discussion of the challenges posed to companies such as Ryanair attempting to sustain low costs and price leadership. We argue that low operating costs and cheap prices achieved through operational efficiency are not sufficient in and of themselves to establish sustainable competitive advantage. Companies also need a clear and focused positioning strategy and unique corporate capabilities and experiences. Lessons from the US indicate that for low fare airlines, a needs-based strategic positioning approach may be most appropriate for establishing sustainable competitive advantage (Porter 1996). Ryanair has successfully adopted this strategy and adapted it to a more rigid and less open European market. Strict adherence to the strategy pioneered by Southwest Airlines in the US is the key to Ryanair's success. An à-la-carte approach, enabling consumer choice over service levels, adopted by many other low fare airlines, serves to dilute the advantage accrued from strategic positioning. Deviation from the strategy - through alliances, over-expansion, or increased operating costs - could result in Ryanair and other such carriers damaging their position and losing competitive advantage.

Introduction

In choosing a competitive strategy, a key consideration for company strategists is how to configure the value equation so as to best meet customer needs and demands. For many companies this means striving to achieve the lowest possible prices for their products or services. Low prices cannot be sustained unless a company maximises its operational efficiency. This largely means that the company has to perform similar activities better than rivals. One way of doing so is to pursue a rigorous and relentless policy of cost cutting. Many low price companies believe that there is always room for improvement when it comes to achieving low operating costs. Some of the most vigorous competitive rivalry occurs in the low price segment of the market.

Beginning in North America and spreading more recently to western Europe, the airline passenger market has witnessed a growing intensity in price-based competition. In this paper we look at the long term viability of needs-based positioning strategy, premised on low cost, drawing lessons from the Irish airline, Ryanair, and its attempt to be the leading low fare airline in Europe.

All airlines seek to lower costs and maximise economies of scale. Economies of scale require significant investments in planes and support facilities. This means high fixed costs and consequently, capacity utilisation is critical (Hinthorne 1996:255). Cutting prices is one tried and trusted way of filling seats and maximising capacity. Ryanair is one of the most cost efficient scheduled airline carrier operating in Europe. Its success rests on a combination of low costs and low fares, together with a high frequency service and extensive (UK-Ireland) route network to rival larger, more established carriers. Its maverick status - non-membership of assorted airline associations, non-participation in alliances - arguably leaves the company open to attack from larger competitors. However, given the firm's gradually expanding route network, its high passenger-per-mile yield[1] and cost ratio, and its increasing revenue, Ryanair may be viewed as a model for both small and large European regional carriers.

A number of questions flow from these issues. Is a simple low cost, price undercutting strategy the most viable long term strategy option for a company such as Ryanair? Studies[2] show that many passengers perceive a lack of emphasis on quality and

service by the airline. Consequently, are cheaper fares enough to sustain competitive advantage? In light of their expansion into mainland Europe and longer haul flights, how will Ryanair balance low fares with increased customer demands for better quality service on longer haul flights? We discuss the limits of a cost-based corporate strategy. Can the low fare model survive and flourish in Europe? In particular, we consider whether this strategy is sustainable if an airline 'Europeanises' and expands beyond its traditional short-haul, geographically limited base.

Strategies for sustainable competitive advantage

Hamel and Prahalad view strategy as comprising both incremental improvements and rapid advances on the part of a company (1993:84). Put another way, they view strategy as comprising both operational effectiveness and risk-taking innovation. Contrary to popular belief in contemporary management, operational effectiveness does not necessarily translate into sustainable profitability.

The three key strands of value creation may be identified as revenue enhancement, cost reduction, and reduction of asset intensity. McKinsey management consultants (1995) argue that for airlines, enhanced revenues will flow from better management of key capabilities such as pricing, capacity, networks, and schedules. Moreover, better cost management means that in addition to making general productivity improvements, the airline will address the issues of crew costs and of further outsourcing. Finally, asset utilisation is improved when airlines adopt a system-wide perspective on their fleets, i.e. reducing the variety of aircraft and splitting off non-core service functions such as maintenance and ramp services. Overall, McKinsey places considerable emphasis on operational efficiency and focusing on core competencies[3]. Porter argues that strategy consists of neither operational improvement nor focusing on a few core competencies (Financial Times, July 19, 1997). Real sustainable advantage comes rather from the way in which the activities of a company fit together. He bases this argument on the premise that core competencies can be duplicated and that resting a company's success on a few core competencies can lead to destructive competition. Successful companies, according to Porter, fit together the

things they do in a way which is very hard to replicate. Strategic fit is reinforced by successful market positioning and the willingness of a company to make hard choices in terms of its cost structure and customer focus. Porter identifies three sources of strategic market positions: variety-based, needs-based, and access-based positioning (1996:66-7). Needs-based positioning - targeting the needs of price sensitive customers - comes closest to conceptualising Ryanair's source of strategic positioning[4]. A focused competitor such as Ikea or Ryanair thrives on groups of customers who are overpriced by more broadly targeted competitors. Successful competitive strategy hinges upon a company's own actions, the reaction of competitors, and the ability to anticipate and rapidly counteract the strategic response of those competitors. Strategic positioning is usually described in terms of customers. US low fare pioneer, Southwest Airlines, serves price and convenience sensitive travellers for example. But the essence of strategy is in the activities - choosing to perform activities differently or to perform different activities than rivals. For instance, Porter provides evidence that Southwest tailors all its activities to deliver low-cost, convenient service on its particular type of route (1996:64). Southwest has staked out a unique and valuable strategic position based on a tailored set of activities. On the routes served by Southwest, a full service airline could never be as convenient or as low cost (Porter 1996:64). Collins and Porras argue that genuinely successful companies understand the difference between what should never change and what should be open for change, between what is truly untouchable and what is not (1996:66). Southwest are an example of such a company - regularly innovating and constantly differentiating themselves from the competition but resisting the urge to tamper with the fundamental features of their strategy formula. The Southwest model is not easily transferable. Continental and United Airlines both attempted to copy the Southwest model for their low-cost US subsidiaries. They were able to duplicate the route structure and other observable and quantifiable elements but they failed to emulate the Southwest culture - or organisational capabilities - the key to its success (Couvert, 1996:61).

The core competencies approach does not work well in the airline industry because airlines have broadly the same competencies (Couvret 1996:61). Their staff, equipment, distribution systems and so forth tend towards a standard mean for most

airline companies. Couvert argues that there are three key questions in any evaluation of an airline's strategy for sustainable competitive advantage: 'Where are you now? How did you get there? and Where are you going?' (1996:60). He argues that virtually everyone is competing by doing very similar things in very similar ways. Building on the work of Collis and Montgomery (1995), Couvret contends that the solution is to adopt a resource-based view of the company, recognising that an airline's routes are its main asset. He further argues that organisational capabilities are an important source of competitive advantage for airlines. Ultimately, the primary physical source of advantage in a successful airline is the combination of its route structure and its history/culture, that is the way it developed or its organisational capabilities (Couvert 1996:63). Following on from this, he argues that:

the single most important strategic factor for an airline is a clear sense of regional focus: knowing where its home base is, and understanding how its network spreads from there...it is critically important for an airline to identify, maintain, and develop the deep market knowledge embedded within its route network, in order to maximise the value of its assets (Couvert 1996:63).

Furthermore, regional focus should not be seen as a limiting factor - a region can have various definitions. A region for Ryanair could justifiably constitute western Europe and not just the British Isles. Several regional airlines on both sides of the Atlantic are amongst the most profitable in the industry. Ryanair is a clear example of this fact. Companies are reaching the limits of incremental improvement. Many need to reinvent themselves instead (Hamel 1996:69). Hamel argues that if you take any industry, you will find three kinds of companies: first, rule makers - incumbents that built the industry, e.g. American Airlines (or British Airways); second, rule takers - companies that pay homage to the industrial 'lords', e.g. US Air (or British Midland); and third, rule breakers - the industry revolutionaries, intent on overturning the industrial order, e.g. Southwest Airlines (or Ryanair). Hamel contends that strategy is revolution and everything else is just tactics (1996:70). This concurs with Porter's distinction between strategy as unique positions and hard choices, and everything else being merely operational efficiency. Nine routes to industry revolution may be

identified (Hamel 1996:72). Ryanair has taken the route termed reconceiving a product or service, through radically improving the value equation:

> In every industry, there is a ratio that relates price to performance: X units of cash buys Y units of value. The challenge is to improve that value ratio and to do so radically... such a fundamental redefinition of the value equation forces a reconception of the product or service (Hamel 1996:72).

This is essentially what Ryanair have done on, for example, the Dublin-London route, becoming so-called 'value revolutionaries' (Hamel 1996) in the process. This correlates with Kim and Mauborgne's concept of 'value innovators', wherein a company refuses to take its industry's conditions and norms as given, preferring instead to pursue market innovation through making quantum leaps in value (1997:105). Ryanair has relentlessly pursued this strategy, targeting the mass air travel market and offering unrivalled value for money. It has served as value innovator on both secondary routes, dominated by charter carriers, and primary routes, controlled by large established airlines. Prices dropped, the markets grew, and Ryanair experienced high growth and sustained profitability.

The long term viability of low price strategy: the case of Ryanair

Across a wide range of industries, throughout the global economy, traditional market leaders are under attack from low price competitors. These low price firms are steadily eroding the profit margins and market share of their more established rivals. This, often cut-throat, competition is particularly evident in the airline industry. In the US industry, established carriers have twice had to face the market onslaught of low fare carriers. They successfully beat many of them off in the early 1980s, through skilful use of their yield management systems, allowing them to sell spare capacity at equally low fares (Barkin et al. 1995:87). People Express was the most prominent victim of this strategy. The traditional carriers encountered a renewed challenge a decade later and have not been as successful in eradicating it. Many of the newer low

fare operators, such as Reno Air and Markair, have learned the lesson of People Express and are careful not to be goaded into rapid over-expansion.

At roughly the same time as the 'second battle' in the US, against the backdrop of European air transport liberalisation, a plethora of low fare carriers emerged in Europe. Learning from their American contemporaries, these firms pursued low cost strategies with direct, short haul services and limited route networks. This approach was deemed necessary if such firms were to achieve sustainable competitive advantage. Chief among Europe's low fare airlines is Ryanair. It is an interesting study given that it predates all other such operators and European airline liberalisation measures. Ryanair has established itself as the leading independent European low fare airline, consistently expanding its route network and increasing its profit margins. Ryanair describes itself as a low fare airline. It believes that it is out on its own and is a company that break barriers. Its core ideology is encapsulated in its mission statement:

Ryanair will become Europe's most profitable, lowest cost scheduled airline by providing its low fares/no frills service in all markets in which it operates to the benefit of our passengers, people and shareholders (Corporate mission statement 1997).

If we deconstruct this corporate vision along the lines offered by Collins and Porras (1996), we can identify Ryanair's core values and core purpose. These provide the overall framework within which the company's strategy is formulated. Ryanair's core values - its constant and enduring guiding principles - are low price, value for money, and efficient service. These values should not alter, regardless of market or environmental changes (Collins and Porras 1996:67). The company's core purpose, by distinction, is its very reason for being. For Ryanair, this is to provide cheap, safe, and reliable air travel for all.

With the advent of European airline liberalisation, many more low cost carriers have entered the market. Companies like Virgin Express and Easyjet also pursue a low fare, no frills service. They, like Ryanair, look for airports with lower charges and shorter turnaround times, with little concern for interline connections. However, as the UK Civil Aviation Authority point out, the underlying approach of these companies seems

generally more like that of ValuJet in the US than of Southwest. Most notably, they place less emphasis than Southwest or Ryanair on providing a high frequency of operation in all of the markets they serve (CAA 1995:57). Most of the other new entrant low cost airlines such as Jersey European Airways, Spanair, EuroBelgian, and Air Southwest, also offer a limited service and operate on a small number of routes.

Ryanair's competitive advantage derives in large part from the way its activities fit and reinforce one another. Fit locks out imitators by creating a chain that is as strong as its strongest link. Like Southwest Airlines, Ryanair's activities complement one another in ways that create real economic value. One activity's cost is lowered because of the way other activities are performed. Similarly, one activity's value to customers can be enhanced by a company's other activities. That is the way strategic fit creates competitive advantage and superior profitability. The fit among activities substantially reduces cost or increases differentiation (Porter 1996:73).

Southwest's sense of regional focus (on the south western United States) and its development of its route network from that base, is also key to its competitive advantage (Couvret, 1996:63). Similarly, Ryanair's regional focus is the British Isles and although it has begun to branch out from there to other parts of Europe, its focus on the home base remains clear and committed. A danger may be if Ryanair expands too far, too quickly, losing sight of its regional base and entering into an industry position where it may be in danger of being sandwiched between the large, global carriers and the more focused regional carriers. Southwest has developed well beyond its original focus of the south western United States. There is therefore no reason why Ryanair cannot do the same, provided its new routes are built on the solid base of home territory.

Porter (1985) described three ways in which a firm can achieve sustainable competitive advantage: cost leadership strategy, differentiation strategy, and focus strategy. Cost is generated by performing activities and cost advantage arises from performing particular activities more efficiently than competitors (Porter 1996:62). Furthermore, a low cost leader must, as Lynch argues, shave costs off of every element of the value chain (1997:487). As part of its generic strategy, Ryanair has chosen a cost leadership strategy where a firm sets out to become:

the low-cost producer in its industry...a low-cost producer must find and exploit all sources of cost advantage (Porter 1985:14-5).

Lynch contends that a firm which succeeds in achieving the lowest costs has a clear sustainable competitive advantage (1997:487). Such a low cost strategy can have different manifestations. These are described as (i) the 'cheap and cheerful' strategy, dependent on low cost and low value-added; (ii) reduced price strategy but with an emphasis on quality; (iii) competitive prices with a better quality and more reliable product or service than rivals (Johnson and Scholes 1997:253-4). Porter argues that low cost firms usually sell a standard or no frills product or service and that such a firm will generally be an above-average performer in its industry, provided it can command prices on or about the industry average (1985:15). Ryanair pursues a strategy in line with option one, cheap and cheerful, with low operating costs and low profit margins. Ryanair believes that it is operating on more than mere operational efficiency, arguing that cost reduction is more like a religion within the company[5]. Every day, management thinks about how to reduce cost. An example is that Ryanair was the first airline in countries in which it operates to reduce travel agent commission from 9 to 7.5 per cent. They did this in the midst of their stock market flotation - a time when most companies would not be doing anything which might jeopardise their flotation.

Kay argues that in the European airline industry, costs are dominated by three main factors - labour, fuel, and capital costs (1993:294). He further contends that:

> Substantial differences in costs per unit of output can result from differences in the rate of fleet utilization (the proportion of potential flying time for which a plane is actually in the air) and in the load factors achieved in passenger carriage, since a flight costs much the same to operate whether there are empty seats on it or not (Kay 1993:294).

As figure 1 illustrates, Ryanair directly targets both labour and capital outlay for continuous cost reduction. Moreover, in striving to maximise aircraft utilisation, the company indirectly targets fuel expenditure for cost reduction.

Figure 1

Where Ryanair cuts costs
1. *Secondary airports* (lower charges and less congestion means airline can increase punctuality rates and gate turnaround times).
2. *Standardised fleet* (lower training costs and cheaper parts and equipment supplies).
3. *Point-to-point services* (direct, non-stop routes; through-service with no waiting on baggage transfers).
4. *Maximise aircraft utilisation.*
5. *Cheaper product design* (no assigned seating; no free food or drink).
6. *No frequent flyer programme.*
7. *Non-participation in alliances* (code sharing and baggage transfer services lowers punctuality and aircraft utilisation rates and raises handling costs).
8. *Minimise aircraft capital outlay* (purchase used aircraft of a single type).
9. *Minimise personnel costs* (increase staff-passenger ratio; employee compensation linked to productivity-based pay incentives).
10. *Customer service costs* (outsource capital intensive activities, e.g. passenger and aircraft handling; increase direct sales through telephone reservation system).
11. *Lower travel agent fees* (reduce associated travel agent commission (9 to 7.5%).

Taken together, these cost cutting principles form a very strong base for the success of a low cost corporate strategy. Emphasising factors such as fleet utilisation and aiming overall to maximise passenger load factors rather than yield ratios[6], Ryanair can reduce its costs per unit of output, along the lines previously advanced by Kay (1993). It is often feasible to pursue a strategy of low price to achieve competitive advantage in an area such as air transport, where low price is important and a business has cost advantage over competitors operating in that segment (Johnson and Scoles 1997 :254-5). This is generally the case with Ryanair. However, as Barkin et al. indicate, 'a successful concept alone does not turn a low-cost competitor into a major threat' (1995:91). The critical issue is whether the low-cost airline can *sustain* its competitive advantage over time and gradually expand its operations. There are problems linked to

the notion of sustainable cost leadership. Porter does not mean short term cost advantage or just low cost. Sustainable cost leadership means having the lowest cost compared with competitors over time. This is unlikely to be achieved simply by pruning costs - competitors can and will do that too. The question then is, how competitive advantage can be achieved - if at all - through cost leadership. Market share advantage might be one possible answer. This provides a company with cost advantages through factors such as economies of scale and experience curve effects. There are different perspectives on what degree of advantage a company requires in order to sustain advantage over a long period of time. Buzzell and Gale argue that a firm with a high absolute market share may not have a high relative share because there may be a competitor who also has a comparable share (1987). This is the case with Ryanair, which possesses roughly the same absolute market share as the state-owned airline, Aer Lingus, on its main Ireland-UK routes. Buzzell and Gale (1987) contend that 40 to 70 per cent of the relative market share is necessary in order to achieve sustainable market power advantage. On routes such as Dublin-London, Ryanair controls less than 40 per cent of the total share of passenger traffic - a little less than that controlled by its nearest rival, Aer Lingus. On the basis of this argument, we must call into question the feasibility of Ryanair's long term strategy of maintaining competitive advantage on a purely cost based strategy alone. In developing strategy, it is in any case dangerous to assume a direct link between relative market share advantage and sustainable advantage in the market because there is little evidence of sustainability: dominant firms do lose market share and others overtake them. We need only think of the fall from market grace of companies like IBM to substantiate this argument. Market share itself is not what is important but rather the advantage that it can bestow. Relative share advantage can give cost advantages but this requires a proactive and innovative management. Without this, advantage will be lost to competitors:

In itself, low cost does not yield competitive advantage; it is how managers employ a low cost base that matters (Johnson and Scholes 1997:255).

