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Congestion in European Airspace

A Pricing Solution?

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Abstract

This article deals with Air Traffic Control (ATC) pricing as a means of sorting out the European airspace congestion problem. For several years the situation has been worsening. Insufficient capacity of the ATC system, poor coordination between European ATC providers, and a high traffic level, as a consequence of economic growth, price competition, and hub-and-spoke organisation, explain a congested sky. The present ATC pricing rule is not designed to solve this problem. Components of this rule do not give airlines incentives to modify their choices. The article makes a proposal for a new rule, so that the airlines' equilibrium choices are also optimal choices, from a social point of view.

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1. Introduction

The objective of this paper is to analyse the air congestion problem. In 1999, more than one-third of flights were delayed for more than fifteen minutes in the Eurocontrol area.[1] The member States of Eurocontrol decided to get together in order to organise airline flight plans. Among other activities, Eurocontrol is in charge of collecting and analysing the data on the delays in European air transport. The Central Office for Delay Analysis (CODA) classifies those delays by origins, such as weather, security, airport, ATFM (Air Traffic Flow Management), and airlines.

The Air Traffic Control (ATC) services are the origin of almost 23 per cent of European delays. On the one hand, this is due to a problem of insufficient capacity. For example, an increase of 5 per cent of the traffic was expected in France for 1999, while the actual rate was 8 per cent. This under-estimation of traffic growth led to insufficient capacity, essentially in terms of controllers and of airspace re-organisation.[2]

On the other hand, the ATC systems are poorly co-ordinated in Europe. The Eurocontrol organisation was set up with no loss of sovereignty for each country. Each one has its own equipment, with its own language, and due to a high level of complexity the change from one system to another leads to a waste of time.

Airlines are the main users of ATC and the context of commercial air transport has changed. The high traffic level results from both economic growth with an increase in demand, and liberalisation with a re-organisation of supply. The new airline strategies are also at the origin of the present air congestion. With liberalisation, reducing costs and organising networks in a more efficient way became the principal aim of airlines. The reorientation of linear route systems to hub and spoke operations was already a feature of Europe's air transport. The advantage of this strategy is to allow connections with less well-served routes. Through better utilisation of their aircraft and flight crews, considerable economies of density are obtained. At the same time airlines derive economies of scope. First, two routes served by the same airline are less costly than two airlines operating on one route. Second, serving two routes jointly, with the same connection city, is less costly than operating on two

[1]The member States of Eurocontrol are: Albania, Austria, Belgium, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Finland, France, the Former Yugoslav Republic of Macedonia (FYROM), Germany, Greece, Hungary, Ireland, Italy, Luxembourg, Malta, Moldova, Monaco, Norway, Netherlands, Portugal, Romania, Slovak Republic, Slovenia, Spain, Sweden, Switzerland, Turkey, UK.

[2]The high level of delays in 1999 can also be explained by the Kosovo war. An important part of the civil airspace was used for military flights.

routes separately. A first step of the reorganisation after liberalisation was to reinforce the advantages of hub and spoke configuration by a better co-ordination between flights at the hub. Connecting flights were concentrated around several time periods in a day.

With a static framework, this reinforcement of positive network externalities reduces the number of movements. But hard price competition also came with liberalisation. Airlines proposed low prices, attracting more passengers and increasing traffic. Moreover, for short-haul routes with high demand, airlines use their smaller aircraft supplying very frequent flights.[3] It seems that airlines do not take into account how much their strategies worsen the quality of air transport services and this gives rise to negative externalities on the ATC.

Delays are very costly. A study (ITA, 2000) shows that annual overall costs supported by airlines and passengers could be estimated between 6.6 and 11.5 billion Euros for 1999.

The European Commission developed a project whose aim is to reduce the delays. New governance structures for the ATC services, new air roads designed according to the traffic flow, and new fees are suggested. In this article, we focus on the idea of new fees to regulate the air traffic. Indeed, this solution matches the sources of congestion described above. It solves the problem of insufficient capacity with incentives for airlines so that they modify their choices.

The first part of this article describes the present ATC pricing rule in Europe. We tried to find an *a posteriori* explanation of this formula. A model, developed by Morrison in 1987, gives results very similar to the present pricing rule. We comment on this formula, showing what is wrong with it and why it cannot lead to a solution of the congestion problem. The second part of this article develops a new economic model in order to obtain a more efficient pricing rule. This new model differs from Morrison's in several ways.

