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AIRPORT DEREGULATION AND AIRLINE COMPETITION

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Abstract

Liberalisation has affected all parts of the air travel industry, with airports as well as airlines increasingly run on commercial lines. This paper models interactions between airports and airlines to show that, for example, the potential benefits to passengers of increased competition between airlines may be (more than) absorbed by the unregulated airports through which they travel, and that effecting airport competition in one country may lead to the majority of the gains going abroad. The policy conclusion is that the (de)regulation of airlines and associated services should be fully co-ordinated and internationally coherent.

Keywords: Airports, airlines, competition, deregulation.

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1. Introduction

In recent years the worldwide trend towards liberalisation and privatisation has made its mark on all parts of the air travel industry, with airports as well as airlines increasingly likely to be run on commercial lines. In the UK the process of setting the price controls for the five years from April 2003 for the four key airports to which they are currently applied (those 'designated' under the 1986 Airports Act – Heathrow, Gatwick and Stansted near London, plus Manchester) has sparked calls for the whole regulatory system to be discarded. For example in his recent contribution to this *Journal* Starkie (2001) argues that complementarity between the aeronautical and the commercial services provided by airports gives an incentive for "the airport business, left to its own devices, to behave in an economically efficient manner" (page 125), and that formal price-cap regulation should therefore be lifted from the four airports. Condie (2000) uses a different argument – that airlines at the London airports are in a situation akin to bilateral oligopoly – to reach broadly the same conclusion: price regulation is inappropriate, as "the imposition of formal price caps on this market structure merely redistributes wealth from the airport to the airline without any gain to consumers given the lack of market access to Heathrow" (page 384).

Indeed, a clear distinction must be drawn between airports like Heathrow and other national hubs constrained by a combination of congestion and grandfather rights to timetable slots, and the smaller and (often) newer airports where utilisation is well below capacity. In the latter case we would expect any redistribution of wealth to airlines to attract new entrants to that sector (which is already liberalised); it is clear from the case studies presented by Barrett (2000) that across Europe there is a ready demand for access from low-cost airlines in particular. The large discounts on airport charges cited by Barrett show that the airlines have considerable bargaining power in these circumstances, and the benefits of competition in the air travel sector as a whole do seem to be reaching passengers. At the congested airports however it is a different story. If unregulated, these airports might find themselves in a stronger market position than the airlines, and therefore able to erode gains from competition between airlines through countervailing increases in airport charges and other commercial service charges under their control. The apparent higher profitability of airports relative to most airlines (Doganis, 1992) suggests that this is not an implausible outcome. It is likely to be particularly true for the three London airports which, under the 1986 Act, are under the single ownership of BAA, potentially giving them considerable market power.T[1]

This paper uses a modelling approach to examine the issues for policymaking across the whole air passenger industry that are raised by the potential removal of regulatory constraints on airports. The key to the argument is the complementarities that exist between airports and the airlines that use them, as opposed to those within airports emphasised by Starkie, but both papers underline the importance of 'joined up' policy-making which takes account of such cross-sector effects. It is the overall price of a flight – that is, airport charges and other taxes as well as the ticket price – that matters to passengers.

A key concern is the potential exercise of monopoly power by airports if the level of regulation were reduced. The next section of this paper therefore considers a simple three-sector model of air travel between two countries (domestic and foreign), where each country has a monopoly airport serviced by two competing airlines (one domestic and one foreign).

[1] The decision to allow BAA single ownership of these key airports was based on a number of arguments (see Foster (1984) for example); these included cost considerations and the view that effective price competition between airports was unlikely to be effective. Recently, serious questions have been raised about the validity of these assumptions, especially in the light of the activities of Ryanair and other low-cost operators (Barrett, 2000).

We use this model to examine the effects of monopoly airports upon the gains to consumers arising from increased competition between airlines. We then turn in Section 3 to the effects of airport competition via the introduction of a rival airport in the domestic country. We would expect there to be gains domestically as the rival airports compete on services such as car-parking as well as landing charges, but we show that much of the benefit is likely to be appropriated by the remaining monopoly element in the industry – the foreign airport.

Section 4 introduces a government in each country to our model, so that there are now potentially five elements to the overall price of a journey: two government taxes, two airport charges and the flight price. The model assumes that the domestic government introduces a flat rate tax designed to maximise government revenue. The five-sector analysis can be extended to the case of a separation of aeronautical and commercial services, as would follow from the adoption of a 'dual till' methodology in regulation (for some of the recent debate on this proposal see Civil Aviation Authority (2001, 2002) or Competition Commission (2002)). Section 5 concludes the paper with a summary of the main findings and some suggestions for further research.