An alternative solution may be in product cost advantage: the product cost advantage enjoyed by low-cost airlines such as Ryanair is more sustainable because traditional carriers have set certain service and quality standards which they would find difficult to abandon (Barkin et al. 1995:92). The established customer base of many large airlines may not wish to do without in-flight meals, baggage transfer facilities, business class seating, and so forth. Process cost advantages may also be sustainable as established carriers often cannot emulate the high utilisation practices of their low-cost competitors. The example of Continental Lite[7] illustrates this weakness among larger airlines.

An important aside at this point concerns Porter's tendency to use the terms 'cost leadership' and 'low price' as though they are interchangeable. This is not the case: cost is an input measure to a firm, whereas price is an output measure. As Johnson and Scholes point out, because a company is pursuing a cost leadership or cost reduction strategy, it does not necessarily mean that it will choose to price lower than competition. For instance, it may choose to invest higher margins in research or in marketing (1997:255). This is the case with highly cost efficient companies such as General Electric or Unilever. It is partly the case with several low cost airlines (notably Easyjet and Ryanair). Witness for instance the in-house central reservation system which both Easyjet and Ryanair have developed or the high profile advertising campaign which they maintain in the UK.

All airlines - regardless of size - want to minimise costs. Identifying potential cost savings is the easy part of the analysis; designing the best way to implement cost reductions is the difficult part and varies from company to company. The important point to remember is that the main risks of pursuing a low cost/low price strategy are price war and low margins. It is vital to be the cost leader and not just one of many (Johnson and Scholes 1997:251).

There is one further problem with the notion of cost leadership - indeed with cost based strategies in general. In itself, low cost does not provide competitive advantage. Competitive advantage can only be achieved in terms of a product or service which is seen by the user to have an advantage over the competition. Competitive advantage is therefore achieved through an organisation's output - its cost base being relevant only in so far as it may provide a means of achieving or improving that output. Porter

(1985) added that it may be more useful to think of 'cost based' strategies, the benefits of which (such as increased margins or low prices) can be used to achieve competitive advantage.

In 1995 the UK Civil Aviation Authority identified 34 international routes within Europe (excluding the UK) where potential existed for a new carrier. Eight of these involved Scandinavian airports and a further nine involved Paris and Brussels. Ryanair appear to have taken these suggestions into account when choosing new routes during 1996/7. Moreover, Ryanair have deliberately targeted airports where no scheduled services previously existed. Airports such as Paris Beauvais, Brussels Charleroi, and Stockholm Skavska are all up to one hour outside of their respective cities. Despite this, within three months, Ryanair gained a 20 per cent share of the London-Stockholm market, a 40 per cent share of the Dublin-Paris market, and almost a 50 per cent share of the Dublin-Brussels market[8]. This is further evidence that price - not location, convenience, service, and so on - is a significant factor in determining a regional airline's competitive advantage.

Competitive challenges to low cost sustainability

Ryanair claim to have increased the levels of air traffic between Ireland and the UK considerably. This is a new and relatively unexplored phenomenon in the European airline industry. British Midland Airways has produced the results of an analysis on passenger figures in which it contends that:

> By examining individual routes, it can be shown that the arrival of new carriers has a dynamic effect on the number of passengers travelling on a particular route... By competing with incumbent carriers and with each other to offer better deals to the customer, whether on price or on service, new entrants serve to increase the size of the whole market, rather than merely stealing existing traffic (1997:15).

This is precisely what Ryanair has achieved. The airline encouraged passenger growth on its routes, by competing on price and not on service. Such a strategy can invoke problems, both internal and external in nature. First, if another carrier enters the

market, competing on price or on another form of differentiation, this may adversely affect Ryanair's market share and profitability. An imminent challenge here is British Airway's fledgling low cost carrier, Go, which operates from London Stansted Airport and competes directly with Ryanair on its Stockholm and Oslo routes for instance.

A second (internal) problem or challenge concerns market volatility. Ryanair has consistently increased its profit margins since the early 1990s. However, what happens to them when an economic downturn is evident, as leisure travel is usually one of the first areas to be hit[9]. In this situation, bear in mind that Ryanair have few if any allies to support it whereas many other carriers are part of strategic alliances or code-sharing agreements which can act as a support if certain parts of the market experience declining traffic volumes. Similarly, travel agent co-operation can enhance the support needed by airlines during times of economic difficulty, by running various promotions and so forth. Ryanair cannot count on this support mechanism either, given its generally strained relationship with travel agents as a result of its drive to reduce commission rates.

Third, Ryanair could face the problem of pricing itself out of the market. For instance, travel agents are already rejecting the company as a client because Ryanair has cut their commission rates, and passengers have begun to notice and criticise the length of time spent on the telephone when booking flights through Ryanair's direct reservations service[10].

Fourth, all but one of Ryanair's existing fleet will have to be revamped to meet EU noise laws by 2002, at an estimated cost of $1.4 million per plane. Moreover, with an average age of 15.8 years, the entire flotilla will have to be replaced come 2005-2008[11]. In addition, the EU-wide phasing out of duty free is likely to hit Ryanair hard: on-board shopping currently accounts for 5 per cent of total operating revenue and one-third of flight attendants' wages (Blomberg 1997).

Fifth, the carrier's service record is weak. Although statistically Ryanair appears to fare quite well in terms of customer satisfaction[12], passenger surveys[13] indicate that the company sometimes experiences significant flaws in customer services. Outsourcing of ground level customer services activities partly accounts for this problem. In most airports, Ryanair has no dedicated customer service personnel, which can mean that

passengers have no direct point of contact with the airline if and when problems occur. This differs from Southwest, which prides itself on having a very good, awarding winning customer service, with a well-trained and attentive ground crew.

A final problem emanates from labour unrest at the company, as witnessed by the baggage handlers dispute of early 1998. Although the dispute in question involved only three per cent of Ryanair employees, a significant portion of flights were either disrupted or cancelled and public confidence in the company was undermined. Such unrest arises from the fact that Ryanair refuses to recognise trade unions, preferring to negotiate directly with workers on issues of pay and conditions. The baggage handlers dispute arose because Ryanair baggage handlers at Dublin Airport insisted that a trade union represent them in their bid to improve wages[14] and working conditions (*The Examiner*, p.8, 14th January 1998). The resultant limited industrial action served to damage Ryanair's populist corporate image and weaken its strategic fit and position. The stance of Ryanair management was further undermined when Southwest Airline's workers (who are unionised) voiced their support for the striking Ryanair ground crew (*The Examiner*, 16th January 1998). Once again, Ryanair can learn valuable lessons from their US role model. Ryanair must emulate the Southwest Airlines policy of maintaining well-paid gate and ground crews, whose productivity in turnarounds is enhanced by flexible union rules. This flexibility (on working conditions) has been worked out jointly between the airline's management and trade unions. Ryanair's rapid gate turnaround, which allows frequent departures and greater use of aircraft, is essential to its high-convenience, low-cost positioning. It is crucial to the success of Ryanair's strategic fit and overall corporate strategy. The company's relationship with its employees is central to such a strategy. Kay argues that the relationship a firm establishes with its employees constitutes part of its distinct network of relational contracts - so called 'internal architecture' (1993:66). This architecture (internal and external) is on of the three primary sources of distinctive capability which a firm possesses, and which help differentiate it from its competitors and establish sustainable competitive advantage. Disputes such as that which occurred in 1998 between Ryanair management and baggage handlers could and should be avoided through a more generous wage compensation scheme on the part of Ryanair and greater flexibility on the part of Irish trade unions with regards to worker conditions[15].

Such problems serve to damage Ryanair's internal architecture and weaken the company's distinctive capabilities. This in turn challenges the competitive advantage attained by Ryanair and could undermine its low cost strategy if adequate strategic responses are not found.

Whilst some commentators are sceptical that further expansion into Europe is the correct move for Ryanair, others believe that with the right routes, Ryanair will succeed (Guild 1995:73). It is commonly agreed that the airline has proven itself in the Irish-UK market and must now seek new growth markets if it is to survive and prosper in the long term and truly be the Southwest of Europe. There are however some real dangers for low-cost carriers attempting to expand into longer haul markets. As Barkin et al. point out, the cost advantages accrued on short-haul, high traffic markets - low input costs and cheaper product and process designs - will weaken for longer haul markets (1995:93). In particular, the advantage gained through product or process design will lessen: passengers are likely to demand better in-flight service, more leg room, and so forth, when they are on a longer flight and the benefit accrued through fast turnaround is not as important. Moreover, introducing practices such as baggage transfers, frequent flyer programmes, and so on, merely leads low-cost operators into seeking landing slots at more expensive airports and other forms of head-to-head competition with established carriers, on their home turf, as it were. Overall, advantage through utilisation for instance, would be more difficult.

Forecasts and conclusions

The experience and market success of Ryanair is of relevance to other small and medium sized airlines attempting to consolidate and expand their market shares. A study of Ryanair's cost leadership, needs-based positioning strategy consequently has wider implications for the European airline industry, and indeed for other industries which are being revolutionised by low cost entrants.

To answer the questions advanced at the paper's outset, we can say that first, a low cost/low price strategy alone is insufficient to ensure the long term market success of a company. Any advantage accrued by these means is usually short-term as cost

reductions and low prices can easily be emulated by competitors - particularly large, established market leaders. Moreover, as our Ryanair example indicates, market volatility, price wars, dubious service standards, and weak internal architecture, can all have a disproportionately negative influence on the competitive advantage of stand-alone companies with low profit margins and limited resources. Second, low price can increase a firm's customer base but, unless the firm maintains *the* lowest prices in the industry, it will not guarantee customer loyalty. Even with the lowest prices, a firm can lose market share if it fails to respond to changing customer needs and demands. This may occur in the European low fare airlines market as companies such as Ryanair expand the economic scale and geographical scope of their services. Deepening a position involves making the company's activities more distinctive, strengthening fit, and communicating the strategy better to those customers who value it. Companies need to resist the temptation to target new customers or markets in which the company has little special to offer. The moral of the strategy story is, be distinctive at what you do best rather than simply tackling potentially higher growth areas, where you take on more competitors, and your uniqueness declines. This is where low cost companies need to thread cautiously. The urge to expand rapidly and develop new markets is difficult to resist. However, in pursuing a rapid growth policy, companies such as low fare airlines risk losing all they have struggled so valiantly to achieve. Ryanair has consolidated its base and taken time to deepen its strategic position. Its route expansion is carefully planned, to ensure that the company can offer something - low price, value for money - which competitors do not emphasise. It is this adherence to a needs-based positioning strategy, combined with a unique route network and a dominant cost reduction corporate ethos (resulting in the maximisation of operational efficiency), which places a low cost company such as Ryanair in a favourable long term competitive position within the European airline market.

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Endnotes

[1] An airline's passenger-per-mile yield is calculated by dividing the cost per passenger per mile by the revenue per passenger per mile.

[2] Ryanair passenger surveys conducted at London Stansted Airport, August 1997.

[3] The concept of 'core competencies' derives from the work of Hamel and Prahalad (1990; 1994). The authors define core competencies as 'the collective learning in the organization, especially how to coordinate diverse production skills and integrate multiple streams of technologies' (1990, p.82).

[4] It should be noted that Ryanair's expansion strategy has also been predicated (in part) on access-based positioning. Ryanair is the first airline to offer regular scheduled services between Dublin and Bournemouth or Dublin and Teeside for example. As such, Ryanair has targeted customer segements previously denied convenient and low price access to air transport.

[5] Interview with Ryanair management, Dublin, September 1997.

[6] Ryanair's objective is to fill as many seats as possible on every flight, rather than to achieve the maximum revenue per passenger on every flight. Its profit is therefore determined by high capacity and low profit margins, rather than low or standard capacity and higher profit margins, as with many conventional airlines.

[7] Continental Lite was established in the 1980s as the low cost subsidiary of Continental Airlines. Its market failure is generally accredited to its inability to emulate the product and process advantages of successful existing low cost competitors such as Southwest Airlines. For further details see Porter (1996), 'What is strategy?'.

[8] These figures were obtained from Ryanair's marketing department.

[9] Ryanair is no longer as dependent on the leisure travel market as it once was. They have introduced the practice of not requiring a Saturday night stop-over for a lower fare - a two night stop-over will suffice. This can be advantageous for the business traveller. A large number of business people are now beginning to use Ryanair, particularly out of the UK. There are a lot of small companies whose owners or managers are very close to the numbers and they want the cheapest flight possible when they are travelling to a meeting. These 'kindred spirits' use Ryanair so as to keep their costs down. Some large corporations - especially those which are American owned - increasingly push their employees to fly with the best price operator and not the best service.

[10] This argument was sustained in passenger surveys conducted at London Stansted Airport, August 1997.

[11] This process has begun, with Ryanair's placement in early 1998 of the largest ever aircraft order by an Irish airline (45 Boeing 737-800's valued at over $2 billion).

[12] During the first half of 1996 for instance, Ryanair experienced only 2.62 per cent of complaints per one thousand passengers. This compares with 3.97 for Southwest and a US average of 5.36.

[13] Passenger surveys conducted at London Stansted Airport, August 1997.

[14] Figures show that Ryanair ground crew take home I£13,000 per annum, compared with I£16,000 in other airline operators (The Examiner, p.8, 14th January 1998).

[15] Ryanair salary levels did increase during the 1997/8 period, with the average staff salary increasing from IR£20,146 to IR£22,261. Also, the airline became the first Irish publicly quote company to establish a company-wide share option scheme.

Assessing Two Means of Promoting Interlining:

IATA versus Alliances

by

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Paper presented at the

Air Transport Research Group Symposium

Air Transport In The New Millenium:

Opportunities In Competitive Markets

Dublin, July 20-21, 1998

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Assessing Two Means of Promoting Interlining:

IATA versus Alliances

Introduction

Interlining occurs any time the passenger uses the services of at least two airlines when he flies from his origin to his destination. Three types of interlining can be distinguished according to the travel. "Roundtrip Interlining" corresponds to the cases when the passengers flies with airline X from A to B and with airline Y from B to A, whereas, "Connection Interlining" occurs when X carries the passenger from A to B and Y from B to C. These first two types are also named "Programmed Interlining" since the passenger decides to fly with different airlines when he buys his ticket. The last type of interlining is named "Flexibility Interlining": once the passenger bought his ticket for a travel on a given airline, he has the possibility either to switch airline or to change his routing within the maximum allowed deviation.

As illustrated above, interlining can be considered as a joint-product: an interlining flight is made of several elementary goods of the air transport, i.e. several sectors flown by different airlines. These combined sector flights can be either complementary or substitute elementary goods.

This paper focuses on the arrangements set up by the airlines to promote these kinds of joint products and proposes a comparison between them. Very briefly, there are two distinct means for the airlines to offer interlining. IATA is the multilateral mode and it rests on a tariff coordination, whereas the bilateral mean to promote interlining, i.e. the commercial agreements between the airlines, generally don't require any price coordination. The competition policy background is the following: a block exemption has been granted to the IATA tariffs conferences provided that they help the promotion of interlining. In this paper, we try to analyse to what extend could this tariff co-ordination be a necessary device to set up interlining.

Two different co-operative arrangements are firstly presented: the multilateral system, IATA, and the bilateral one, the commercial agreements. The presentation focuses on the devices that are used by the airlines to make their networks compatible in any of these arrangements. Secondly, the two different interlining, the "universal" one, produced by IATA, and the "club" interlining, produced by the commercial agreements, are being compared from what could be

the consumer viewpoint: the quality of the travel is examined as well as its final price. Thirdly and lastly, the issue of anticompetitive effects of these co-operative agreements is being addressed.

1. How is interlining set-up?

Once they have decided to make their networks compatible, the airlines arrange a co-ordination scheme, covering technical features as well as the airline's revenue requirements. The technical features are mainly aimed at monitoring the cooperative relation. Airlines agree on the issuance of a single transportation document, on the baggage handling procedures and claims, but also on some financial points, like the date of reimbursement, the currency of transaction etc.