2. The Present ATC Pricing Rule

2.1. The European en-route charges

Among the Eurocontrol services there is a Central Route Charges Office (CRCO) in charge of computing, collecting, and reallocating a sole bill

[3]For instance, Air France supplies its "La Navette" services between Paris and several cities of the south of France.

paid by airspace users controlled in en-route centres of member countries. The charges received by the States are defined by the following formula:

$$R_i = T_i \times \frac{D_i}{100} \times \sqrt{\frac{M}{50}} \tag{1}$$

where T_i is the unit rate of the state i, D_i is the distance flown in kilometres in the airspace of the state i, and M is the maximum take-off weight in metric tons of the aircraft.

ATC services charge fees in order to recover their costs. Due to disparities in equipment costs, wages, and productivity, the variable of adjustment between costs and revenues differs between member countries of Eurocontrol. The unit rate is computed so that revenues equal costs. Its value, depending on the cost and traffic forecast by each state, changes every year. Table (1) shows the value of unit rate for each control area in Euros in 1999.

The distance used is the orthodromic distance between the entry and exit points of each geographical area based on the actual route of the aircraft. Before 1998, it was based on the commonly used route. Therefore with such a rule it was possible that an airline would pay en-route charges to a state its aircraft had not crossed if it decided to take another route. This mechanism led to great inefficiencies. For example, when the controllers of South of France went on strike in 1994, flights were re-routed to Germany. But for flights that commonly used routes across France, French ATC services received charges for services they did not supply and Germany was not paid for its ATC services. Now, such a problem does not arise.

Table 1

National Unit Rates for 2002 (in Euro).

Austria	70.82	Italy	58.57
Belgium-Luxembourg	90.47	Malta	39.79
Bulgaria	55.30	Netherlands	59.81
Croatia	44.40	Norway	65.69
Cyprus	26.21	Portugal	57.41
Czech Republic	40.63	Romania	47.06
Denmark	54.37	Slovak Republic	58.35
France	59.91	Slovenia	60.10
FYROM	52.64	Spain	62.20
Germany	77.22	Sweden	61.38
Greece	38.76	Switzerland	87.62
Hungary	37.92	Turkey	30.11
Ireland	22.15	UK	82.33

Source: Eurocontrol

The weight used to compute the charges is the maximum take-off weight (MTOW). Different MTOW for the same type of aircraft can occur due to different fittings made by airlines.

In order to see how this pricing rule can be modified to improve its incentive actions on the airlines' choices it may be interesting to see which principles led to this formula and by which economic model they can be summarised.

2.2. An economic justification

There is no trace of the process that led ATC authorities to charge ATC services as described by the formula (1). However under the Eurocontrol International Convention relating to air navigation of 1960, the Member States considered that the establishment of a common route charges system was done according to the guidelines recommended by the ICAO.[4]

The ICAO's advice essentially concerns equity. It is not necessary for users to pay the same price for an identical level of service, the price can be related to the ability to pay of users. The aircraft weight seems to have been chosen in that way, as a proxy for the value of the service to the user because the larger the aircraft, the more important are revenues for the airline. However, ICAO recognises that a larger aircraft can improve the productivity of airlines and it also implies that the ATC services are less essential since it contributes to a lower level of traffic. So according to ICAO, the charges must increase less proportionally than the aircraft weight. This is the reason why the square root of the aircraft weight appears in the formula.

As flights travel over a country for different distances, ICAO suggests taking into account the distance flown for charges to airspace users as a means of representing en-route ATC services used. Once using the distance was accepted, it was necessary to choose a way to measure it. A distance "as the crow flies" in each crossed country was selected. By this means, overcharging airlines due to the fact they are obliged to follow air routes with a radar beacon is avoided. Second, it ensures that each country that participated in the control will be paid for it. Choosing distance disadvantages neither the airlines, nor the countries.

In the absence of incentive constraints for the ATC provider to break even, the easiest way for countries to achieve it was to adjust revenues to costs by a unit rate determined each year.

[4]ICAO: International Civil Aviation Organisation.

As the ATC pricing rule is defined, the existence of congestion is not taken into account. The present formula was established in 1971, when congestion was not a problem and it has never been revised.

To go further from an economic point of view, we can say that the ICAO's principles that prevail in the present ATC pricing amount to "Ramsey-Boiteux" pricing.

Marginal cost pricing in the presence of increasing returns to scale leads to a budget deficit. Operating transfer of funds is a solution to recover results first-best. But it may be impossible or difficult to operate such transfers. The idea of the Ramsey-Boiteux pricing is based on the obligation that a regulated firm with increasing returns to scale has to break even. Thus, a budget constraint is added to the regulator's programme of global surplus.