2. The Simple Case: A Monopoly Domestic Airport

Suppose we have a domestic and a foreign country, each with its own monopoly airport which charges passengers on departure an airport charge of p_D and p_F, respectively. Further, suppose each country has its own airline offering return flights between the two countries (a common result of bilateral agreements), whose services are perfect substitutes with uniform return fare, p_A. It follows from this that the total cost of travel incurred by each passenger for the return trip, P, is given by:[2]

(1) $$P = p_D + p_A + p_F .$$

Suppose total demand for return air travel between the two countries, Q, is identical in each country (so that, for a given price, consumption in each country is $Q/2$), and takes the linear form:

(2) $$Q = \alpha - \beta P ,$$

where α and β are positive constants. As both the origin and destination airports service all Q passengers, and assuming that both airports operate with constant long-run marginal cost (per passenger), c_i ($i = D, F$), profit for the i^{th} airport is:[3]

(3) $$\pi_i = (p_i - c_i)Q . \qquad (i = D, F)$$

Maximising profit with respect to price yields the following first-order condition:

(4) $$\frac{d\pi_i}{dp_i} = (p_i - c_i)\frac{dQ}{dp_i} + Q = 0 .$$

Using the chain rule (4) can be written:

(5) $$(p_i - c_i)\frac{dQ}{dP}\frac{dP}{dp_i} + Q = 0 .$$

From (2):

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[2] Although passengers make their travel decisions on the basis of the composite price P, for our purposes it is necessary to consider how this breaks down into its constituent parts. Given the nature of the problem, the services of the three sectors are perfect complements.

[3] The simplifying assumption of constant long-run marginal cost is not uncommon in the literature (e.g. Pels et al., 1997). Doganis (1992, p. 49) suggests that unit costs are constant for throughput above about 3 million passengers per year. To aid tractability, fixed costs are ignored here; this does not affect the nature of our results.

(6) $$\frac{dQ}{dP} = -\beta .$$

Since total demand is a function only of the composite price, it follows that the firms in each sector will take into account the likely prices charged by their counterparts in each other sector when setting their own prices. We characterise this interdependence amongst the three sectors as follows:

(7) $$\frac{dP}{dp_g} = 1 + \sum_{h \neq g} \gamma_{hg} , \qquad (h \neq g = D, A, F)$$

where $\gamma_{hg} = \dfrac{dp_h}{dp_g}$ is a conjectural variation term which measures firm g's expectation of the response in p_h to a change in p_g, and can be interpreted as the implicit collusiveness of the industry.[4] Assuming all firms hold the same expectation about the reaction of other sectors' prices to a change in their own sector's price allows us to drop arguments on the conjectural variation term, thus:

(8) $$\frac{dP}{dp_g} = 1 + 2\gamma . \qquad (-0.5 < \gamma \leq 1)^5 \qquad (g = D, A, F)$$

Joint profit maximisation across the three sectors is characterised by $\gamma = 1$, whilst lower values of γ represent increasingly competitive pricing behaviour. Independent pricing is characterised by $\gamma = 0$. Values of $\gamma < 0$ imply accommodating pricing behaviour.

Using (6) and (8) in (5), we have:

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[4] Conjectural variation terms have been used to characterise conduct in both theoretical and empirical analyses. The approach has its advocates (such as Fraser, 1994, and Bresnahan, 1989), and critics (Shapiro, 1989).

[5] The lower limit on this term is necessary to ensure output in (9) below is greater than zero.

(9) $$(p_i - c_i) - \frac{Q}{\beta(1+2\gamma)} = 0.$$

It follows from (9) that:

(10) $$\frac{d\pi_D}{dp_D} + \frac{d\pi_F}{dp_F} = (p_D + p_F) - (c_D + c_F) - \frac{2Q}{\beta(1+2\gamma)} = 0.$$

Now, since the total number of return trips between the two countries is shared between the two airlines:

(11) $$Q = \sum_j q_{Aj}\,, \quad (j = 1, 2)$$

where q_{Aj} is the demand for travel using the j^{th} airline. Assuming that both airlines operate with common constant long-run marginal cost (per passenger), c_A, profit for the j^{th} airline is:

(12) $$\pi_{Aj} = (p_A - c_A)q_{Aj}\,.$$

Profit maximisation implies the following first order condition:

(13) $$\frac{d\pi_{Aj}}{dq_{Aj}} = (p_A - c_A) + q_{Aj}\frac{dp_A}{dq_{Aj}} = 0\,.$$

Using the chain rule (13) can be written:

(14) $$(p_A - c_A) + q_{Aj}\frac{dp_A}{dP}\frac{dP}{dQ}\frac{dQ}{dq_{Aj}} = 0\,.$$

We assume that each airline makes its output decisions based upon an understanding of its interdependence with its rival's output decisions as characterised by:[6]

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[6] Note, it is assumed that whilst the airlines make decisions on quantity, the final equilibrium is achieved in accordance with the fact that both airlines understand the effect that their output decisions will have on the sector's price, and also the reaction to this of the price setting of the other sectors (captured by the price conjectural variation term).