An airline will commit itself into an interlining relation only if it knows in advance the amount of the revenue it would receive for the transportation of the " interlining " passenger. This condition directly comes from our empirical investigations: airlines put forward that they cannot accept passenger at any price, nor can they engage a cooperation if they don't know how much money they would yield out of it! Thus, airlines agree on the amount of the individual revenue they would perceive out of this joint-production. Our comparative analysis of the two ways of promoting interlining, IATA and the commercial agreements between airlines, will be centred on this issue, namely the revenue requirement of the airlines.

IATA : promoting " universal " interlining

IATA provides the airlines with a double device complying with their revenue requirement: the IATA fare, resulting from the IATA tariffs conferences, and corresponding to the final price of the interlining ticket and the prorate rules, aimed at dividing the total interlining revenue according to the number of miles flown on each sector. If the airlines agreed only on the reimbursement rules, the ticket issuing airline would be free to sell the interlining travel at any price, and therefore, would determine the revenue that the carrying airline would receive. This solution is not satisfactory for the airlines as they wish to be ensured in advance of the revenue they would get.

> ### IATA tariffs conferences: main points
>
> The IATA tariffs conferences are devided into distinct geographic areas. The one dealing with the intra-EU traffic is named PTC-2 Within Europe[1]. Only 25 airlines are concerned with the block exemption granted to these conferences: all the EU and the AEA "nation flag carriers" are members, as well as 9 "regional airlines" (Crossair, Lauda Air, Portugalia, Air UK, Air Littoral, British Midlands, GB Airways, Maersk Air, Meridiana)[2].
>
> The output of these tariffs conferences are the IATA fares. If any member airline agrees upon a IATA fare, afterwards, it cannot refuse the right to any other member airline to issue tickets on its own services, provided that the tickets is issued at a IATA fare.
>
> Any decision must be adopted unanimously. The decision procedure within the IATA tariffs conferences is the following. The tariffs proposals come out of the bilateral negotiations, named Country by Country, or CBC: each carriers involved in the traffic between the pair of countries must unanimously approve these submissions. These submissions must then be approved by every airline during the full sessions. Indeed, each airline has a veto right: it can oppose a tariff proposal during any CBCs or can vote against the final package gathering all the proposals.

Currently, the most promotional fares are being deleted from the IATA fare structure. The airlines which originated this trend have rather big networks, either of their own or thanks to their commercial agreements. Furthermore, they perfectly manage the "new" yield management and pricing techniques. These airlines prefer to see the following fares discussed within the IATA tariffs conferences: the Normal fares, targeted on the businessman, and the Pex, the least restrictive of the promotional fares tageted on the tourist. The reason of this move towards deletion is that either their "online" revenue or their "bilateral interlining" revenue would be higher than the "multilateral interlining" shared revenue they could expect for the cheapest fares.

We assume that IATA produces a "universal" interlining as the agreed fares are available for every single airline member of IATA. Indeed, the rationale behind the IATA system is the following: once an airline agreed a IATA fare, it is then obliged to grant any other IATA airline with the right to sell seats on its own services, as long as the seat is sold at the agreed IATA fare.

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[1] 52 airlines are member of these tariffs conferences. PTC2 includes the European traffic, included the European part of the former USSR, Iceland, Acores, and Northern Africa (Morocco, Algeria, and Tunisia).
[2] The latter are characterised by a network strategy with a regional hub. Virgin Express is the only low cost airline which is a member of these tariffs conferences, but it neve attends any of them. The no-frills airline's startegy is rather to enter a highly profitable route and to cut prices: they are not very much interested in interlining.

The commercial agreements: promoting " club " interlining

The airlines that own i) a wide international and domestic network, ii) many flight frequencies, iii) a hub strategy that diminishes the connecting times for the multisector flights are capable of keeping the passenger on their own services from most of the origins to most of the destinations. For the markets they don't directly fly, these airlines will try to set some agreements with the concerned regional airlines, which will, in return, have an access to networks with a wider scope.

The commercial agreements are aimed at putting in common the networks of different airlines in order to offer a joint product to the passenger, i.e. a travel combining sectors flown by different airlines but with the benefits of a single airline flight. With the code-sharing agreements or the joint Frequent Flyer Programs, the passenger "feels" that he will be flown through by a single airline. Moreover, allied airlines often seek a better schedule co-ordination, an advantageous gates location at the connecting airport, etc. If the airlines cooperate successfully, the quality of the service can be as good as for an online flight. Nevertheless, we will still name it "interlining" since two different carriers are involved in the transportation and since each exchanged passenger implies a financial transaction.

In these commercial agreements, several devices exist and guarantee the generated unit revenue to the airlines. Most of the mechanisms used don't require any tariff co-ordination: the pricing freedom of each partner is not constrained by the agreement. For instance, regarding the SPA (Special Prorate Agreements), the carrying airline requires a fixed revenue, or a percentage of one of its own fares and the ticket issuing airline can sell the travel at whatever price, as long as it pays the carrying airline its required revenue.

We will refer to the interlining set up by the commercial agreements as "club" interlining since the agreement is restricted to its members.

IATA fare setting and the airlines fare setting: two different approaches

The liberalisation of the European sky led to new competition dimensions for the airlines: the capability of setting the "right" price and the final distribution.

The capability of setting the "right price" refers to the faculty of discriminating between the different types of passengers: the final prices must be as close as possible to the willingness to pay of each passenger in order to maximise the global revenue of the flight[3]. This requires to

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[3] According to their price sensitivity, different final prices will be proposed to the passengers. On the one hand, the promotional tariffs must be attractive enough for the tourist, and on the other hand, the normal fares must extract the integrality of the businessman's willingness to pay

master the pricing and yield management techniques which in turn, require important technological investment, as well as human[4].

The final distribution power of an airline lies within its capability to inform the passenger on its services and prices. In this context, choosing a tariffs distributing channel, or more generally speaking, a Computerised Reservation System, becomes meaningful. As consequential is the geographic scope of the final distribution[5] as well as the relations with the travel agencies.

Do all the European airlines master these pricing and distribution techniques. The trend is that every airlines adopt these techniques. Nevertheless, there are still some discrepancies between them, reflecting their competitive advantages. All the airlines underline i) the required human investment and ii) the importance of the relations with the travel agencies, insisting on the possible anti-competitive effect of the "commission overriding". The regional airlines we met confirm that they do use the yield management, but in its simplest version. On the other hand, the Northern Europe "nation flag carriers" master highly sophisticated versions. The Southern Europe "nation flag carriers" seem to be the least equipped.

Currently, in Europe, there are two ways of determining the final prices of the airline's tickets and each way corresponds to a specific air travel product. The role of the IATA tariffs conferences should be limited to setting up the price of some specific products, the "universal" interlining travels. On the other hand, the final prices of the products restricted to the services of a specific airline, referred to as "carrier fares" are determined in a price competition context, and thanks to the pricing techniques of each airline. The following table sums up the characteristics of the IATA fares and the carriers coded fares.

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[4] Sabre is the main provider for the yield management and pricing techniques. When it sells its system to one airline. a Sabre top executive spends a couple of years in the airline to set up the whole pricing system. After "having tought Air France the pricing basics" –sic the Europe pricing manager-, this guy is now doing the same job in Alitalia since November 97.

[5] The hubbing developpment leads to an increase in the demand location area. beyond the national frontiers of the carrier. For instance. British Airways tries to attract passengers from all over Europe to Heathrow to carry them on its long haul destinations. But information on the proposed flights and their prices must be available to the potential travellers

IATA fare	Carrier's fare
Interlining travels only	Online and on allied carrier's services travels only
Co-operation context: device used to set up the "universal" interlining	Competition context: device set up to extract the passenger's willingness to pay
The IATA structure contains the Normal Fare and the Pex	Trend to the fares multiplication
Agreed for 6 months at most. Changing unilaterally the agreement seems to be useless since the other member airlines can immediately cancel the move	Can be modified by the airline when it wishes. Quick response to the market evolutions
Coming from a collective negotiation: adjusted to the least efficient airline	Reflects the commercial strategy. Use more or less sophisticated of the pricing and revenue management techniques
Available in every CRS, and thus, for every consumer, whatever his location	The availability depends on the distributing strategy of the airlines (GDS, CRS, travel agencies)

2. Compared analysis of the "universal" interlining and the "club" interlining

Here, we will compare the interlining services promoted by IATA and the commercial agreements. What are the pros and cons for the businessman and for the tourist of the "universal" interlining and of the "club" interlining?

"Universal" interlining's quality is higher than "club" interlining's one.

Since it allows the construction of any interlining travel for any routing in Europe, the multilateral IATA system is particularly interesting for the passengers of the outlying areas of Europe. Indeed, the commercial agreements mainly concern high density traffic zones. One can assume that for a not very dense route, the setting up and monitoring cost of the relevant commercial agreement might be higher than the expected benefits, whereas it is relatively not costly to discuss a marginal route in the IATA procedures. Therefore, we affirm that only IATA can set up interlining for the outlying areas with little traffic.

We'll now focus on situations where both means of promoting interlining exist, i.e. the relatively dense traffic zones. The quality of interlining rests on the diversity of two features of the travel: the frequencies and the possible routings. Table 1 presents the quality of each interlining category according to its promotion mode.

Table 1. **Which quality for the universal and the club interlinings?**

	Round-trip Interlining	Connection Interlining			Flexibility Interlining	
	Available Frequencies	Available Frequencies	Available Routings	Duration of the travel	Available Frequencies	Available Routings
IATA	+	+	+	-	+ +	+ +
Commercial Agreements	-	-	-	+	- -	- -

The "universal" interlining produced thanks to IATA provides the passenger with a greater diversity: more frequencies and/or routings are available for his choice. Conversely, the "club" interlining produced by the commercial agreements offers less possibilities since a fewer number of airlines participate to the agreement.

To conclude, the "universal" interlining produced by IATA is of a better quality than the club interlining produced by the commercial agreements. The geographic coverage of the universal interlining is comprehensive; any passenger, tourist[6] or businessman, can chose between a greater variety of travels. At last, only IATA can provide the businessman with satisfying possibilities of airline switches or re-routing, once he bought his ticket.

The "universal" interlining is more expensive than the commercial agreement's one[7].

The allied airlines seek to attract as many passengers as possible on their services. Their fares are set up so that the travel resulting from this co-operation is more attractive than the existing alternatives: the "universal" interlining, or the other "club" interlining on the same market, if any. A certain competition emerges between these air travel solutions, competition that would lead to a certain price reduction. Moreover, most of the commercial agreements don't constrain at all the pricing policy: one can reasonably assume that the prices set up by the allied airlines would reflect their costs[8].

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[6] In spite of the current move towards the deletion of the IATA very promotional fares, a Pex remains in the IATA structure.

[7] The final price comparison is restricted to the roundtrip and connexion interlining for the areas with a sufficient traffic where these kinds of interlining can be proposed either thanks to IATA or to the commercial agreements.

[8] On the other hand, it is frequently assumed that some alliances reduce the airline's costs. The ground maintenance equipements, the boarding gates at the connecting point are being shared by the partners. Furthermore, the induced extra traffic leads to a better fleet utilisation and to an improved load factor. These

The rationale behind the IATA pricing is very different from the rationale behind the commercial agreements pricing. The IATA fare comes from a collective negotiation: it is set up so that the airline with the highest costs will be satisfied. Indeed, the IATA fares are supposed to be applied by a great number of airlines, which all have different costs. The decision procedures, and specifically, the unanimity rule are such that it is almost impossible to go against the economic interest of the least efficient member since there is no exclusion procedure in IATA. The most efficient airlines –with the lowest costs- will be prompt to accept this price level since it will ensure them a high profit. Two other elements make the IATA price more expensive. Only price increases are voted, and never price decreases. The deletion of the promotional fares from the IATA structure is such that the "club" interlining flights are less expensive than the "universal" interlining flights, which are offered for the higher tariff classes only.

Some final distribution features make the IATA interlining flight not very attractive. First, according to the display rules on the CRS, the interlining flight is shown after the direct flight and the online connection. The code sharing agreements are a suitable response to this constraint. Secund, the flights are ranked on the screen according to an increasing range: airlines compete on very small amounts of money to be shown in the first positions and the IATA fares are at the very bottom of the screens. Third, the travel agencies commissions incite them to sell certain airlines' flights. Fourth, any pooling of the Frequent Flyer Programs make the commercial agreement more attractive for the passenger.

To conclude, the "club" interlining is proposed to any passenger, tourist or businessman, at a more interesting price than the "universal" interlining. Any commercial agreement is aimed at dragging as many passengers as possible, and most of these agreements don't require any tariff co-ordination. Conversely, the fares coming from the IATA tariffs conferences must satisfy any member, even the most inefficient.

3. Anti-competitive effects of IATA and the commercial agreements

The analysis of the possible anticompetitive effects of the two co-operation means aimed at promoting interlining is threefold: i) what are the exclusionary consequences of any of these agreements?, ii) where are the smaller airline's interests better defended?, iii) what is the influence of the IATA fares on all the carriers fares, business or tourism?

The commercial agreements have an exclusionary effect, whereas IATA has none.

A IATA fare is available for any IATA airline: nobody can be excluded. Any airline which attended the tariffs conferences must accept any passenger holding a ticket issued by any other IATA airline at a IATA fare. In other words, in the IATA system, any airline is allowed to sell seats on any other airline. Since the only condition to be a IATA member rests on the financial soundness of the applicant airline, it is very easy to enter this association. Therefore, one can say that the IATA multilateral system prevents from excluding any airlines that wishes to enter any market.

Any commercial agreement excludes the newcomers since it is restricted to its members. Any regional airline with a network strategy, i.e. interested in interlining, will have to find the best partner. On top of that, alliances might create "fortress hubs" where one or two airlines dominate an airport. This raises barriers to entry, even for the airlines not interested in interlining, like the "no frills" airlines. One can wonder what will be the future for the airlines that have not passed any alliances yet?

	IATA	Commercial Agreements
Forclusion effects	- -	+

IATA better protects the smaller airlines' interests than the commercial agreements.

The national airlines market power could be turned into any abuse of dominant position. Where is that more likely to happen? Under the auspices of IATA or in the commercial agreements?

Within IATA, the unanimity rule provides every airline with the same rights. Theoretically, this system protects the smaller airlines against the bigger ones. Nevertheless, this proposal must be slightly mitigated by the way negotiations really happen. There is a "market leader" effect which make uneasy for smaller airlines to oppose a national airline like British Airways, for instance. Airlines also tend to moderate their demands for fear of retaliation. When opposing, airlines seek to create a opponents coalition, which is always more efficient than opposing alone. All these reasons tend to lessen the equality of rights granted to the IATA members: to a certain extent, smaller airlines depend on the bigger ones. Even if they are fully aware of these

minor drawbacks, the smaller airlines grant the IATA tariffs conferences with a great role for the protection of their interests.

For the commercial agreements, there is a mutual interest: it is not necessarily the bigger airlines that would dominate the smaller one. The form of the agreement plays a great role here. Some agreements are not very binding and the airlines don't commit too much themselves. On the other hand, other types of agreements are very close to a merger (filialisation), or are such that the decision power is transferred to the bigger airline (franchising).

	IATA	Commercial agreements
Smaller airlines interests protection	+ +	+

IATA fares have no influence on the tourist carrier's fares

Two elements are relevant to assert that the IATA fares play no role on the determination of the promotional carrier fares interesting for the tourists. First, the IATA fare structure includes only normal fares and a Pex, corresponding to the higher segment of the tourism market. Any other promotional fare has been suppressed from the IATA structure. Secund, the liberalisation of the European sky led to a multiplication of the tariffs offered to the tourist, and to a decrease in their price levels. The counterpart of this price reduction is that the concerned flights are restricted to the airline's own services, or to its allied partner's ones. For the lower fares, one can talk about a "spot market". Indeed, if the plane is not full, airlines sell their empty seats at the last moment, adjusting thus supply and demand. Nevertheless, the distribution channels of these products are highly specific. The price sensitivity of the tourism passengers is fully exploited by the airlines.

What role play the IATA fares on the business carrier's fares?

The businessman wishes to have a travel with no restriction at all (no reservation in advance, no maximum/minimum stay requirement, etc.). Two products are at his disposal: the first one allows him to switch airline at the last moment, whereas the second one compels him to stay on the very same airline's services. The first one is produced thanks to IATA and its price is set up within the IATA tariffs conferences. The second one is produced according to the strategy of the airline and the competition on the concerned route.

When there is no business carrier fare

When the AEA[9] asserts that the passenger can find a business carrier's fare on the totality of the relevant intra-EU routes, the CAA[10] claims that it is only a very small number of routes that are concerned. According to a survey[11] carried out on 31 routes linking European capitals, a business carrier fare is proposed on only 18 routes, i.e. around 60 % of our sample. What lessons can we draw, from a competition policy point of view, out of the situations where the businessman has only the IATA fare at his disposal? This question is relevant as 40 % of the routes in our sample are concerned.

When the businessman has no other choice than buying the ticket sold at the IATA fare, he is obliged to accept the possibility to switch airline, even if he is not interested at all in buying an interlinable ticket. One can assert that this is a case of " purchase obligation ", since the possibility to switch airline is automatically sold with the other services provided by the business ticket: buy the ticket at the last moment, arrive later at the airport and come out of the plane sooner, enjoy a greater in-flight comfort, etc. The alternative tickets offered are not convenient for the businessman since the promotional tickets content restrictions, like advance purchase, duration of the stay etc. Thus, we assert that when only the IATA fare is available on a route, the businessman is complied to buy it. These situations are a disadvantage for the consumer.