This context of increasing returns and budget constraint is that of the ATC system. An *a posteriori* explanatory economic model for computing the ATC charges with the variables presented above can be found in Morrison (1987), even in a slightly different context.

Morrison's model deals with landing and take-off fees. It concerns airports, but the analysis can be transposed to the en-route ATC. ATC pricing can be characterised as being formulated by ATC authorities to maximise a sum of users' surplus relative to ATC fees, subject to the constraint that revenue equals cost. Compared to Morrison's original model we use neither a weighted sum of users' surplus nor the time period nor the congestion costs. Taking the capacity of ATC as given and assuming demands are independent across user classes, the problem can be stated formally as:

$$\begin{cases} \underset{Q_i}{\text{Max}}\ S(Q_1, \ldots, Q_n) = \sum_{i=1}^{n} \left(\int_0^{Q_i} R_i(u_i) du_i - R_i(Q_i) Q_i \right) \\ \text{s.t.} \quad \sum_{i=1}^{n} R_i(Q_i) Q_i = C(Q_1, \ldots, Q_n) + F, \end{cases} \tag{2}$$

where S is the surplus, $R_i(Q_i)$ is the inverse demand function, R_i is the charge paid by user i characterised by a pair distance-weight (D_i, M_i), Q_i is the quantity of flights operated by users of class i, $C(Q_1, \ldots; Q_n)$ are variable costs, and F are fixed costs of the ATC.

Forming the Lagrangian and solving the first-order conditions for a maximum yields:

$$\frac{R_i - c_i}{R_i} = \frac{1}{\varepsilon_i} \left(\frac{\lambda}{1 + \lambda} \right), \qquad \forall i = 1, \ldots, n, \tag{3}$$

where ε_i is the absolute value of the price elasticity of demand for ATC by users of class i, c_i is the marginal cost of the ATC, and λ is a Lagrangian multiplier. Equation (3) is a Ramsey-Boiteux pricing. The percentage mark-up of price over the marginal cost is inversely proportional to the demand elasticity. In a first approximation (as Morrison makes for landing fees), airlines' elasticity of demand equals the elasticity of passengers' demand with respect to the full price of the ticket (η) times the fraction that ATC charges represent in total flight cost (TC_i) :

$$\varepsilon_i = \eta \frac{R_i}{TC_i}. \tag{4}$$

This means that changes in costs are fully passed on in the ticket prices. The total flight cost (TC_i) is made up of the ATC charges (R_i) and aircraft operating costs (FC_i).[5] Under those assumptions, equation (3) can be solved for ATC charges:

$$R_i = \frac{1}{\eta - 1 + \frac{1}{\lambda}} \left(\eta c_i + \left(1 - \frac{1}{\lambda} \right) FC_i \right). \tag{5}$$

The optimal ATC pricing rule under a budget constraint is based for one part on the costs of the ATC services and for another part on the total flight costs of the airline. The relative importance of these components depends on the demand elasticity of passengers (η) and the extent to which the revenue constraint is binding (λ). The Lagrangian multiplier measures the increase in users' surplus resulting from a one-dollar decrease in the revenue requirement. ATC charges are greater than the marginal cost of supplying ATC services and are proportional to the total flight cost, which is discriminatory pricing.

We now analyse each component of this rule to see why and how it comes from the formula of the model (equation (5)).

In order to break even, the ATC pricing includes a unit rate for each country. It is the transcription of the parameter (λ) in Morrison's model that ensures revenues equal costs.

As the demand elasticity (ε_i in equation (5)) is related to the aircraft weight in the sense that a larger aircraft is less sensitive to variations in ATC prices than a smaller one, one can justify the term M in the present formula of en-route ATC pricing (equation (1)). This elasticity is negatively linked to the total flight costs, themselves assumed to be linked to the aircraft size. In this way, the regulator will look for correcting disparities between different classes of users.

[5] $TC_i = FC_i + R_i$.

According to Ramsey-Boiteux pricing, goods whose demand elasticity is low must be more expensive than goods whose demand elasticity is high. A Ramsey-Boiteux pricing introduces cross-subsidies between consumers. Usually, raising prices leads to a lower demand, but it worsens social welfare. Sometimes we are obliged to increase prices in order to break even. But a way to avoid a too sharp decrease in demand is to raise the prices for the demand that has the lowest demand elasticity.

To apply this system of cross-subsidies between aircraft, we need to identify the flights with low demand elasticity compared to the others. Morrison's idea to proxy this variable is to use the weight of the aircraft. The larger the aircraft, the more important are the revenues for the airline and the less sensitive will be the airline to an increase in cost. Thus, large aircraft have lower price elasticities than small aircraft.