(15) $\dfrac{dQ}{dq_{Aj}} = \dfrac{dq_{Aj}}{dq_{Aj}} + \dfrac{dq_{Ak}}{dq_{Aj}} = 1 + \lambda_{Akj}$,

where $\lambda_{Akj} = \dfrac{dq_{Ak}}{dq_{Aj}}$ measures airline *j*'s expectation of the reaction of airline *k* to a change in *j*'s output.[7] Taking λ_{Akj} to be common for the two airlines, we drop *kj* arguments on this term. Thus:

(16) $\dfrac{dQ}{dq_{Aj}} = 1 + \lambda_A$, $\quad (-1 < \lambda_A \leq 1)$

where $\lambda_A = 1$ if there is collusion, $\lambda_A = 0$ represents independent ("Cournot") behaviour, and $\lambda_A = -1$ is the Bertrand outcome with price equal to marginal cost. Substituting (6), (8) and (16) in (14), we have:

(17) $(p_A - c_A) - \dfrac{q_{Aj}(1+\lambda_A)}{\beta(1+2\gamma)} = 0$.

Thus:

(18) $\dfrac{d\pi_{A1}}{dq_{A1}} + \dfrac{d\pi_{A2}}{dq_{A2}} = 2(p_A - c_A) - \dfrac{Q(1+\lambda_A)}{\beta(1+2\gamma)} = 0$.

Using (2) in (10) and (18) and rearranging gives:

(19a) $p_i = \dfrac{\beta c_i(1+2\gamma) + (\alpha - \beta p_A - \beta p_m)}{2\beta(1+\gamma)}$, $\quad (i \neq m = D, F)$

(19b) $p_A = \dfrac{2\beta c_A(1+2\gamma) + (\alpha - \beta p_D - \beta p_F)(1+\lambda_A)}{\beta((1+\lambda_A) + 2(1+2\gamma))}$.

[7] Brander and Zhang (1990) examined the performance of a range of duopoly models for explaining the behaviour of airlines on US routes, and found that the Cournot model performed best. See also Oum et al. (1993), who found empirical evidence for both quantity setting and Bertrand price competition between airlines.

Solving (19a) and (19b) simultaneously and using (1) gives the following equilibrium (reduced form) expressions for the airline and composite price, respectively:

(20a) $$p_A = \frac{2\beta c_A(3+2\gamma)+(1+\lambda_A)(\alpha-\beta(c_D+c_F))}{\beta(7+4\gamma+\lambda_A)},$$

(20b) $$P = \frac{2\beta(1+2\gamma)(c_D+c_A+c_F)+\alpha(5+\lambda_A)}{\beta(7+4\gamma+\lambda_A)}.$$

From these expressions we can derive the two propositions below.

Proposition 1: **With a monopoly domestic airport, the composite price is more sensitive to changes in (implicit) price conduct amongst the three sectors than to changes in quantity behaviour within the airline sector.** [8]

$$\left|\frac{\partial P}{\partial \gamma}\right| > \frac{\partial P}{\partial \lambda_A}.$$

So, for instance, a move from independent to perfectly collusive pricing amongst all three sectors will yield greater benefits in terms of a reduction in the composite price than will a move from perfectly collusive output behaviour to independent (Cournot) conduct between the airlines.

Proposition 2: **With a monopoly domestic airport, the composite price falls more slowly than air fares for small increases in airline competition.**

$$0 < \frac{\partial P}{\partial \lambda_A} < \frac{\partial p_A}{\partial \lambda_A}.$$

[8] The proofs to all propositions are in the appendix.

Therefore, some of the gains from competition between the airlines are absorbed by the monopoly airports through increases in their airport charges.

We now briefly consider the possibility that airlines compete on price rather than quantity – that is, competition is Bertrand.[9] With the airlines behaving in this way, it follows that their pricing behaviour will be independent of airport charges, hence $\gamma_{Ai} = 0$ ($i = D, F$). Further, if both airports take $p_A = c_A$ as given, $\gamma_{iA} = 0$ ($i = D, F$).

Proposition 3: **From an initial equilibrium with quantity competition between the airlines characterised by λ_A, and with a monopoly domestic airport, the introduction of Bertrand competition in the airline sector (so that $p_A = c_A$ can be taken as given), has a perverse effect, causing the composite price to rise if:**[10]

$$1 + \lambda_A(1+\gamma) - 3\gamma < 0 .$$

The contour in Figure 1 illustrates combinations of λ_A and γ for which the introduction of Bertrand competition is neutral for composite price. The latter will rise (fall) for points below (above) the contour. For instance, if $\lambda_A = 0$ and $\gamma = 0.5$ then P will rise with the introduction of marginal cost pricing in airlines, whilst for $\gamma = 0.5$ and $\lambda_A = 1$, it will fall.