When there is a commercial business fare

Two separate issues must be addressed when the consumer can chose between two types of business travels: one offered by IATA, and the other by the airlines. First, does the IATA fare influence the carrier's fare? Secund, how come airlines match their business fares?

The IATA fare doesn't have any influence on the carrier's fare

Since it stands for the higher quality product, the IATA fare is the highest of the air transport tariff structure. An additional service is provided with a IATA ticket, the possibility to switch airline. The difference between the IATA fare and the carrier's fare depends on the route. In

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[9] AEA. Yearbook 1997, p. 24.

[10] CAA. The Single European Aviation Market: Progress So Far. September 1995, CAP 654.

[11] For 31 routes linking several European capitals, we have the following figures: the level of the IATA normal fare. the level of the business fares proposed by the carriers, the number of flights operated by each airline of the route. the state of the flights differenciation. We refer to "differenciated flights" when their departure times are different enough to make them not substitutes. For instance, if airline X operates the 8.00 a.m. glight on route Ab and airline Y the 12.00 a.m. one. we will say that the flights are differenciated since they are not substitute. Conversely. if X operates the 8.00 a.m. flight and Y the 8.30 a.m. one. the passenger has the choice between the two airlines and the flights are considered as not differenciated. Annex 1 presents these routes' characteristics.

average, the carrier's fare represents 84 % of the IATA fare, but this varies from 62 % to 96 %, as it is shown in graph 1.

Graph 1. Carrier's business fare as a % of the IATA fare
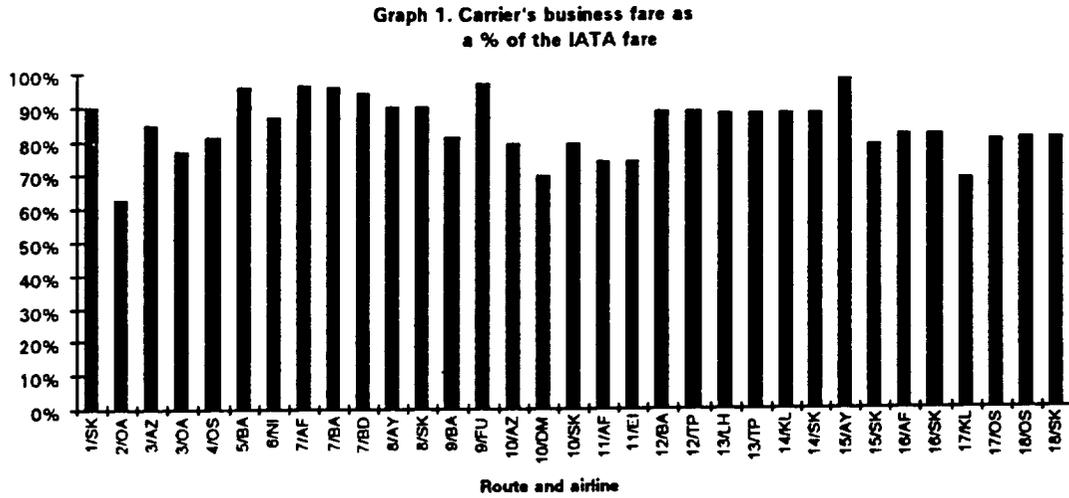
Would the carrier's fares be less expensive if the IATA fares didn't exist? The liberalisation process led to the development of the discrimination between the different types of passengers as the pricing basic mechanism. Airlines seek to extract the totality of the business passengers willingness to pay, independently of the IATA price level. Since these passengers are not price sensitive, airlines will propose the highest possible fare. The IATA fare play no role in on the carriers fares levels.

The price matching phenomenon is completely independent from the presence of a IATA fare.

Only 18 routes present a carrier's business fare out of the 31 of our sample. The carrier's business fares proposed are equal in half of the cases, as graph 2 illustrates it.

Graph 2. Routes with a carrier's business fare
(CBF)

Each airline of the route
propose a different CBF
28%

Only one airline offer a
CBF
17%

All the airlines offer the
same CBF
55%
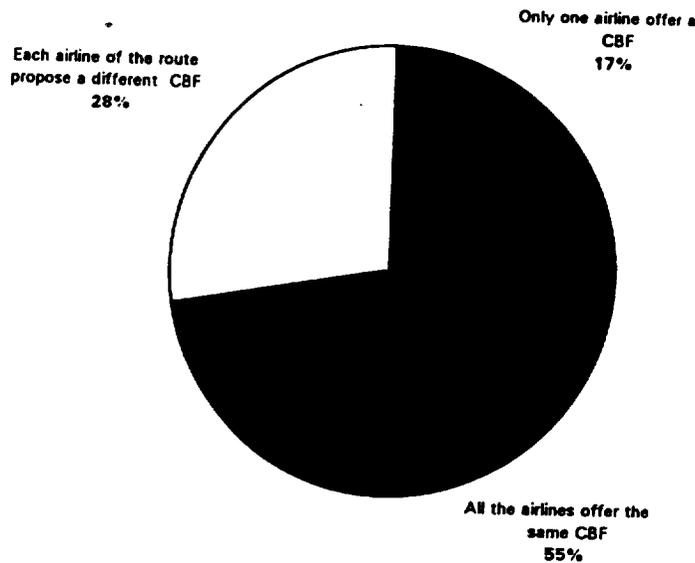
The airlines which match their prices offer very similar products since the schedules are very close in time. The travels are not differentiated. The price matching phenomenon is not connected to the existence of a IATA fare.

From a competition policy viewpoint, what can we say about the price matching phenomenon. Does it translate a tacit collusion between the airlines? Or, does it mean that airlines extract the passenger's willingness to pay? This question is beyond the scope of this paper and is a very delicate one. One can put forward that since the air transport prices are public and displayed through the CRSs, the tacit collusion possibilities are not neglectible.[12]. On the other hand, if the airlines offer similar products and if their prices are set so that the passenger's willingness to pay is fully extracted, the price identity is not very surprising.

Concluding remarks

Is IATA the place where airlines set up explicit price fixing agreements? Or, is IATA a co-operative arrangement aimed at promoting a specific air transport product, the "universal" interlining? In other words, what is the role of IATA today? Cartel, or multilateral production mode of a joint-product, namely interlining?

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[12] In the United States, the case " United States vs US Airline tariff publishing company " (civil action no. 92-2854, DDC, December 21, 1992), led to new rules for the published tariffs in the CRSs. These public prices became automatically enforcable, since before that, the airlines communicated through the CRSs, displaying

As an interlining production mode,-IATA is today challenged by the commercial agreements, which offer interlining as well, of a poorer quality but cheaper. Nevertheless, only IATA offers the flexibility interlining with a quality level that would satisfy the business passengers. And the geographic coverage of IATA is wider, this benefits the consumer from the outlying areas of Europe. As far as quality is concerned, IATA is more interesting for the passenger, businessman or tourist.

Regarding the possible anticompetitive effects of these agreements, the commercial agreements present a higher risk of empeding the entry than IATA and the smaller airline's interests are better taken into account within IATA than in the commercial agreements.

On the other hand, the price fixing role that held IATA has been considerably reduced. The tourist fully benefits from the price competition and the tourism tickets prices have no connection with the IATA prices. Conversely, the business passenger cannot always chose between a IATA fare and a carrier's fare. For 40 % of the routes of our sample, IATA remains the price fixing place. But, when there is a carrier's fare alternative to the IATA fare, the price level of the latter has no influence on the former. Indeed, the airline's current price setting is aimed at extracting the totality of the business passenger willingness to pay, whose price sensitivity is very low.

Deregulation and Schedule Competition in Simple Airline Networks

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2nd ATRG Conference
Dublin, 20 - 21 July 1998

Abstract

This paper considers airline scheduling in a small airline network where at least one of the firms in the market operates a hub-and-spoke system. We model airline competition in frequencies and prices as a two stage game: in the first stage, airlines choose frequencies on the legs in their network, in the second stage they choose prices for direct and connecting markets. The two-stage setup of the model allows airlines to choose asymmetric frequency equilibria such that price competition is reduced. We consider profit maximizing schedule solutions for two types of networks, and compare monopoly solutions with competition in part of the network. The numerical results indicate that deregulation in part of the network has a positive effect on aggregate consumer welfare. While prices for their tickets go down, connecting passengers lose because their schedule delay and travel time costs increase under the duopoly schedule equilibrium. Furthermore, industry profit decreases after deregulation.

1. Introduction[1]

In deregulated airline markets, carriers are free to choose the values of the variables affecting their profits. Out of the large number of decisions to be made in practice, the decisions on flight frequency and price on each route in an airlines network are of major importance. Frequency, or the number of flights offered per unit of time, determines consumer welfare by affecting not only the gap between desired departure times and actual departure times, but also the transfer time of passengers who are not on direct flights. Also, total flight frequency has a negative external effect on households suffering from noise and emission of pollutants. Interpreting frequency as quality of service, the frequency decision affects both the number of passengers and their willingness to pay. On the other hand, frequency clearly is a major determinant of airline costs, so that quality is costly to provide. Furthermore, frequency affects both quality of service and - given aircraft size - capacity at the same time and can thus be assumed to influence prices. A further basic aspect of airline markets is the small number of competitors, implying that competing carriers take the possible reactions of their opponents into account when making decisions, e.g., on frequencies and prices. Finally, it has been observed that prices in the airline industry are adjusted daily, whereas changes in frequency (schedules) can be assumed to be much less flexible.

The present paper wishes to model airline competition while taking into account the above observations. Consumer demand is affected by price, schedule delay and transfer time, while the latter two are determined by the airlines' frequency decisions. We consider airline behaviour in a small airline network, under monopoly and duopoly competition respectively and we restrict the analysis to situations where at least one of the firms in the market operates a hub-and-spoke (HS) system. The difference in decision flexibility between frequency and price is accounted for by modeling airline competition as a two stage game: in the first stage, airlines choose schedules. i.e. flight frequencies for each link in their network, while in the second stage, having observed the respective first stage choices, they choose prices. The equilibrium is thus computed as the subgame perfect Nash solution in schedules. A central policy issue addressed by the model is the welfare effect induced by airline deregulation, defined as the introduction of competition in (a part of) the network.

A number of articles in the large literature on airline (network) competition and deregulation are particularly relevant for this paper. The model has the same two stage structure as the network design model in Lederer (1993). but differs in two ways. Firstly. customer demand is distributed with respect to preferred departure times, so that there is not one least price 'path' per origin-destination (OD) market and more than one firm provide transport between OD markets in equilibrium. Secondly, demand in each market is elastic with respect to both frequency and price.[2] Brueckner and Spiller (1991) use a model of quantity setting duopoly competition in a network; they conclude that with returns to density or cost complementarities in a network, competition in a part of the network may result in an overall welfare decrease because of the negative externalities imposed on the other passengers in the system. Using a similar model Nero (1996) concludes that airline deregulation unambiguously improves welfare in the network when returns to density are absent. The present paper analyzes the introduction of competition in a simple network using the two-stage schedule competition model outlined above.

The paper is organized as follows. We introduce and calibrate the model in the next section, and discuss some of its properties. We then consider simulated market outcomes under monopoly and duopoly competition for two simple airline networks. Section 3 discusses monopoly and leg competition in a one-hub network. In section 4, monopoly and duopoly solutions in a network with two hubs are analyzed. The outcomes under monopoly and competition are compared in terms of welfare.

2. The model

2.1. Demand

A base assumption of the model is that at least one airline operates a hub-and-spoke (HS) system. Therefore, passengers fly either directly to their destination (local passengers) or have to transfer to a connecting flight (connecting passengers). Connecting passengers are assumed to use the services of one airline only during their trip. Furthermore, we do not consider demand for which more than

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[2]Furthermore, passengers are assumed not to 'bundle' flights. i.e., not to switch between airlines when when making a transfer. Lederer (1993) shows that such bundling may lead to non-existence of the price equilibrium.

one transfer is necessary, so that connecting passengers are on two flights during their trip, passing through two spokes or legs s via a hub. Passengers make one-way trips between nodes (cities) in the network, so that the market m for transport between cities Y and Z represents two one-way markets $m_{Y \to Z}$ and $m_{Z \to Y}$.

A traveler derives gross utility $\bar{v}$ from making a trip, and faces a price p. Furthermore, a consumer suffers a linear schedule delay cost $\theta_1 x$ when the flight leaves at a time distance $x = |t_{dep} - t_{pref}|$ from his or her preferred departure time,[3] and a linear travel time cost $\theta_2 d$, where d is the duration of the trip. Given the network layout, trip duration in the model is fixed for local passengers, whereas it depends on the departure frequency on the second spoke travelled during the trip for connecting passengers. When the gross valuation exceeds the sum of price, schedule delay cost and travel time cost, the traveler buys a ticket. We note that the schedule delay of a connecting passenger is determined by the departure time of the first of his two flights, whereas his travel time is partly determined by the departure time of the second flight.

Consumer preferences with respect to departure time are represented by a circle of (time) length L on which potential passengers are distributed uniformly. The departure times of flights on a particular leg of the network are also located on this time circle: we consider the departure times of flights i and $i + 1$, t_i and t_{i+1} respectively, which are separated by headway H. Flights are spaced equally on the circle. Therefore, the headway is determined endogenously as the time length of the circle divided by the total number of flights F offered by airlines on the particular leg, i.e.

$$H = \frac{L}{F} \tag{2.1}$$

Potential passengers who are 'located' at some preferred departure time $x \in (0, H)$ face a time distance x with respect to the departure time t_i of flight i and a distance $(H - x)$ with respect to t_{i+1}. These potential passengers derive the following net utilities or consumer surplus from the two options:

$$v_i = \bar{v} - p_i - \theta_1 x - \theta_2 d \tag{2.2}$$
$$v_{i+1} = \bar{v} - p_{i+1} - \theta(H - x) - \theta_2 d$$

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[3] We thus make the assumption that the utility loss caused by taking a flight at a time distance x *earlier* than the preferred departure time is equal to the utility loss caused by taking a flight at x *later* than the preferred departure time. The term 'schedule delay cost' is meant to capture both types of utility loss.

4

Clearly, a consumer will choose the flight belonging to the larger of the above expressions and buy a ticket if the net utility is positive. For the moment, we shall assume that the travel time of the two options is equal. We can now derive the distance x_b between t_i and the boundary between the market areas of the two flights as that value of x for which $v_i = v_{i+1}$. This gives

$$x_{b+} = \frac{p_{i+1} - p_i + \theta_1 H}{2\theta_1} \qquad (2.3)$$

All potential passengers located between t_i and x_{b+} will take flight i, if they fly at all, and those located between x_{b+} and t_{i+1} will choose flight $i + 1$, again, if they fly at all. The number of passengers with preferred departure time $x \in (0, x_{b+})$ actually taking flight i is calculated as the number of potential passengers with gross utilities $\overline{v_i} > p_i + \theta_1 x + \theta_2 d$; we represent this number by $D \cdot g(p_i + \theta_1 x + \theta_2 d)$, where D is a density parameter. Demand for flight i from potential passengers with preferred departure times $x \geq t_i$ can be obtained by adding the number of passengers over all preferred departure times x between t_i and x_{b+}. We include the demand from passengers with preferred departure times earlier than t_i, [4] giving

$$q_i = D \int_{x_{b-}}^{x_{b+}} g(p_i + \theta_1 x + \theta_2 d)\, dx \qquad (2.4)$$

Aggregate demand for flight i is calculated as the sum of direct passengers and connecting passengers who choose the flight on the first leg of their journey.

We now consider the demand for travel in one-way market $m_{Y \to Z}$, which is either a direct market for local passengers on spoke s or a transfer market for which s is the first spoke to be travelled. Aggregate demand for market $m_{Y \to Z}$ is found by summing $q_{m_{Y \to Z}, i}$ over all flights. Thus, for an airline l operating a departure frequency $f_{l,s}$ in spoke s, demand $Q_{l, m_{Y \to Z}}$ is

$$Q_{l, m_{Y - Z}} = \sum_{i=1}^{f_{l,s}} q_i (p_i, p_{i-1}, p_{i+1}, H, d) \qquad (2.5)$$

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[4] The location x_{b-} which marks the boundary between the market areas of flight i and an earlier flight $i - 1$ departing at time t_{i-1} is found in the same way as x_{b-}, i.e.,

$$x_{b-} = \frac{p_{i-1} - p_i + \theta H_-}{2\theta}$$

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Finally. total demand for city-pair market YZ is the sum of the demand in the two one-way markets $m_{Y\to Z}$ and $m_{Z\to Y}$ respectively.

2.2. Configurations

We proceed by analyzing the duopoly configuration of flights in a particular time period, represented by the circular 'time' market. For notational convenience, we consider a one-way non-stop duopoly market in the following. Consider a departure i operated by airline l. There are three possibilities: departure i may have either two, one or zero neighbouring departures offered by a competing airline $-l$; we refer to such departures as 'unfriendly neighbours', while we call two neighbouring flights operated by one and the same airline 'friendly neighbours'.