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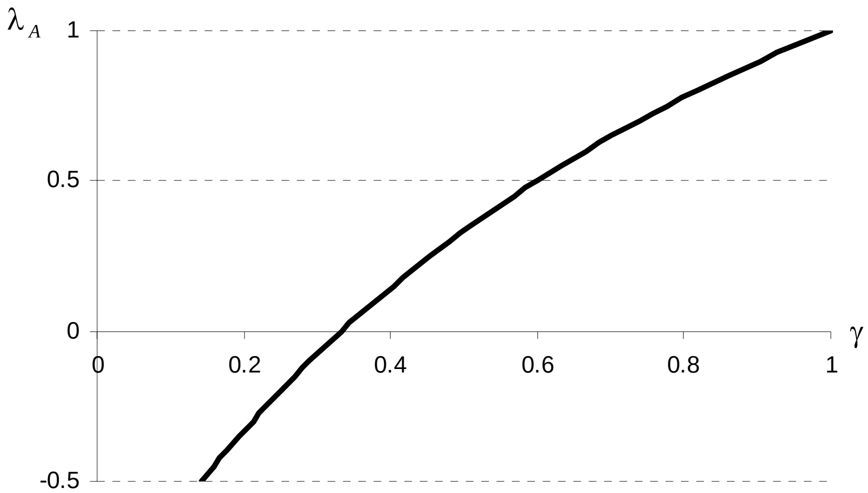
[9] Oum et al.'s (1993, p.183) empirical results suggest this is more likely on more leisure-oriented routes.

[10] Note, it is assumed that γ is not affected by the introduction of Bertrand competition between the airlines. However, it may not be unreasonable to suppose that γ might actually increase (i.e. price collusion between two sectors is easier than with three). This would have downward pressure on the composite price and would therefore reduce the likelihood of an increase in P.

Figure 1: Price-neutral Bertrand competition between airlines



3. Domestic Airport Competition

The assumption of a single domestic airport is clearly too strong in most cases. Most passengers will have some choice of departure point; indeed unless they live close to one particular airport they may well be happy to consider a number of options. The analysis could reflect the specific case of a break-up of BAA in the UK, which could give London three genuinely competing airports (in addition to Luton and London City), or more generally the rise of regional competition to existing airports. In many cases low-cost airlines such as Ryanair have used secondary airports to establish services in competition with those of a national carrier from a neighbouring large airport; examples include Stansted and Luton versus Heathrow and Gatwick, Charleroi versus Brussels, and Hahn versus Frankfurt (Barrett, 2000, page 21). Equally, some of the secondary airports have set out to attract the airlines; the chief commercial officer of one low-cost airline, Buzz, has referred to being "courted by a number of UK airports" when opening up a new market (*The Independent*, 31 October 2002, page 25).

In this section we model the total number of passengers as being split between two competing domestic airports, which are assumed, for simplicity, to be perfect substitutes. The total number of passengers is now split between two competing domestic airports:

(21) $$Q = \sum_j q_{Dj} . \quad (j = 1, 2)$$

The modelling here is analogous to the case of duopoly airlines. It follows from (14) that the first order condition is:

(22) $$(p_D - c_D) + q_{Dj} \frac{dp_D}{dP} \frac{dP}{dQ} \frac{dQ}{dq_{Dj}} = 0 .$$

Using (6) and (8) in (22):

(23) $$(p_D - c_D) - \frac{q_{Dj}(1 + \lambda_D)}{\beta(1 + 2\gamma)} = 0 ,$$

where $\lambda_{Dj} = \dfrac{dq_{Dm}}{dq_{Dj}}$ is a conjectural variation term which characterises output behaviour in the domestic airport sector. Taking this term to be the same for both domestic airports, we can drop the *mj* subscripts. Thus:

(24) $$\frac{d\pi_{D1}}{dq_{D1}} + \frac{d\pi_{D2}}{dq_{D2}} = 2(p_D - c_D) - \frac{Q}{\beta} \frac{(1 + \lambda_D)}{(1 + 2\gamma)} = 0 .$$

Using (2) and (1) in (24) and re-arranging, we get:

(25) $$p_D = \frac{2\beta c_D (1 + 2\gamma) + (\alpha - \beta p_A - \beta p_F)(1 + \lambda_D)}{\beta((1 + \lambda_D) + 2(1 + 2\gamma))} .$$

Solving (19a) for *F*, (19b) and (25) simultaneously, the reduced form equilibrium prices are:

(26a) $$p_r = \frac{\beta c_r (5 + \lambda_s + 4\gamma) + (1 + \lambda_r)(\alpha - \beta c_s - \beta c_F)}{\beta(6 + 4\gamma + \lambda_A + \lambda_D)} , \qquad (r \neq s = D, A)$$

(26b) $p_F = \dfrac{\beta c_F(4+\lambda_A+\lambda_D+4\gamma)+2(\alpha-\beta c_D-\beta c_A)}{\beta(6+4\gamma+\lambda_D+\lambda_A)}$.

From (2), the equilibrium composite price is then:

(26c) $P = \dfrac{2\beta(1+2\gamma)(c_D+c_A+c_F)+\alpha(4+\lambda_D+\lambda_A)}{\beta(6+4\gamma+\lambda_D+\lambda_A)}$.