The expression for the market boundary x_b in the demand per flight function q depends on the configuration of the departures. With an interlaced configuration. for each departure i the price for both the earlier and the later departure ($i-1$ and $i+1$ respectively) is set non-cooperatively by a competing airline. Note that each airline sets one and the same price for all its tickets, i.e., there is no price differentiation between departures of one firm.[5] A departure i with two unfriendly neighbours faces market boundaries

$$x_{b-} = \frac{p_{i-1} - p_i + \theta H}{2\theta}$$

$$x_{b+} = \frac{p_{i+1} - p_i + \theta H}{2\theta} \tag{2.6}$$

from which demand for flight i is derived using equation (2.4). We refer to the demand for this type of flight as q_{cc} or completely competitive demand.

In the case of a non-competitive flight (with no unfriendly neighbours), demand is derived from the market boundaries

$$x_{b-} = x_{b+} = \frac{H}{2} \tag{2.7}$$

because prices are the same for these flights. We refer to this type of demand as q_{nc}.[6] We note that for any specification of the demand function, completely competitive demand is more price sensitive than non-competitive demand.

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[5]Therefore, in case of a duopoly the price of both competing departures is the same.

[6]An explicit analysis of demand for the intermediate case of a 'semi-competitive' flight i . i.e., a flight with only one unfriendly neighbour $i-1$ and one friendly neighbour $i+1$ is omitted.

6

For the market as a whole, we can now distinguish between two extremes. In a monopoly market, all departures are offered by the same airline; on the other hand, there is the completely interlaced equilibrium, in which all flights have unfriendly neighbours. Of course, there are many possible configurations between these extremes. The range of configurations implies that with multiproduct competition, monopoly and oligopoly become relative rather than absolute concepts. We consider two configurations in figure 1.

(1a)

A symmetric completely
interlaced duopoly
configuration

(1b)

A slightly asymmetric non-
interlaced duopoly
configuration
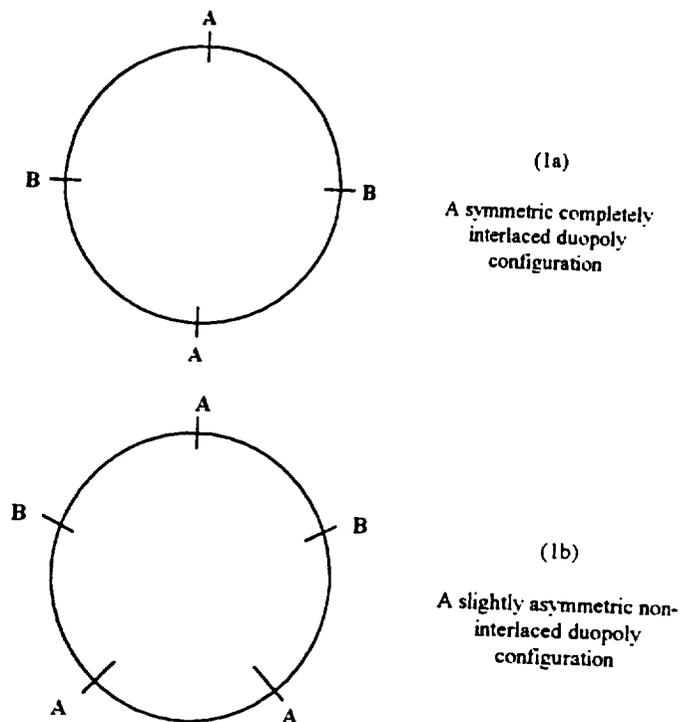
Figure 1: Multiproduct configurations

Note that the number of such flights is always a multiple of 2, and we therefore rewrite the demand for two 'semi-competitive' flights as the demand for one competitive flight q_{cc} and one non-competitive flight q_{nc}.

The first configuration in figure 1 is a completely interlaced duopoly. When a duopolist analyzes the effect of a unit increase in departure frequency starting from a symmetric interlaced configuration, he necessarily considers a 'slightly asymmetric' configuration. As is illustrated in figure 1b, all non-symmetric duopoly configurations are non-interlaced. An implication of the model structure is that the form of the demand functions in an airline duopoly changes at $f_l = f_{-l}$.[7] Aggregate demand over all departures Q consists of two parts. For airline l, aggregate demand in the market is

$$Q_l = f_l q_{cc} \qquad \text{if} \quad f_l \leq f_{-l} \qquad (2.8)$$

$$Q_l = (f_l - f_{-l}) q_{nc} + f_{-l} q_{cc} \quad \text{if} \quad f_l > f_{-l} \qquad (2.9)$$

Using equations (2.1), (2.3), (2.4) and (2.5), we note that

$$\frac{\partial Q_l}{\partial f_l} > 0$$

$$\frac{\partial Q_l}{\partial f_{-l}} > 0$$

$$\frac{\partial Q_l}{\partial p_l} < 0$$

$$\frac{\partial Q_l}{\partial p_{-l}} > 0$$

The demand and profit function of both duopoly airlines have the exact same form. Clearly, when the first line of the demand function is relevant for one airline, the second is relevant for the other. Only when $f_l = f_{-l}$, the two parts of the demand function give the same value.

2.3. Cost and profit

For each flight, the costs consist of a (major) fixed part FC and a marginal cost c per passenger. The model assumes that each airline l charges a single ticket price for each city-pair market $m, m = 1, ..., M_l$ it operates. Furthermore, airlines decide on the flight schedule, that is, the departure frequency for each spoke $s, s = 1, ..., S_l$ in their network. Thus, airline behaviour is represented by the

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[7]Here and in the following, the subscript $-l$ refers to the competitor of airline l.

vectors $\bar{p}_l = \{p_1, ..., p_{M_l}\}$ and $\bar{f}_l = \{f_1, ..., f_{S_l}\}$. Using (2.5) and (2.1). profits of airline l facing a competitor $-l$ in one or more of the markets in its network are

$$\Pi_l = \sum_{m=1}^{M_l} (p_m - c) Q_{l,m} \left(\bar{f}_l, \bar{p}_l, \bar{f}_{-l}, \bar{p}_{-l}\right) - 2 \sum_{s=1}^{S_l} f_{l,s} FC \qquad (2.10)$$

2.4. Calibration

For the calibration of the model we follow the procedure in Norman and Strandenes (1994), viz., solving for the demand parameters using price, frequency, cost and demand observations for a base monopoly situation in combination with the monopolist's first order conditions. Firstly, we impose a linear form on the point demand function $g(.)$ in (2.4):[8]

$$g(p + \theta_1 x + \theta_2 d) = \alpha - p - \theta_1 x - \theta_2 d \qquad (2.11)$$

Monopoly demand per flight is then derived as

$$q = D \int_{x_{b-}}^{x_{b+}} g(.) dx = 2Dx_b \left(\alpha - p - \theta_1 \frac{x_b}{2} - \theta_2 d\right) \qquad (2.12)$$

Data are available for a non-stop monopoly route only. We note that for such a trip, the monopolists first order conditions only refer to price and frequency on the leg. With the demand equation, we have a system of three equations, which allows solving for the three demand parameters $D, \hat{\alpha}$, and $\theta_1,$[9] with $\hat{\alpha} = \alpha - \theta_2 d$. The data thus do not enable us to directly infer a value for θ_2, which represents the common value of travel time. Morrison and Winston (1989) report estimated values of travel and transfer time to be much higher (a factor 10 and 20, respectively) than the value of schedule delay. The relative values seem to depend on the type of traveler. As indicated by Morrison and Winston, business travelers are likely to have a much higher relative value of θ_1 than other travelers. Dobson and Lederer (1993), use a value of schedule delay higher than the value

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[8]The demand specification ultimately depends on the assumed distribution of gross valuations v. A well known alternative is the negative exponential distribution, as used in e.g. Evans (1987). However, that specification does not allow one to solve the calibration equations for the parameters of the model. The specification used here is conform Greenhut et al. (1987).

[9]Data refer to the pre-deregulation Tel Aviv - Eilat monopoly. and consist of price. frequency and passenger observations. Furthermore. we dispose of passenger and per flight cost data.

of travel time in their simulation model, while Berechman and de Wit (1996) use a single value of time to calculate utility as a function of flight frequency for local and connecting passengers.[10] Given the scarcity of evidence and the difficulty of comparing parameter values between rather different models, we do not assign a fixed value to θ_2 here. Rather, we investigate the sensitivity of the results to changes in the relative value, and look for restrictions on the parameter value in the next section.

As indicated above, for local passengers, the utility loss caused by the time involved in the trip is represented by the parameter $\hat{\alpha} = \alpha - \theta_2 d$. For connecting passengers, the calculation differs on three accounts. Firstly, the trip consists of two leg flights. Secondly, the connecting passengers have to wait for a connecting flight. Thirdly, the gross trip valuation may differ between non-stop and on-stop travel. In order to simplify the calculations, we have assumed the following. For connecting passengers', gross trip valuation is higher than for local passengers, e.g., because of the larger travel distance. However, the difference in trip valuation is exactly matched by the utility loss derived from the incremental travel time. Therefore, the parameter $\hat{\alpha}$ has the same value for both passenger types. The difference between the demand functions, however, stems from the waiting time of the connecting passengers, which depends on the frequency of the airline on the second leg of the trip. We thus have, for connecting passengers

$$d_c = \mu H_{leg2} = \mu \frac{L}{F_{leg2}} \tag{2.13}$$

where μ is a parameter indicating proportion of the headway time on the second leg which the passenger has to wait, with $0 \leq \mu \leq 1$. Thus, even at a low frequency on the second leg, the waiting time can be small when arrival and departure times of connecting flights are close. We have chosen an arbitrary value of $\mu = 0.5$ in the calculations. The base set of parameters is presented in Table 1, with all monetary equivalents in US$.

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[10]They do, however, distinguish between business and non-business passengers.

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Table 1:
base simulation coefficients

calibrated parameters	
D	0.49
$\hat{a}$ (\$)	174.47
θ_1 (\$)	131.58
imposed parameter	
μ	0.5
cost parameters (\$)	
c	5
FC	1500

Using these parameter values, we simulated frequency and price decisions in network markets. The simulation results are presented and discussed in the next sections.

3. A one-hub network

In this section, we consider the effects of introducing competition in a simple network consisting of one hub and two spokes, as depicted in Figure 2. We assume that the network is symmetric in the sense that legs 1 and 2 have the same length, and that all markets have the same density. Using the same type of aircraft on both legs, the demand and cost characteristics are equal on non-stop flights.
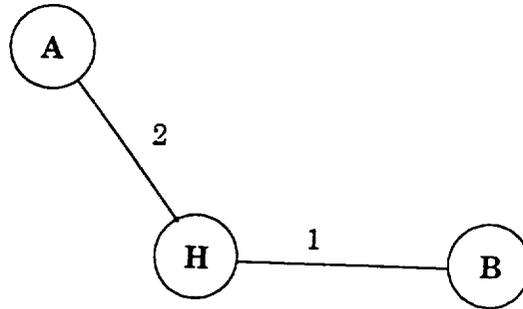
Figure 2

3.1. Monopoly

We first consider the schedule choice of a monopolist, who operates a HS system in the above network. As the monopolist does not have to take into account the

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possible actions of an opponent, the problem is simply

$$\max_{\bar{f},\bar{p}} \Pi = \sum_{m=1}^{M} (p_m - c) Q_m \left(\bar{f}, \bar{p} \right) - 2 \sum_{s=1}^{S} f_s FC \tag{3.1}$$

where M is the number of markets, and S the numebr of spokes. Clearly, the number of spokes is two, so that $\bar{f} = \{f_1, f_2\}$. We distinguish three city-pair markets, viz., the local markets AH and HB, and the connecting market AB, so that $\bar{p} = \{p_{AH}, p_{HB}, p_{AB}\}$.

We start by considering the price solution of the monopolist. Using (2.12), we derive as the monopoly price solution for a given market

$$p_{mon}^* = \frac{c + \alpha - \theta_1 \frac{x_h}{2} - \theta_2 d}{2} \tag{3.2}$$

We may conclude that, for given flight frequency, the profit maximizing monopoly price decreases in both θ_1 and θ_2, and so, given (2.12), revenues decrease in both parameters. Similarly, we can derive a expression for the frequency decision of the monopolist. Considering a non-stop market for simplicity, we have

$$F_{mon}^* = \sqrt{\frac{(p - c)\theta_1 L}{4FC}} \tag{3.3}$$

Next, we analyze the simultaneous solution to the monopoly network problem (3.1). Using the parameters from Table 1, we solve for $\bar{f}$ and $\bar{p}$ for varying θ_2, we have calculated profit maximizing frequencies and prices for a range of values of θ_2. The results are presented in Figure 3, which only shows results for one of the two identical local markets and legs.

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Monopoly Solution and Profit
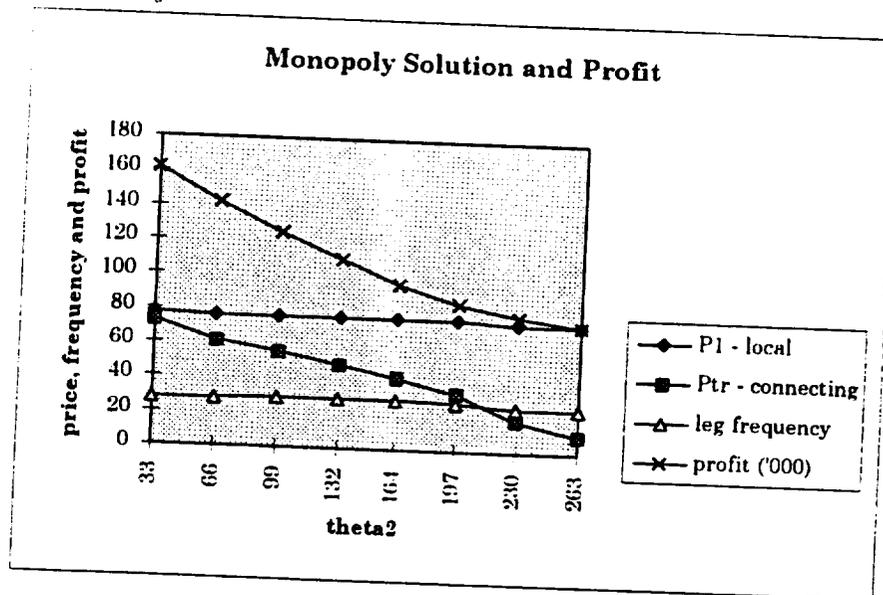
Figure 3

As Figure 3 illustrates, the price in the connecting market decreases in θ_2, as the travel time costs increase. The monopolist can counteract the negative demand effect by increasing the departure frequency in the legs (which has a small positive effect on the price in the direct market). The profit maximizing frequency is concave in θ_2. Clearly, the overall effect of an increase in θ_2 on profit is negative. From this conclusion, we can derive a restriction on the value of θ_2. From the calibration data, we know the profit of a single leg market. A monopolist will choose a HS network, whenever the profit of such a network is larger than the profit in a fully-connected (FC) network. Therefore, from the assumption that the monopolist operates a HS network, a maximum value for θ_2 follows, viz., the value of $\theta_2 = \widehat{\theta_2}$ for which the profit of both network types are equal. Put differently, values of θ_2 have to be consistent with the choice of the network type. In the following simulations, we use the maximum value of θ_2 consistent with the HS network type, viz., $\theta_2 = 0.8 * \theta_1$.

3.2. Leg competition

We now consider the introduction of competition in leg 1 of the network in Figure 2. e.g., after entry of a small airline only serving the local market between H and B. An important asymmetry is thus present in the competition in market 1. The

incumbent, airline 1, carries both local and connecting passengers on leg 1, while the entrant, airline 2, only carries local passengers.

We consider the outcome of the following two-stage frequency and price game. Both airlines face the profit function

$$\Pi_l = \sum_{m=1}^{M_l} (p_m - c) Q_m \left(\bar{f_l}, \bar{p_l}, \bar{f}_{-l}, \bar{p}_{-l} \right) - 2 \sum_{s=1}^{S_l} f_{l,s} FC \qquad (3.4)$$

with $M_1 = 3, M_2 = 1$ and $S_1 = 2, S_2 = 1$. The equilibrium is found by solving the game backwards: for each pair of schedules $\{\bar{f}_1, \bar{f}_2\}$ the Nash equilibrium in prices $\{\bar{p}_1^*, \bar{p}_2^*\}$ is calculated as the set of prices at which

$$\Pi_l \left(\bar{p}_l^*, \bar{p}_{-l}^*, \bar{f}_l, \bar{f}_{-l} \right) > \Pi_l \left(\bar{p}_l, \bar{p}_{-l}^*, \bar{f}_l, \bar{f}_{-l} \right), \quad l = 1, 2 \qquad (3.5)$$

(Note that for airline 2, the problem is confined to finding a single departure frequency and a single price). Given the second stage price equilibria, the first stage Nash equilibrium in flight schedules is calculated as the set of schedules for which

$$\Pi_l \left(\bar{f}_l^*, \bar{f}_{-l}^*, \bar{p}_l^*, \bar{p}_{-l}^* \right) > \Pi_l \left(\bar{f}_l, \bar{f}_{-l}^*, \bar{p}_l^*, \bar{p}_{-l}^* \right), \quad l = 1, 2 \qquad (3.6)$$

The first stage equilibrium choices and market outcomes are compared with the monopoly solution in Table 2 below.