The next three propositions now follow straightforwardly.

Proposition 4: **With duopoly domestic airports, the composite price is more sensitive to changes in (implicit) price conduct amongst all three sectors than to changes in quantity conduct between the airlines, and more so the more collusive the quantity conduct between the two domestic airports:**

$$\left|\frac{\partial P}{\partial \gamma}\right| > \frac{\partial P}{\partial \lambda_A}, \frac{\partial}{\partial \lambda_D}\left(\frac{\dfrac{\partial P}{\partial \lambda_A}}{\left|\dfrac{\partial P}{\partial \gamma}\right|}\right) < 0.$$

Therefore, as in the monopoly domestic airport case, the composite price falls more quickly with more collusive pricing behaviour amongst all three sectors than it does with improvements in airline competition. However, the superiority of the former is reduced with more competitive (output) behaviour between the two domestic airports.

Proposition 5: **With duopoly domestic airports, the composite price falls more slowly than air fares for small increases in airline competition but to a lesser extent for less collusive behaviour between the domestic airports:**

$$0 < \frac{\partial P}{\partial \lambda_A} < \frac{\partial p_A}{\partial \lambda_A}, \ \frac{\partial}{\partial \lambda_D}\left(\frac{\frac{\partial P}{\partial \lambda_A}}{\frac{\partial p_A}{\partial \lambda_A}}\right) < 0.$$

Therefore, some of the benefits from increased airline competition will be absorbed by the domestic and foreign airports, but the extent of this absorption decreases as the domestic airports become less collusive.

Proposition 6: **With a foreign airport monopoly and duopoly domestic airports, the majority of the gains from increasing competition between the domestic airports accrue to the foreign country, since:**

$$\frac{\partial p_D}{\partial \lambda_D} > 0, \frac{\partial p_F}{\partial \lambda_D} < 0.$$

It follows from the assumptions of symmetry for both airlines and consumers that differences in the distribution of surplus between the two countries will depend solely upon differences in the margins of the foreign and domestic airports. Since the foreign and domestic airport charges increase and decrease respectively, with competition in the domestic airport sector, the surplus accruing to the foreign country must increase relative to that for the domestic country.

Proposition 7: **With a foreign airport monopoly and non-perfectly collusive output behaviour between the duopoly domestic airports ($\lambda_D < 1$), the majority of the gains from competition between the airlines accrue to the foreign country, since:**

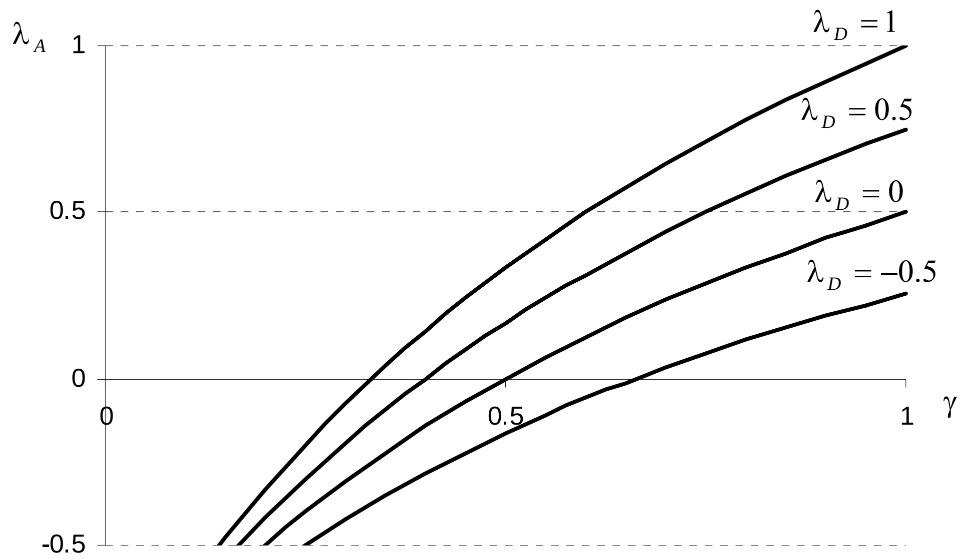
$$\left|\frac{\partial p_D}{\partial \lambda_A}\right| < \left|\frac{\partial p_F}{\partial \lambda_A}\right|.$$

As in Proposition 6, the surplus accruing to the foreign country from improvements in airline competition increases relative to that for the domestic country (where conduct is less than perfectly collusive), since the foreign airport charge increases more quickly with reductions in λ_A***.***

Proposition 8: **From an initial equilibrium with quantity competition between the airlines characterised by** λ_A**, and with domestic duopoly airports, the introduction of Bertrand competition in the airline sector (so that** $p_A = c_A$ **can be taken as given), has a perverse effect, causing the composite price to rise if:**

$$1 + \lambda_A(1+\gamma) - \gamma(\lambda_D + 2) < 0\,.$$

Figure 2: Price-neutral Bertrand competition between airlines with duopoly domestic airports



As in Figure 1, the contours in Figure 2 illustrate combinations of λ_A and γ for which the introduction of Bertrand competition is neutral for composite price. Lower contours represent more competitive behaviour between the two domestic airports and hence the perverse result is less likely for more competitive output behaviour between the domestic airports. For instance, if $\lambda_A = 0$ and $\gamma = 0.5$ the composite price will rise (fall) if λ_D is positive (negative).

4. A Policy Warning

Finally we consider the introduction of taxes and other government levies on the industry. The potential for raising revenue from air travel has not escaped the attention of governments worldwide, with many levying departure taxes on passengers in a form similar to Air Passenger Duty in the UK. In many cases, environmental issues form at least part of the motivation for such taxes. However, such actions essentially add extra decision-making sectors to the model, and we show that this raises serious issues for policy-makers.

To illustrate the point we take a simplified model with monopoly airports in both the foreign and domestic countries, a monopoly airline and a government sector in each country. We assume that the governments introduce a flat rate tax per passenger chosen to maximise revenue and that the introduction of the government sector adds no extra costs (the marginal cost of raising taxes in this way is zero). This gives rise to the following proposition.

Proposition 9: **If $\gamma < 1$ ($\gamma = 1$), the introduction of new revenue generating sectors to the n-sector air passenger model with monopoly in each sector leads to an increase (no change) in the composite price of travel, even when (when) these new sectors do not add to the existing unit cost per passenger, $\overline{C}(= c_D + c_A + c_F)$:**[11]

$$\frac{\partial P}{\partial n}\Big|_{\overline{C},\gamma<1} > 0\,,\ \frac{\partial P}{\partial n}\Big|_{\overline{C},\gamma=1} = 0$$

Indeed, the warning extends beyond the involvement of governments interested in raising revenue. The analysis here can equally be applied to the issue of the ownership of aeronautical and commercial airport services (such as car parking and retail operations). Assuming these are perfect complements and that operating costs are independent of ownership, the separation of the two functions may cause the total costs of travel to rise.

5. Conclusion

Our aim in this paper has been to analyse the ways in which changes in one of the sectors involved in the provision of air travel can have effects elsewhere in the supply 'chain'. In

[11] It can be shown that this result is even more robust if we accept that γ may decrease with *n* (i.e. price collusion becomes less easy with more sectors).

particular we have shown that the potential benefits to passengers of increased competition between airlines may well be absorbed by the unregulated airports at which they begin or end their journeys. In extreme circumstances the net effects for passengers may even be negative.

The main implication for policy-makers from this work is the need for co-ordinated action across different sectors involved in producing one end product – here, air travel by a passenger from origin to destination. The different sectors need to be controlled together, as regulators cannot assume that their actions in one sector will be neutral elsewhere. Furthermore, the possibility that the benefits of regulatory action in one country may be (largely) captured by foreign airports or airlines emphasises the case for co-ordinated international action such as that undertaken by the European Union or IATA. Unilateral approaches are likely to be less rewarding.

Our prime interest here has been the effects of the complementary nature of airports and airlines, and we have therefore abstracted from some important features of many existing airports. In particular we have not considered capacity and congestion issues such as those examined by Condie (2000), and nor did we allow for the effects of location and any rents which stem from it (see Beesley, 1999). Both of these would repay further investigation; the former is particularly relevant in the UK context where the principal airport – London Heathrow – suffers from severe capacity constraints. Indeed many passengers from the northern part of the UK prefer to make long-haul trips via Schiphol airport in the Netherlands rather than Heathrow, thus demonstrating that international borders need not constitute any barrier to passengers – nor any barrier to the revenue raised by airport charges. Where passengers can divert to nearby facilities in other countries, as is possible for many European airports, the elasticity of revenue with respect to airport charges may be quite high. The active competition between Hong Kong International Airport and its competitors in South East Asia, including 10 and 15 per cent cuts in charges in 2000 and 2001, provides a good illustration of this sort of international switching (Centre for Asia Pacific Aviation, 2002). An examination of the effects of international substitutability on our model would therefore also be of interest.

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Appendix

Proof 1: ***Differentiating (20b) with respect to*** γ ***and*** λ_A ***yields, respectively:***

(A1) $$\frac{\partial P}{\partial \gamma} = -\frac{4\{\alpha - \beta(c_D + c_A + c_F)\}(5 + \lambda_A)}{\beta(7 + 4\gamma + \lambda_A)^2} < 0,$$

(A2) $$\frac{\partial P}{\partial \lambda_A} = \frac{2\{\alpha - \beta(c_D + c_A + c_F)\}(1 + 2\gamma)}{\beta(7 + 4\gamma + \lambda_A)^2} > 0.$$