Table 2
Market equilibria: 1 hub network

	Monopoly	Leg competition	
		airline 1	airline 2
schedules	$\{29, 29\}$	$\{26, 29\}$	13
prices	$\{76, 76, 54\}$	$\{66.76, 52\}$	57
passengers	$\{1673, 1673, 1161\}$	$\{1330, 1673, 1113\}$	820
profit	121221	87410	16944
CS ('000) per market	$\{62.4, 62.4, 31.5\}$	$\{99.9, 62.4, 29.6\}$	
CS total	156326	191952	
welfare	277547	296307	

We note a few interesting characteristics of the equilibrium. As explained in section 2, asymmetric frequency choices result in non-interlaced configurations

of departures. This confers the monopoly power to the airline with the higher number of departures, which explains the asymmetry in pricing. Clearly, the schedule asymmetry is determined by the network asymmetry: for airline 1, the marginal flight has a higher profitability because it serves both the local duopoly market and the monopoly market for connecting passengers.

The overall conclusion is that leg competition raises welfare. Not surprisingly, a reallocation of surplus from producers to consumers takes place. Aggregate consumer surplus increases by some 23%, which represents a gain for local travelers in market 1 (60%), a loss for connecting passengers (-6%), while nothing changes for local passengers in market 2. Note that the welfare loss for connecting passengers caused by airline 1's frequency decrease in leg 1 is partly compensated by the lower ticket price. This conclusion is partly in line with the conclusion by Brueckner and Spiller (1991). In their model, leg competition raises welfare for local passengers in market 1 and hurts connecting passengers too. The reason for the latter welfare effect is, however, the existence of negative cost externalities between markets, which also causes a welfare reduction for local passengers in market 2. In our model, connecting passengers are affected through the higher costs of schedule delay and travel time, not through an increase in price (marginal cost). Therefore, local passengers in market 2 are not affected, while local passengers in market 1 benefit from both higher flight frequencies and lower prices. Note that the two-stage character of the model gives both airlines an incentive not to choose symmetric frequencies: with a symmetric, interlaced configuration of departures, price competition is more intense and second stage prices are lower than in a non-symmetric equilibrium. Finally, we note that the model outcomes represent a slight S-curve effect, that is, airline 1, carries a share of the passengers traveling on leg 1 that is higher than it's share of departures. The effect is a result of the connecting travel carried by airline 1 while having a lower than proportional share of the local traffic, as a result of the high price in market 1.

4. A two-hub network

In this section, we investigate the solution of firms to the network frequency-price problem for a slightly more complex network under regimes of monopoly and competition. The network under consideration now consists of 2 hubs and three spokes or legs, as depicted in Figure 4.

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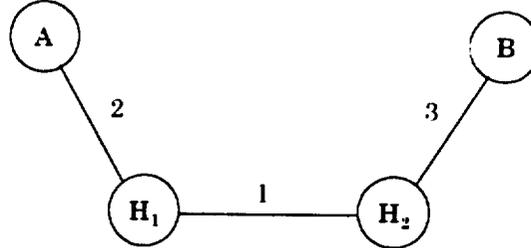
Figure 4

4.1. Monopoly

The monopoly network problem has the same general form as for the one-hub network presented in (3.1). In this case, however, $S = 3$ and we distinguish $M = 5$ city pair markets, viz., three markets for local passengers AH_1, H_1H_2, H_2B and two markets for connecting passengers AH_2 and H_1B.[11] The monopoly network problem can be interpreted either as the scheduling problem of a single airline operating two hubs or a as the problem of two airlines maximizing joint profits. In the latter interpretation, local market H_1H_2 may represent a route market between hubs of flag carriers before deregulation in the European Union, which until recently were governed by restrictive bilaterals, while the other markets can be thought of as hinterland monopoly markets in the absence of cabotage, e.g., as in Nero (1996).

Using the same parameters as in the one-hub system, the (base) solution to the monopoly scheduling problem is $\overline{f} = \{f_1, f_2, f_3\} = \{36.29, 29\}$ and $\overline{p} = \{p_{H_1H_2}, p_{AH_1}, p_{H_2B}, p_{AH_2}, p_{H_1B}\} = \{79, 76, 76, 58, 58\}$. As before, $\theta_2 = 0.8 * \theta_1$, a value at which the HS system is slightly more profitable than the FC system. As before, equilibrium profit decreases in θ_2.

4.2. Hub competition

We now consider the case of competition on the local market H_1H_2. The situation can be interpreted as an example of partial deregulation, in the sense that a collusive bilateral, containing capacity and fare restrictions is abolished for the international route H_1H_2, while carriers continue to operate monopoly routes

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[11]As indicated before, we do not consider trips for which more than one transfer is necessary.

within their respective countries. The model assumes that two identical airlines with identical hinterland markets compete on H_1H_2. In the following, airline 1 operates the monopoly markets AH_1 and AH_2, and airline 2 operates monopoly markets H_2B and H_1B.

The results of the base simulation are compared with the monopoly regime in Table 3.

Table 3
Market equilibria: 2 hub network

	Monopoly	Hub competition	
		airline 1	airline 2
schedule	$\{36, 29, 29\}$	$\{24, 28\}$	$\{21, 28\}$
prices	$\{79, 76, 76, 58, 58\}$	$\{54, 76, 50\}$	$\{52, 76, 47\}$
passengers	$\{1735, 1673, 1673, 1242, 1242\}$	$\{1265, 1661, 1059\}$	$\{1171, 1661, 987\}$

A basic characteristic of the equilibrium is the asymmetric frequency choice on leg 1. This result is due to the second stage price competition: airlines have an incentive to avoid symmetry, as this results in lower equilibrium prices.[12] In equilibrium, airline 1 operates 3 monopoly flights, which enables it to charge a higher price in the duopoly market H_1H_2. The higher frequency of airline 1 in leg 1 also lowers schedule delay and travel time for its transfer passengers relative to those of airline 2, so that the price in market AH_2 is higher than in airline 2's transfer market H_1B.

A comparison of the monopoly and hub competition regime shows that the individual duopoly airlines have a lower flight frequency on each leg than the monopolist. On legs 2 and 3, the difference is quite small. On leg 1, however, the individual flight frequencies are much lower with competition, while the combined flight frequency on this leg is much higher. As we have assumed that connecting passengers never transfer to a flight operated by an other airline, the connecting passengers suffer from higher travel times as a result from the decrease in airline flight frequency. This decrease in utility is reflected by the lower transfer demand

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[12]Although the model is different, the results are close the those obtained in two-stage quality-price competition (Shaked and Sutton, 1982), where firms differentiate in order to avoid price competition. In fact, there are two pure strategy asymmetric equilibria with identical firms, only one of which is presented. Furthermore, we do not consider mixed strategies here.

and the much lower prices in the transfer markets of both airlines. The local passengers in duopoly market H_1H_2 do benefit, both from increased flight frequency and lower prices because of price competition. In this market, there is a significant increase in passengers.

In Table 4 below, welfare results of both regimes are compared, where the welfare total is defined as the sum of consumer surplus in all markets plus industry profit. A first result of deregulation in market H_1H_2 is a dramatic decrease in industry profit. Secondly, there is an increase in total consumer surplus. The table shows that the aggregate increase is the sum of a gain for local passengers (in market H_1H_2) and losses for connecting passengers. The result of these opposing changes is a net decrease in the welfare sum.[13]

Table 4
Welfare results: 2 hub model

	Monopoly	Hub competition
industry profit	215016	138545
CS ('000) per market	$\{66, 62, 62, 40, 40\}$	$\{127, 62.62, 28, 31\}$
CS total	269875	309454
welfare	484891	447999

The general welfare result above is qualitatively in line with earlier work on the effect of deregulation in network markets. Nero (1996), using a similar HS network, concludes that for particular parameter combinations in his model, welfare (the sum of consumer surplus and profits) over all markets in the network is higher under monopoly (after an airline merger) than under competition. Brueckner and Spiller (1991) reach a similar conclusion for leg competition. In these papers, the form of the cost function drives the results. In particular, the cost function reflects increasing returns to traffic density, that is, marginal passenger costs are decreasing.

In our model, marginal passenger costs are constant, so that network externalities take the form of demand rather than cost complementarities. This difference, which follows from the model specification, has a number of implications. As indicated in the previous section (leg competition), the introduction of competition in

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[13]In a number of simulations, the sensitivity of the welfare results with respect to the value of travel time parameter θ_2 has been investigated for parameters in the range $0.2\theta_1 \leq \theta_2 \leq \theta_1$. As is to be expected, the negative welfare effect of deregulation increases in θ_2: the qualitative conclusions remain, however, unchanged.

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a local market does not result in higher marginal costs and prices for connecting passengers in our model. Rather, prices decrease for connecting passengers, as their net trip utility decreases in travel time. However, consumer surplus for connecting passengers still decreases, as the price decrease does not compensate the travel time increase. Similarly, the marginal passenger cost of local passengers, e.g. in market AH_1, is constant, so that demand, price and consumer surplus changes, if any, are due to changes in the flight frequency on leg 2. The consumer surplus change is still positive, but is smaller than the profit decrease, so that the overall welfare effect is negative in the two hub model.

Finally, we note that external costs have not been taken into account in the analysis. However, one can expect increased environmental costs in the network, e.g. taking the form of noise and emissions, after deregulation. The effects are not evenly spread over the network. Whereas there is a slight decrease in aircraft movements at airports A and B, there a significant net increase at the hub airports. Clearly, including the external cost to the analysis would only add to the negative welfare result for the hub competition model.

5. Conclusion

This paper presents a model of schedule competition in simple airline networks. We model airline competition in frequencies and prices as a two stage game: in the first stage, airlines choose frequencies on the legs in their network, in the second stage they choose prices for direct and connecting markets. The two-stage setup of the model allows airlines to choose asymmetric frequency equilibria such that price competition is avoided. We consider profit maximizing schedule solutions for two types of networks, and compare monopoly solutions with competition in part of the network.

The numerical results indicate that for both types of networks, the introduction of competition, deregulation, in part of the network has a positive effect on aggregate consumer welfare. However, consumers in transfer markets lose because, under the assumption that they do not transfer to a competing airline's flight, their schedule delay and travel time costs increase. Furthermore, industry profit decreases after deregulation.

In the case of leg competition in a one hub model, the positive consumer surplus effect dominates the profit loss, resulting in an increase in overall consumer surplus. In the case of hub competition, the profit loss dominates, so that there

is a net welfare decrease.

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THE TGV EFFECT: OPPORTUNITIES FOR RECONCILING SUSTAINABILITY WITH AVIATION

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Introduction

The rapid transportation of goods and people over long distances makes aviation an indispensable part of the global economy. The aviation sector is in a phase of very positive growth, and in fact is growing at a faster rate than the global economy. Aviation is an integral component of travel and tourism, the world's largest industry, and is increasingly important in the movement of freight.

In an unlimited economic model, with no external constraints, continued high rates of growth could be expected. This, however, is not the case. Increasing urban pollution, rising greenhouse gas concentrations, national and international regulatory policies, and finite oil reserves all create external constraints on the growth of transportation, including the air sector. At this time, there is no technology that can supplant the speed of air travel for long-haul and intercontinental routes. However, high-speed rail is a viable substitute for short haul and intracontinental trips. In this paper, we present an analysis of the impact that the introduction of high speed rail had on civil aviation in France, and examine the economic opportunities for environmentally and economically sustainable aviation.

External Constraints on the Aviation Industry

Urban Air Quality

Air pollution is now definitively recognized as having a significant negative impact on the health of urban populations. Increased hospital admissions for respiratory problems (e.g. Burnett et al, 1994) and overall mortality rates (Lipfert and Wyzga, 1995) are unquestionably linked to poor air quality. Overall, aviation emissions form a small fraction of total pollutant loading in a country, but large airports are located near large population centres, and thus contribute to the degradation of air quality in the city and regional area. Given that there are reductions occurring in other sectors, it is predicted that airports' relative contribution to urban airsheds will increase (e.g. Netherlands Ministry of

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Housing, 1995; Perl *et al.*, 1997). Emissions from airports may therefore face restrictions from urban authorities in the future.

Greenhouse Gases
The percentage contribution of greenhouse gases from aviation is rising in North America. In the U.S., in 1995 aviation contributed 10.0% of total CO_2 emissions in the transportation sector; this is predicted to rise to 12.9% of total CO_2 transportation-generated emissions by 2010 (Grant *et al.*, 1998). The international community has struggled for years, first with the Toronto Summit (1988), Rio Summit (1992), and most recently at the Kyoto Summit (1997), to set limits on greenhouse gas emissions. Although the agreement reached at Kyoto still remains to be ratified by most countries, legislated reductions in greenhouse gas emissions may be in effect in a few years.

Upper Atmospheric Chemistry
Aircraft are the sole source of anthropogenically generated nitrogen and sulphur oxides, soot, carbon monoxide, and unburned hydrocarbons emitted into the upper troposphere and lower stratosphere. The potential for damage to stratospheric ozone from aviation was first recognized over 25 years ago (Johnston, 1971), and continues to be the focus of scientific research by NASA and the European Aeronox programme. Other effects of the effluents from jet engines on this part of the atmosphere are also being studied (e.g. Fabian and Karcher, 1997). Depending upon the outcomes of this research, constraints may be applied to aviation.

Governmental Environmental Policies
Two European examples offer a sense of future trends in environmental policy being applied to civil aviation. Sweden integrated a carbon tax into its fuel taxation as early as 1991. As well, differential landing fees based on noise output have been in place for some time. The Swedish Civil Aviation Administration is developing a new aircraft classification system that will incorporate pricing for air emissions into future landing fees. Such pollution pricing was introduced at Zurich's Kloten Airport (ZRH) in 1997.

The leading role of Swiss environmental management for aviation stems from a well developed partnership between the public sector airport planners and private sector leaders of the national carrier, Swissair (Perl, 1996). For Swissair, environmental responsibility is seen as a means to more efficient operation. Swissair executives have anticipated that the growth of air transport will trigger some combination of stricter regulatory limits and pollution pricing schemes and have committed to be leaders in developing a strategy that marries economic profit and environmental responsibility. Swissair is thus positioning itself to develop a long run competitive advantage by implementing leading edge environmental practices ahead of its rivals.

2

Since the Swiss public exhibits an extremely high environmental consciousness (Inglehart, 1995), a proactive environmental policy was seen to offer an immediate economic payoff. In the short term, Swissair needed its operations at ZRH (essential if it is to survive the competition that other major European carriers provide from their hubs) to meet with public approval. Switzerland's highly decentralized federal system and direct democracy would have made it impossible to expand ZRH without putting the question before the public in a referendum. Such a vote was taken on June 25, 1995, when voters of the Canton of Zurich approved financing a major expansion of ZRH.

By committing itself to work on minimizing the air, noise, and water pollution arising from increased operations, Swissair was able to campaign effectively in the ZRH expansion referendum. It was also able to have significant input in defining terms which all other carriers using ZRH will have to abide by. As a result, Swissair's environmental leadership has yielded a long run advantage at its principal hub, as other airlines are now charged for various forms of pollution that they create. Swissair and the Zurich airport authority have a very close working relationship, and have jointly pursued the environmental research that has yielded the aircraft emission charges schedule now in effect at ZRH.

This pricing scheme built upon an extensive foundation of environmental research and planning. From noise restrictions and night time flight curfews, to a ban on the extended use of aircraft auxiliary power units, to the use of electric vehicles for ground handling functions, ZRH has pioneered innovations designed to reduce environmental impacts. The airport conducted its first comprehensive emissions inventory in 1989, and integrated these findings into its master planning process. For example, the inventory identified ZRH airside operations contributing 6.8% to the NO_x emissions in metropolitan Zurich, the single largest source (Zurich Airport Authority, 1996).

The resulting emissions pricing policy began by reducing airport landing fees by 5% across the board to make the scheme revenue neutral. The classification scheme is based upon an Engine Emission Factor (EEF), calculated by multiplying an emission index (drawn from ICAO or FAA references) by the maximum engine thrust. The EEF is then subdivided into 5 classes for pricing. Class 5, with the most efficient engine technology (e.g., A320-200 equipped with CFM56-5-A1 engine) pays no pollution charge, and thus receives a 5% reduction in landing fees compared to the previous tariff. Class 1, with the least efficient engine technology (e.g., L1011-500 equipped with RB211-22B engine) pays a 40% premium on the basic landing fee as a pollution surcharge. Revenues generated from the pollution surcharge are dedicated to financing infrastructure improvements that would further reduce airside emissions, such as additional taxiways to reduce taxi time, ground base power hookups to eliminate the use of auxiliary power units, and emissions monitoring equipment.

3

Fossil Fuel Reserves and Resources

The ultimate limiting factor on aviation is fuel. The spectacular growth of world economies in the 20th century has been driven in part by cheap, abundant oil. This however, faces limits. Recently, experts have analysed world estimates of reserves, rates of consumption, and the rate of discovery of new reserves. The next decade is predicted to see the end of the abundant supply of cheap conventional crude oil (Hatfield, 1997; Campbell and Laherrère, 1998). This is not to say that the world will run out of oil -- rather, that as reserves decline it will be more difficult, and costly, to extract the remaining oil from the ground (ibid). Any unconventional liquefied petroleum product also will be more expensive (ibid). In an industry such as aviation, which is so fuel intensive, this is bound to have a profound impact.