Since $-0.5 < \gamma \le 1$ and $-1 < \lambda_A \le 1$ it follows that $2(5 + \lambda_A) > 1 + 2\gamma$, and thus, from comparison of (A1) and (A2), clearly, we have $\left|\frac{\partial P}{\partial \gamma}\right| > \frac{\partial P}{\partial \lambda_A}$. **(Q.E.D.)**

Proof 2: Differentiating (20a) with respect to λ_A gives:

(A3) $$\frac{\partial p_A}{\partial \lambda_A} = \frac{2\{\alpha - \beta(c_D + c_A + c_F)\}(3 + 2\gamma)}{\beta(7 + 4\gamma + \lambda_A)^2} > 0.$$

Since $1 + 2\gamma < 3 + 2\gamma$, it follows from comparison of (A3) with (A2) that $0 < \frac{\partial P}{\partial \lambda_A} < \frac{\partial p_A}{\partial \lambda_A}$.

(Q.E.D.)

Proof 3: Assume the initial equilibrium prices P and p_A are as given by (20a) and (20b) respectively. With Bertrand competition the new equilibrium price in the airline sector p_A is reduced to marginal cost:

(A4) $$\hat{p}_A = c_A,$$

with $\gamma_{Ai} = 0$ and $\gamma_{iA} = 0$ ($i = D, F$). From (7)

(A5) $$\frac{dP}{dp_g} = 1 + \gamma_{hg}, \qquad (h \neq g = D, F)$$

Substituting (A5) in place of (8) in (10), and using (A4), (19a) becomes

(A6) $$p_g = \frac{\beta c_g(1+\gamma) + (\alpha - \beta c_A - \beta p_h)}{\beta(2+\gamma)}.$$

Solving (A6) simultaneously, the reduced form equilibrium prices for domestic and foreign airports, assuming marginal cost pricing between airlines, are given by:

(A7) $$\hat{p}_g = \frac{(\alpha - \beta(c_A + c_h)) + \beta(2+\gamma)c_g}{\beta(3+\gamma)}.$$

Using (A4) and (A7) in (1) gives the reduced form equilibrium composite price:

(A8) $$\hat{P} = \frac{2\alpha + \beta(1+\gamma)(c_D + c_A + c_F)}{\beta(3+\gamma)}.$$

Defining ξ_P as the change in the composite price due to the introduction of Bertrand competition in the airline sector, subtracting (A8) from (20b):

(A9) $$\xi_P = P - \hat{P} = \frac{(\alpha - \beta(c_D + c_A + c_F))(1 + \lambda_A(1+\gamma) - 3\gamma)}{\beta(7 + 4\gamma + \lambda_A)(3+\gamma)},$$

which is positive (negative) if $1 + \lambda_A(1+\gamma) - 3\gamma$ is positive (negative). **(Q.E.D)**

Proof 4: ***Differentiating (26c) with respect to γ and λ_A yields, respectively:***

(A10) $$\frac{\partial P}{\partial \gamma} = \frac{4\{b(c_D + c_A + c_F) - \alpha\}(4 + \lambda_D + \lambda_A)}{\beta(6 + 4\gamma + \lambda_D + \lambda_A)^2} < 0,$$

(A11) $$\frac{\partial P}{\partial \lambda_A} = \frac{2\{\alpha - \beta(c_D + c_A + c_F)\}(1+2\gamma)}{\beta(6 + 4\gamma + \lambda_D + \lambda_A)^2} > 0.$$

Since $-0.5 < \gamma \leq 1$ and $-1 < \lambda_A \leq 1$ it follows that $2(4 + \lambda_D + \lambda_A) > 1 + 2\gamma$, and thus, from comparison of (A10) and (A11), we have $\left|\frac{\partial P}{\partial \gamma}\right| > \frac{\partial P}{\partial \lambda_A}$. Further:

(A12) $\dfrac{\partial}{\partial\lambda_D}\left(\dfrac{\dfrac{\partial P}{\partial\lambda_A}}{\left|\dfrac{\partial P}{\partial\gamma}\right|}\right) = -\dfrac{(1+2\gamma)}{2(4+\lambda_D+\lambda_A)^2} < 0$. **(Q.E.D.)**

Proof 5: ***Differentiating (26a) with respect to*** λ_A ***yields:***

(A13) $\dfrac{\partial p_A}{\partial\lambda_A} = \dfrac{\{\alpha-\beta(c_D+c_A+c_F)\}(5+4\gamma+\lambda_D)}{\beta(6+4\gamma+\lambda_D+\lambda_A)^2} > 0$,

Clearly, from comparison of (A13) and (A11), $\dfrac{\partial p_A}{\partial\lambda_A} > \dfrac{\partial P}{\partial\lambda_A}$. Further:

(A14) $\dfrac{\partial}{\partial\lambda_D}\left(\dfrac{\dfrac{\partial P}{\partial\lambda_A}}{\dfrac{\partial p_A}{\partial\lambda_A}}\right) = -\dfrac{2(1+2\gamma)}{(5+4\gamma+\lambda_D)^2} < 0$. **(Q.E.D.)**