Summary

External constraints on the aviation industry, then, will come in the form of taxes on pollution, potential legislation to reduce greenhouse gas and other emissions, and, ultimately, increasing costs and availability of fuel. Current rates of growth in aviation may therefore not be sustainable. Recognizing these constraints, then, the question is: what are the opportunities that can be created for the aviation industry to become economically and environmentally sustainable?

High Speed Rail in France: Les Trains à Grande Vitesse (TGV)

The first TGV line opened serving the south-east of France on September 27, 1981, with service between Paris and Lyon, with a downtown-downtown travel time of two hours 40 minutes (Haycock, 1995). In May 1982, the service was extended to Marseilles, at five hours 33 minutes. Speed on the Paris-Lyon segment was increased in 1983, and travel time was reduced to exactly two hours (ibid).

On September 24, 1989, the TGV Atlantique, serving western France opened (Haycock, 1995). Travel times were as follows: Nantes, two hours 5 minutes; Bordeaux, three hours, and Toulouse five hours 10 minutes. In the southeast, Nice was accessible by TGV in seven hours 14 minutes (Lewino and Dauvergne, 1989). These travel times remained constant, with the only exception being a 14 minute shortening of the Nice travel time (Fortin, 1994). Projections for the year 2005 include reducing the Marseilles travel time from 4 hours 40 minutes to three hours, and Toulouse from five hours six minutes also to three hours (ibid).

A second advancement in TGV service in France came in the 1990's. At two airports, Charles de Gaulle (CDG) and Lyon-Satolas, a rail terminus was built within the existing airport infrastructure. This created intermodal complimentarity, and while the benefits have yet to be maximized at Satolas, the ability to switch modes within the airport terminal has been successfully adopted and utilized at CDG.

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All TGV equipment in France is electrically powered. More than 90% of the electricity in France is produced by nuclear generation, a zero emission source. Thus, the TGV is a virtually emissions free mode of transport.

In the following section, the impact of the introduction of high speed rail in France on the civil aviation sector is presented. First, the impact of the TGV on domestic air travel between Paris and regional cities is examined. The intermodal complementarity created by the construction of TGV terminals in CDG and Satolas airports is examined second.

The TGV Effect: the impact of high speed rail on French civil aviation

The purpose of this section is to quantify the changes that occurred in French civil aviation with the introduction of high-speed rail. Five airports, in cities of comparable size, were examined in detail; Lyon, Bordeaux, Toulouse, Marseilles, and Nice. Only partial data was available for a sixth city, Nantes. Because inception of the TGV service was staggered across France, it is possible to compare airports of similar size to see the variation in growth rates with and without TGV service to those cities for a specific interval of time.

The parameters analysed were:
1) intercity passenger traffic, between Paris and each airport, 1976-1997
2) total domestic passenger traffic for each airport 1975-1996
3) aircraft movement data, between the two Parisian airports, Charles de Gaulle (CDG) and Orly, and each regional airport, 1975-1996

Multiple sources were used for the collection of data. Intercity passenger traffic between Paris and the individual airports was obtained from the International Civil Aviation Organisation (ICAO; Table 1; Figure 1). Total annual domestic passenger volumes for each airport were obtained from the annual ICAO Digest of Statistics (Table 2; Figure 2).

The data on aircraft movements for the Paris-regional airport trips was collated from the Official Airline Guide, International Edition, published annually. Data concerning the number of flights per year by model of aircraft was extracted from these volumes for each city. A programme with a perpetual calendar was written in Microsoft Visual Basic 4.0 to facilitate the counting. At this writing, the work is complete enough to allow a comparison of aircraft movements between Lyon and Bordeaux (Table 3).

The data in Tables 1 and 2 was analysed to obtain growth rates for intervals of different levels of TGV service. The starting year (1975 or 1976) is the earliest year for which complete data was available. The interval up to 1981 is the pre-TGV era. The years 1981-1984 are the period in which the impact of full TGV service to Lyon developed. From 1984-1989, Lyon and Marseilles had TGV, but

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the other cities did not. The period 1989-1997 is the time when TGV service was in place for all cities in the analysis.

The data in all cases was fit to a growth model $y=b*m^x$, minimizing least squares errors. The growth rates obtained (Tables 4, 5, and 6) represent an average annual compounded rate of increase. These rates are not dependent just on the first and last points, but rather, the model fits the entire curve.

The first, pre-TGV interval shows healthy growth rates at all cities (Tables 4 and 5). The most dramatic evidence of the TGV effect is the 17% drop in passenger traffic in 1981-1984 Paris-Lyon (Table 4). This drop in passenger traffic was so dramatic that it even impacted on the entire annual total domestic passenger traffic at Lyon-Satolas airport, with an 8% drop (Table 5).

In France, most head-to-head, non-connecting flights to Paris go to Orly, while those arriving from or embarking on trans-oceanic or intercontinental flights transfer through CDG. A drop in total domestic passenger volumes at both CDG and Orly is seen (Table 5), although it is not justifiable to attribute this exclusively to the TGV effect without taking into consideration other external market factors.

The period of 1984-89 is a period of stabilization. The overall growth in total domestic passengers (Table 5) is very close for all cities. The loss of the Paris market at Lyon-Satolas seems to have been made up, with a growth rate in total domestic passengers at 8.7%, second only to Orly for that interval. The growth was clearly not made up in the Paris-Lyon market, where the average annual rate of growth was just 0.8% (Table 4).

With the opening of the TGV Atlantique, the TGV effect was again seen, this time most strongly in Nantes, with a 5% drop in passengers to Paris (Table 4). The drop was slightly less dramatic at Bordeaux, with a 0.3% annual rate of increase (Table 4). The decreases were not as dramatic as Lyon, as the travel time is longer, supporting the conclusions of Pavaux (1991).

The magnitude of the drop is a manifestation of the travel time. If high-speed train travel is less than three hours, three quarters of the people travelling by public transportation (air or rail) will take the train (Pavaux, 1991). The market share of travellers using the train decreases linearly with the logarithm of the time of train travel (ibid). This is clearly visible in the minor impact that the TGV has had on Marseilles, Nice, and Toulouse.

The pattern of the TGV effect on aircraft movements between Bordeaux-Paris and Lyon-Paris also shows a TGV effect. In the interval 1984-89, after two hour downtown-downtown Lyon-Paris TGV service was in effect, the rate of increase in annual air movements to Orly was only 0.53% (Table 6). This is in stark

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contrast with Bordeaux, with no TGV service at this time, and a 9.3% increase in traffic to Paris in the same interval.

The dominant aircraft used between Paris, Bordeaux and Lyon pre-TGV were the Caravelle, DC-10, and Dassault-Mercure. The Airbus 300 came into service on both these routes in 1978. Post-TGV, in 1984-89, on Bordeaux-Paris it was the Caravelle, Dassault-Mercure, and Airbus 300. However, Paris-Lyon traffic was handled by the Caravelle and Dassault-Mercure, and increasingly, the small ATR turboprop. Therefore, there was not only a decrease in the number of flights serving Lyon, but also in the size of aircraft. Generally, aircraft weight corresponds to quantity of pollutant produced (Woodmansey and Patterson, 1994). Therefore, fewer flights with smaller aircraft mean significant emission reductions on the Lyon-Paris flight path and at Lyon-Satolas airport, when compared to Bordeaux for the same interval. Calculation of these emissions are part of the ongoing research for this project.

Intermodal Air/Rail at Airports
A second major phase in the TGV development occurred in the 1990's with the construction of rail terminals for high-speed trains at CDG and Lyon-Satolas airports. Previously, CDG airport was not connected effectively with either rail or road links to the rest of France (Perl, in press, 1998). A collaboration between the Société Nationale des Chemins de fer Français (SNCF) and Aéroports de Paris (ADP) resulted from independent external pressures on the two corporations (ibid). The net result was the construction of facilities which permitted linked intermodal travel, opening first in November 1994 at CDG, and later at Lyon-Satolas.

The construction of a TGV station inside the air terminal made it possible to switch from a plane to a train almost as easily as changing planes. The intermodal baggage handling facilities at CDG and Satolas are not yet in place, but eventually one will be able to check a suitcase at the airport and then pick it up at the train station at the final destination (or vice versa). As for the moment, elevators, moving sidewalks, and luggage carts make the air/rail transfer relatively easy. Given the enthusiasm with which the travelling public switched to rail for intercity travel on short-haul routes, the same modal switch on short-haul routes may be anticipated for travellers connecting to long-haul flights to or from short-haul feeder routes. For example, a passenger arriving at CDG from North America, whose final destination is Lyon, can now connect easily at CDG to the TGV, instead of another flight, and arrive in central Lyon in approximately the same travel time.

In summary, the partnership between SNCF and ADP interconnected France's air and high speed rail networks at two airports, and generated mutually advantageous opportunities for growth for both companies (Perl, in press, 1998). With this new infrastructure, opportunities for inter-modal complimentarity

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occur, offering economic gains to both air and rail. The introduction of intermodal facilities at airports creates the possibility for linkage between the two transportation modes, instead of head to head competition. It allows for an optimization of technology mixing between modes. The transfer of short haul traffic to rail at airports opens up the runway and terminal capacity, thus creating an opportunity to have growth in long haul flights. Finally, joint co-operation between air and rail companies moves aviation closer to sustainable development.

Opportunities for economic growth

Sustainability in civil aviation is about more than the environmental impacts of aircraft engine emissions. In its broadest conception, it is about finding the real opportunities to "do better with less" that will enrich those firms and jurisdictions that pioneer ways to make aviation less polluting without a proportionate (drastic) reduction in mobility. For medium distance travel, high speed rail has proven itself capable of substituting, in part, for aircraft. The "TGV Effect" demonstrates this, and we have quantified the resulting changes in civil aviation. But even greater environmental savings may arise from linking air and fast train journeys over medium to long distances, in the way that aircraft on short routes feed long-haul flights at hub airports.

Airlines can share in the economic benefits of such intermodal innovation. By freeing up space (in both physical and ecological senses) at crowded and polluted hub airports, fast trains could feed passengers into longer distance flights. Both airlines and railroads could profit from such interline connections. And as Richard Branson has shown in England, airline and fast train ownership are not mutually exclusive.

As in any economic transformation, there will be leaders and laggards in capitalizing on the opportunity to link fast train travel with aviation. Leading firms will reap significant rewards by moving people and freight with reduced environmental impact. There will also be laggards that cling to "business as usual" strategies even after they have become a significant liability. Environmental leaders can gain credibility from their early initiatives, which in turn facilitate partnership with government and environmental advocates in framing sustainable transportation practices. Swissair's example at ZRH illustrates the formative role that an innovative firm can play in shaping the rules that its competitors will then have to abide by. Leaders like Swissair are able to translate their initiative into bottom line business success by shaping sustainable transport options that fit with their organizational and technical strengths. On the other hand, laggards will have to react to sustainable transport priorities that are not of their own making. Catching up to implement programmes that their rivals helped create will be costly, so costly that some laggards might not survive the transition (similar to the casualties of global economic competition). The key

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difference between firms that identify the economic opportunities of leading sustainable aviation initiatives and those that resist change as a threat to their business will be understanding the lessons of recent evolution in the relationship between air and other transport modes, as illustrated by the TGV effect.

Conclusions

The aviation industry is in a period of expansion, growing at a faster rate than the global economy. In an unconstrained economic model, this growth could be expected to continue unhindered. However, several external factors may limit the aviation industry. Increasing urban air pollution, greenhouse gases, and changing upper atmospheric chemistry could lead to regulations restricting emissions from aircraft. Some jurisdictions, notably Sweden and Switzerland, have already applied pollution pricing, a carbon tax, and differential landing fees (based on noise) to civil aviation. The ultimate restriction on aviation (and indeed all carbon-based energy use) is the finite quantity of fossil fuels on earth. But, there are options for the aviation industry.

It has been demonstrated in this paper that the introduction of high speed rail produces a dramatic modal shift in passenger traffic on short haul routes, from air to rail. The construction of intermodal facilities (high-speed rail stations) in airports, such as those at CDG and Satolas, provides opportunities for complimentarity between air and rail, rather than competition. The ability to switch from air to rail at an airport with the same degree of ease as switching planes makes possible all kinds of economic opportunities for airlines to expand the travel options offered to the public. As these trains are electrically powered in France this provides emission reductions when the trains replace short-haul flights. This optimization of travel modes moves aviation closer to economic and environmental sustainability.

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Figure 1. Parisian Intercity Passenger Traffic

Legend:
- Bordeaux
- Lyon
- Marseilles
- Nice
- Nantes
- Toulouse

Passenger traffic (000's)

3500 · 3000 · 2500 · 2000 · 1500 · 1000 · 500 · 0

1976 1977 1978 1979 1980 1981 1982 1983 1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997

Figure 2. Total Domestic Passenger Traffic

Legend:
- ● LYON
- □ MARSEILLE
- ◆ NICE
- ◇ TOULOUSE
- ▲ BORDEAUX
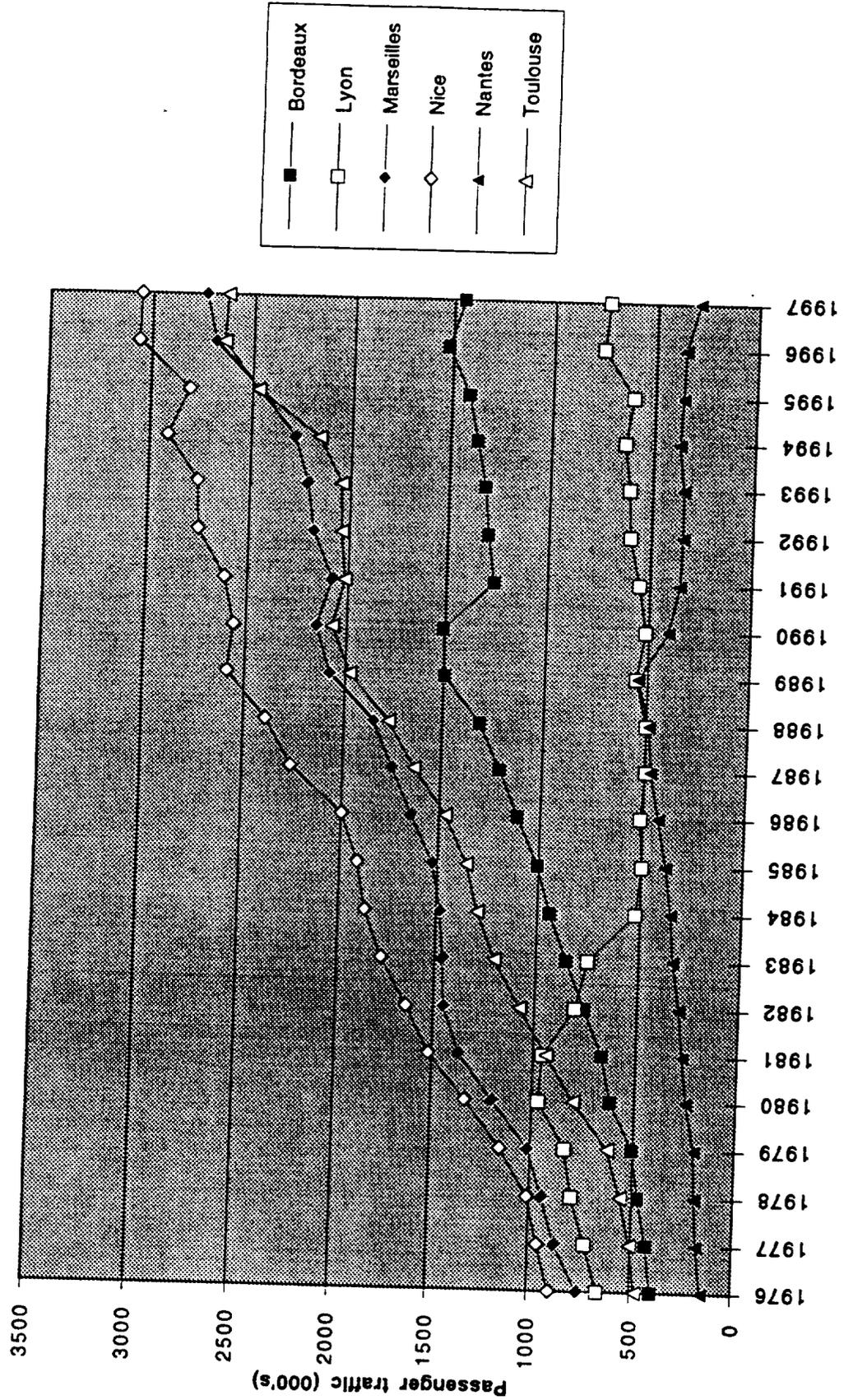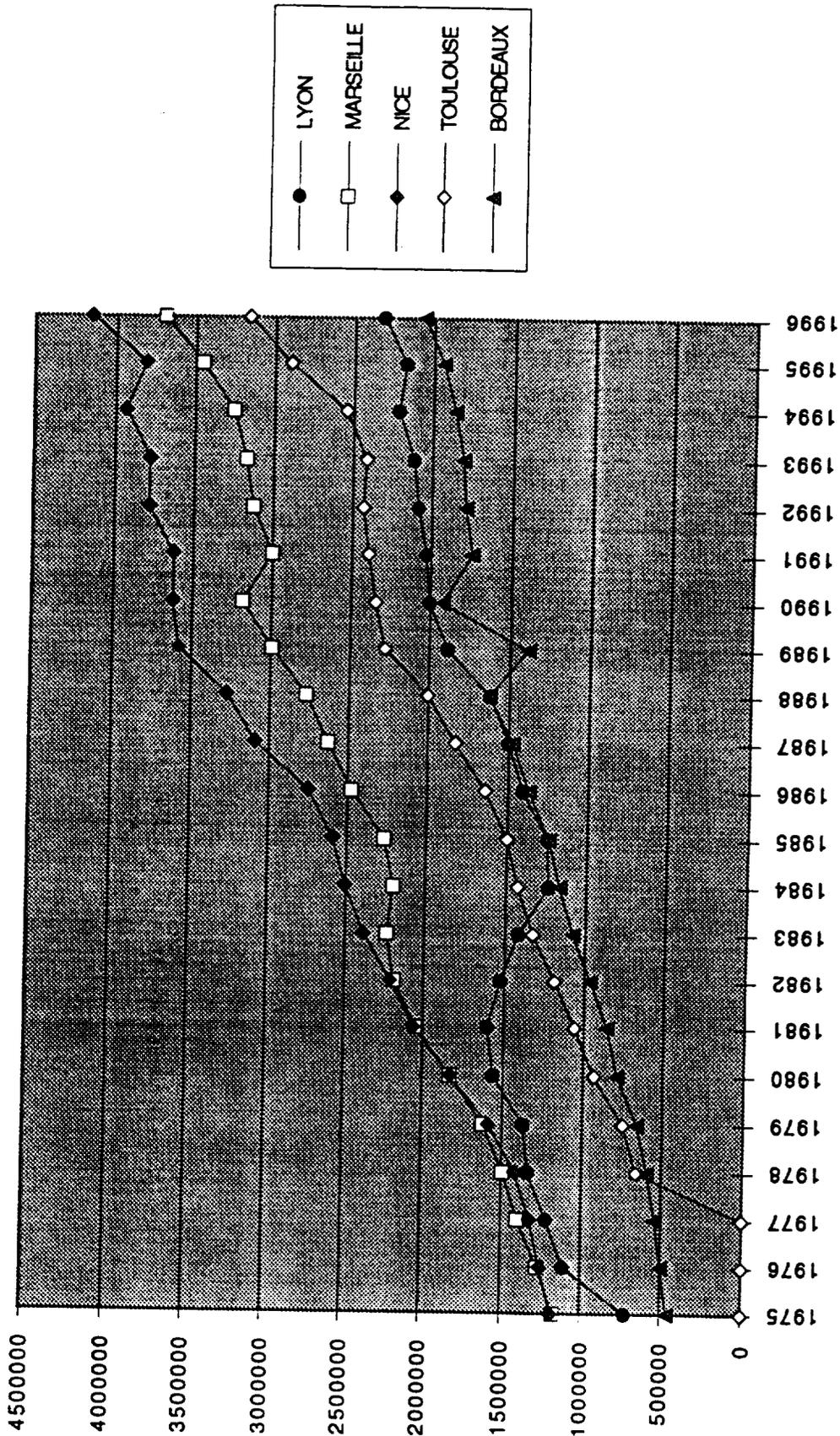
Table 1. Paris Intercity Passenger Traffic 1976-1997