Proof 6: Differentiating (26b) and (26a) with respect to λ_D, we have respectively:

(A15) $\dfrac{\partial p_F}{\partial\lambda_D} = -\dfrac{2(\alpha-\beta(c_D+c_A+c_F))}{\beta(6+\lambda_D+\lambda_A+4\gamma)^2} < 0$,

(A16) $\dfrac{\partial p_D}{\partial\lambda_D} = \dfrac{(\alpha-\beta(c_D+c_A+c_F))(5+\lambda_A+4\gamma)}{\beta(6+\lambda_D+\lambda_A+4\gamma)^2} > 0$. **(Q.E.D)**

Proof 7: Differentiating (26b) and (26a) with respect to λ_A, we have respectively:

(A17) $\dfrac{\partial p_F}{\partial\lambda_A} = -\dfrac{2(\alpha-\beta(c_D+c_A+c_F))}{\beta(6+\lambda_D+\lambda_A+4\gamma)^2} < 0$,

(A18) $\dfrac{\partial p_D}{\partial\lambda_A} = -\dfrac{(\alpha-\beta(c_D+c_A+c_F))(1+\lambda_D)}{\beta(6+\lambda_D+\lambda_A+4\gamma)^2} < 0$.

From comparison of (A17) and (A18), if the domestic airports do not collude perfectly ($\lambda_D < 1$), then increases in output competition between the airlines will result in the foreign airport charge rising faster than the domestic airport price. **(Q.E.D)**

Proof 8: The initial equilibrium prices, P and p_A, are given by (26c) and (26a), respectively. After the introduction of Bertrand competition in the airline sector, p_A is reduced to marginal cost:

(A19) $\hat{p}_A = c_A$,

From (7):

(A20) $\dfrac{dP}{dp_g} = 1 + \gamma_{hg}$. $\qquad$ ($h \neq g = D, F$)

Substituting (A20) in place of (8) in (23), and using (A19), (25) and (26b) become respectively:

(A21) $$p_D = \frac{2\beta c_D(1+\gamma) + (\alpha - \beta c_A - \beta p_F)(1+\lambda_D)}{\beta(3+\lambda_D+2\gamma)},$$

(A22) $$p_F = \frac{\beta c_F(1+\gamma) + (\alpha - \beta c_A - \beta p_D)}{\beta(2+\gamma)}.$$

Solving (A21) and (A22) simultaneously, yields the reduced form equilibrium prices for domestic and foreign airports assuming marginal cost pricing between airlines, respectively:

(A23) $$\hat{p}_D = \frac{(\alpha - \beta(c_A + c_F))(1+\lambda_D) + 2\beta(2+\gamma)c_D}{\beta(\lambda_D + 2\gamma + 5)},$$

(A24) $$\hat{p}_F = \frac{2\alpha + \beta((3+\lambda_D+2\gamma)c_F - 2(c_A + c_D))}{\beta(\lambda_D + 2\gamma + 5)}.$$

Using (A21), (A23) and (A24) in (1) gives the reduced form equilibrium composite price:

(A25) $\hat{P} = \dfrac{\alpha(3+\lambda_D) + 2\beta(1+\gamma)(c_D + c_A + c_F)}{\beta(\lambda_D + 2\gamma + 5)}$.

Defining ξ_P as the change in the composite price due to the introduction of Bertrand competition in the airline sector, subtracting (A25) from (26c):

(A26) $\xi_P = P - \hat{P} = \dfrac{2(\alpha - \beta(c_D + c_A + c_F))(1 + \lambda_A(1+\gamma) - \gamma(\lambda_D + 2))}{\beta(6 + 4\gamma + \lambda_D + \lambda_A)(5 + 2\gamma + \lambda_D)}$,

which is positive (negative) if $1 + \lambda_A(1+\gamma) - \gamma(\lambda_D + 2)$ is positive (negative). **(Q.E.D)**

Proof 9: With *n* sectors and symmetric price conjectures, from (7):

(A27) $\dfrac{dP}{dp_g} = 1 + \gamma(n-1)$. $(g = 1,\ldots,n)$

Assuming each sector is characterised by profit-maximising monopoly (equivalent to revenue maximisation for government sectors with zero costs), from (9):

(A28) $(p_g - c_g) - \dfrac{Q}{\beta(1+\gamma(n-1))} = 0$.

Summing (A28) for all *g*:

(A29) $(P - \overline{C}) - \dfrac{nQ}{\beta(1+2\gamma)} = 0$.

Using (2) in (A29):

(A30) $P = \dfrac{n\alpha + \beta\overline{C}(1+\gamma(n-1))}{\beta(1+n+\gamma(n-1))}$.

Differentiating (A30) with respect to *n*:

(A31) $\dfrac{\partial P}{\partial n} = \dfrac{(\alpha - \beta\overline{C})(1-\gamma)}{\beta(1+n+\gamma(n-1))^2} > 0$,

(Q.E.D.)