Year	Bordeaux	Lyon	Marseilles	Nice	Nantes	Toulouse
1976	396	663.8	762.5	897.3	149.8	475.2
1977	423.3	730.8	874	955.7	176.3	506.1
1978	471.8	798.5	939.8	1010.4	190.4	561.7
1979	506.4	838.2	1012.7	1148.1	201	629.6
1980	623.1	967.9	1194.4	1328.9	245.5	805.4
1981	669.7	954.8	1363.4	1519.5	271.9	937.4
1982	764	806.9	1450	1637.6	292.9	1070.9
1983	856.5	754.2	1461.1	1771.6	331.2	1201.8
1984	940.9	525.2	1479.6	1863.5	349.1	1293.8
1985	1004.1	497.9	1526.7	1910.3	380.9	1355
1986	1109.5	514.3	1643	1997.6	425.3	1468.5
1987	1204.9	495.8	1744.4	2256.8	469.6	1634
1988	1310.3	501.2	1846.5	2388.6	486	1767.3
1989	1495.1	557.3	2076.4	2585.2	547	1976.9
1990	1509	517	2147.5	2559.2	404.4	2070
1991	1258.3	551.5	2077	2611.4	353	2014.2
1992	1295.4	604	2173.9	2747.1	345.7	2038.8
1993	1316.3	614.7	2211.1	2754.1	346.7	2043.4
1994	1362.7	643.2	2279.6	2907.9	373.5	2156.1
1995	1411.9	607.2	2461.3	2805.6	362.5	2469.3
1996	1520.4	758.7	2682	3059.5	354.3	2642.5
1997	1445	736.2	2734.6	3052.9	294.1	2629

Table 2. Total Domestic Passenger Traffic 1975-1996

Year	Bordeaux	Toulouse	Lyon	Marseilles	Nice	Orly	CDG
1975	455000	***	719000	1177000	1188000	4446000	499000
1976	499000	***	1118000	1277000	1262000	4655000	765000
1977	535000	***	1227000	1402000	1324000	5017000	853000
1978	589000	658000	1341000	1495000	1420000	5430000	996000
1979	654244	742879	1373177	1615751	1583197	6075647	1095130
1980	784799	929000	1561373	1825259	1819785	7076080	1269515
1981	854203	1065752	1600670	2044754	2057919	8290070	1418955
1982	961029	1194000	1522169	2189409	2213102	8765604	1640962
1983	1082583	1332759	1420256	2240000	2384083	9410863	1718702
1984	1174255	1430804	1242762	2204665	2504481	9863706	1505052
1985	1246422	1499748	1251379	2265498	2587000	10253265	1512162
1986	1376036	1638953	1409467	2475768	2741758	11337234	1527896
1987	1478054	1823663	1499441	2627166	3089100	12498185	1593406
1988	1620432	2000878	1616046	2766050	3270435	13501938	1715487
1989	1392772	2282775	1882226	2988460	3579445	14958491	1993000
1990	1920000	2345000	2001829	3185221	3625000	15120000	1631000
1991	1740000	2394239	2027594	2998955	3626000	14587394	2227507
1992	1782648	2431679	2085565	3126651	3782731	15085491	2325556
1993	1800953	2416699	2118857	3172377	3778575	15150378	2359232
1994	1855382	2542568	2215542	3252915	3931181	15352049	2672748
1995	1933349	2893916	2175084	3451194	3809823	15533537	2461677
1996	2060401	3160852	2315607	3692393	4154000	16742976	2761333

Table 3. Aircraft Movement Data

Aircraft movement data: City to Orly				Aircraft movement data: City to CDG		
Year	Bordeaux	Lyon		Year	Bordeaux	Lyon
1975	2145	3237		1975	546	1005
1976	1993	3122		1976	647	1047
1977	2105	2730		1977	807	1121
1978	2294	2772		1978	635	998
1979	2383	2915		1979	734	1144
1980	2412	3013		1980	734	1099
1981	2246	2770		1981	752	1071
1982	1992	2541		1982	927	1282
1983	1920	2225		1983	1012	1129
1984	1975	1730		1984	1014	999
1985	1937	1880		1985	876	984
1986	2121	1981		1986	784	1065
1987	2240	1802		1987	752	1002
1988	2780	2099		1988	780	1218
1989	2932	1713		1989	1213	1255
1990	2869	1741		1990	1238	1282

Table 4. Growth rates in Paris-other city passenger data (from Table 1)

	1976-1981	1981-1984	1984-1989	1989-1997	1976-1997
Bordeaux	11.65%	12.01%	9.56%	0.28%	6.62%
Nantes	12.20%	9.12%	9.18%	-4.48%	3.50%
Marseilles	11.84%	2.56%	6.87%	3.66%	5.69%
Nice	11.31%	7.15%	7.19%	2.36%	6.07%
Toulouse	15.04%	11.43%	9.02%	3.97%	8.48%
Lyon	8.05%	-16.98%	0.80%	4.29%	-1.26%

Table 5. Growth rates in total domestic passenger traffic (from Table 2).

	1975-1981	1981-1984	1984-1989	1989-1996	1975-1996
Paris-Orly	10.91%	6.10%	8.97%	1.30%	6.81%
Paris-CDG	17.01%	2.26%	5.35%	6.01%	6.36%
Bordeaux	11.30%	11.34%	5.01%	3.61%	7.61%
Lyon	12.03%	-7.85%	8.65%	2.59%	3.87%
Marseille	9.39%	2.52%	6.42%	2.58%	5.24%
Nice	9.57%	6.86%	7.74%	1.84%	6.41%

Table 6. Growth rates in intercity aircraft movements (from Table 3).

City pairs	1976-1981	1984-1989
Bordeaux to Orly	3.03%	9.31%
Lyon to Orly	-0.72%	0.53%
Bordeaux to CDG	1.77%	1.46%
Lyon to CDG	0.55%	5.04%
Bordeaux to Paris (combined)	2.69%	7.01%
Lyon to Paris (combined)	-0.40%	2.25%

Policy Issues in the Express Carrier Sector

Michael D'Arcy

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Dublin

The Competitive Market for Air Transport in the new millennium will be characterised by:

- A global marketplace;

- Air Transport being a facilitator not a driver;

- International, Regional and National policies and regulatory frameworks evolving to reflect this reality.

The true drivers of the global market are:

- The Internet

- The Global Financial Markets

- Integrated International Express Delivery Services

- They are the precursors to how information and goods will move around this global economy;

- Their primary effect has been to make distance, time and national borders increasingly irrelevant in the global marketplace for goods and services;

- The movement of goods by air must continue to evolve organisational, operational and regulatory conditions to facilitate, and benefit from, these forces.

According to WTO Secretary General Renato Ruggiero:

"The borderless global economy[1]"' will, create opportunities and be marked by:

- Increasing indifference to geography, distance and time;

- Transaction costs for consumers and business falling rapidly;

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[1] "Services in a Bordeless Economy" (Berlin 23 October 1997)

- The many steps that intervene between buyer and seller — distribution, sales, retailing-being compressed;
- Electronic commerce reducing, or almost eliminating, the costs of market entry;
- A far greater number of suppliers entering a market because starting a new business will be much easier.

The global economy as defined by Renato Ruggiero (Cont):
- SME's joining MNC's as *"full participants"* in the global marketplace;
- Business in developing countries being able to overcome many of the obstacles of infrastructure, capital and transportation which limited their economic potential in the past;
- Consumers everywhere benefiting from, and so supporting personally and politically, this growing global competition;
- Ireland today proves the WTO Secretary General's model works.

Global Integrators have pioneered services which are characterised by:
- Providing a *Physical Communications,* not a transport, service;
- Operating highly integrated, tightly managed, multi-modal, <u>any</u> door to <u>every</u> door, *delivery services* for information and goods which an individual can carry;
- Achieving for every individual shipment, irrespective of its origin or destination, exceptional levels of speed, control, reliability, information and security;
- Offering a, generally, transparently priced service, with many value added features possible including the movement and delivery of items being electronically tracked, traced, re-routed and (via the Internet) confirmed;
- Establishing consumer brand identities which have defined not just their business but their sector.

Air Transport Services are a crucial link for delivery services, but they:
- Are only used by integrators to the extent they can be combined with offices, buildings, telecommunications facilities, computers, sorting equipment, automobiles, trucks, aircraft,

ships and other vehicles, services and people as may be necessary to deliver every package, anywhere, everytime;

- Rarely prioritise the facilitation of goods ahead of people;
- Often see freight as, at best incremental revenue, and at worst an awkward but necessary evil.

The Air Transport of goods in the next millennium will be predominantly by this express model:

- According to the Avmark Aviation Economist the % of express (or J.J.T.) freight to all air cargo will be 39% by 2000 (up from 18% in 1990);
- Airbus Industries forecasts the number of all-cargo aircraft will be 1,701 by 2005 (up from 1184 in 1994);
- A Boeing survey has calculated that 90% of all U.S. air cargo will be 'express' by 2010.

The air transport opportunities created by these developments may include:

- A fundamental re-structuring and re-organisation of the traditional air cargo market;
- The development of new streamlined, seamless, integrated and flexible freight only airports and airport facilities;
- The development of new fiscal procedures for the customs control of goods and the collection of duties and
  - VAT;
- A dramatic expansion of I.T. services to track, trace and record seamless integrated door to door delivery;
- The evolution of diverse air and logistics services.

In my opinion the key questions for regulators, policy makers and indeed air transport operators in the realisation of these opportunities and the enhancement of the role of air transport in delivering services include:

- Will the regulatory framework governing delivery services ensure that all providers can innovate cost-effectively, and continue to reliably serve their customers constantly changing requirements?

- Will the regulatory interventions which create questionable and increasingly archaic and costly barriers be removed quickly enough?

- Will competition be extended to include the markets traditionally reserved to public postal operators?

- Will opportunities for new players to enter the market be facilitated?

- Will the movement of goods by air be given the separate, distinct and relevant attention it needs and deserves?

Governments policy makers and regulators provides the necessary leverage to ensure user friendly answers to all of these questions:

- Most importantly, the WTO must include delivery services in the proposed GATT's on services;

- The significant implications of a truly global market for air transport services, must be positively embraced, not resisted or, worse, ignored;

- Flexible and responsive 'open skies' policies and agreements which allow carriers plan their route network, capacity and frequency on the basis of commercial considerations are essential;

- Establishment criteria limiting air carriers to their own 'national' state should be removed;

- EU airport users which meet relevant, objective and nondiscriminatory criteria, established and regulated by the Member State, must be allowed to self-handle;

- Customs procedures based upon the sharing of responsibility with approved operators and not exclusively on the surveillance and checking of individual shipments must continue to be developed;

- Security procedures, based upon credible threat assessments, which accommodate the particular needs of trade, are essential;

- Monopolies in any aspect of the transport chain must be eliminated if not economically and operationally justified according to objective, fair and relevant criteria;

- Dominant providers must be rigorously policed to ensure no abuses of competition law take place;

- Any operator granted reserved services or exclusive rights must be rigorously regulated to ensure no cross-subsidisation takes place from these privileged businesses to their activities in competitive markets;

Credible, authoritative and user focussed cost accounting procedures for airports and

airport authorities must be developed, implemented and enforced by effective

Ireland is addressing much (but not all) of this agenda and so is rapidly evolving as

a case study of the benefits to be accrued:

- A vibrant and competitive delivery services market, liberalised financial and investment services and an increasingly competitive telecommunications and IT sector;
- The elimination of many of the disadvantages of being a peripheral island some distance from our markets;
- Competitive air transport services moving substantial and growing volumes of people and goods;
- A pro-active, progressive and, generally, supportive Government committed to facilitating trade and sustaining this growth;
- Growing pressure on Government to remove residual investment gaps and operational inefficiencies especially in the transport infrastructure;
- Thriving value added, fast growth businesses, industries and sectors, especially those which are knowledge based.

The Air Transport Research Group of the WCTR Society was formally launched as a special interest group at the 7th Triennial WCTR in Sydney, Australia in 1995. Since then, our membership base has expanded rapidly, and now includes over 400 active transportation researchers, policy-makers, industry executives, major corporations and research institutes from 28 countries. It became a tradition that the ATRG would hold an international conference at least once a year. In 1998, the ATRG organized a consecutive stream of 14 aviation sessions at the 8th Triennial WCTR Conference (July 12-17: Antwerp). Again, on 19-21 July, 1998, the ATRG Symposium was organized and executed every successfully by Dr. Aisling Reynolds-Feighan of the University College of Dublin. The Aviation Institute at the University of Nebraska at Omaha has published the Proceedings of the 1998 ATRG Dublin Symposium (being co-edited by Dr. Aisling Reynolds-Feighan and Professor Brent Bowen), and the Proceedings of the 1998 WCTR-ATRG Conference (being co-edited by Professors Tae H. Oum and Brent Bowen).

REPORT DOCUMENTATION PAGE

1. AGENCY USE ONLY (Leave blank)	2. REPORT DATE December, 1998	3. REPORT TYPE AND DATES COVERED Monograph Report

4. TITLE AND SUBTITLE

The Symposium Proceedings of the 1998 Air Transport Research Group (ATRG)

5. FUNDING NUMBERS

NAGW-4414

6. AUTHOR(S)

Aisling Reynolds-Feighan & Brent D. Bowen (Eds.)

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

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8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

University of Nebraska at Omaha Aviatoin Institute
NASA Nebraska Space Grant
6001 Dodge Street, Allwine Hall 422
Omaha, NE 68182-0508

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

98-3, 98-4 & 98-5

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT

12b. DISTRIBUTION CODE

13. ABSTRACT (Maximum 200 words)

See Attached Sheet (over)

14. SUBJECT TERMS

Aviation, Airlines, Transportation, Air Transport Research Group, Airport Management, Airline Networks, Airline Alliances, Deregulation, Airfreight, Airline Competition & Financing

15. NUMBER OF PAGES

varies

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	