As a result of applying a Ramsey-Boiteux pricing rule, different size aircraft would pay different ATC charges for an identical service.

Moreover, according to equation (5) two arguments can explain why the variable distance is used to compute the ATC charges.

First, regarding weight, the distance is present through the demand elasticity. Charges are linked to the total flight costs, which are assumed to be correlated with the distance. The longer the flight, the higher are the revenues of the airline and the less sensitive is the airline to an increase in costs.

Second, the marginal cost of ATC services for one flight is correlated to the flown distance covered. The ATC costs are not influenced by the size of the aircraft: control is done in the same way and the aircraft size does not modify the ATC costs. It is different for the distance. The longer the flight distance, the more ATC services are required and the more costly they are. Thus, inserting the distance in the formula is also a way to take into account a component of the ATC cost.

2.3. What's wrong with the present ATC pricing rule?

This section shows the kind of problems that exist due to the en-route charges system. The analysis gives some insights to a proposal for a more efficient ATC pricing rule.

The first criticism of the system, developed by some airlines as well as some economists, comes from an efficiency problem in the cost control. The unit rates are computed in order to equalise forecast revenues of ATC providers with forecast costs. Therefore, there are no incentives for ATC providers to control their costs since they know that they will be fully covered without effort. In 1995, some airlines did not want to pay the French ATC provider because they considered that the bill was too high compared to the service. The French Council of State decided[6] that the ATC authority, the government, is not allowed to charge airlines for services done in the general interest and for services from which they do not benefit. Those airlines won their case in court because ATC fees were, on the one hand, for expenditure in the general interest of passengers and of the over-flown populations and, on the other hand, for expenditure by the French civil aviation administration that was not connected to the ATC services. After this event, the French ATC provider made some efforts on transparency: the part of the French civil aviation budget financed by ATC users was reduced to 57.8 per cent in 1999, and there now exists the civil aviation tax, different from the ATC fees, that is essentially used for security missions.

The second criticism concerns the measurement of the service provided to aircraft. One proxy of the output of an ATC provider is the flown distance controlled. Actually, the workload of a controller depends on the heterogeneity of the traffic. An ATC sector with significant crossings needs more attention than an ATC sector with parallel paths. Thus, the measurement of distance covered by the aircraft is not completely sufficient to characterise the output and so the work provided by the controllers. The level of output supplied seems to be influenced by the heterogeneity of the traffic since trajectories and aircraft speeds are different. The definition of an ATC output is widely discussed.

Third, the ATC pricing rule is in favour of small aircraft compared to large ones, due to the fact they pay less although they hold up the airspace and require control as much as large aircraft. Moreover, the airlines prefer to impose scheduled flights on small aircraft (A320, B737) with a high level of frequency, rather than to supply larger aircraft that would be less frequent. This reduces the difference between the flight departure times and the preferred departure times of passengers, thus increasing their willingness to pay for those flights. For example, in 1999 in Europe, the number of movements increased by 8 per cent whereas the number of passengers increased only by 5 per cent. However, the European airspace congestion has reached unusual levels. The present pricing rule does not give incentives to airlines to use larger aircraft in order to carry as many passengers but with less congestion.

Fourth, the objective of the installation of a hub is to minimise the operating costs of conveying passengers having the same origin city but not the same destination and those having the same destination but different origin cities. However, the airlines wish to co-ordinate arriving schedule and departure times while avoiding too much "disutility" for the

[6]10th February 1995, *Chambre syndicale du transport aérien*.

passengers. This strategy creates congestion during short time periods, reinforced by competition because all airlines have the same preferred flight periods. Knowing that congestion is a time phenomenon, the absence of peak-load pricing does not lead to efficient allocation of flight times.

3. A New ATC Pricing Rule

3.1. Why is Morrison's model not satisfactory?

According to the results of the previous model, incentives to reduce air congestion are very low, not to say absent. Some criticisms of the assumptions in Morrison's model (1987) can be addressed.

First, it is surprising that a public authority choice for a pricing rule does not consider passengers' utility. Moreover, such an objective function must also take into account the fact that congestion exists and that it has a cost (private and social cost). For simplicity, we do not introduce the period along which the flight is operated: our model is a model of congestion pricing, not a model of peak-load pricing.

In our new model, passengers are introduced by vertical relationship. The upstream firm is the ATC provider, the downstream industry is made up of airlines and final consumers are passengers. Then, before maximising the ATC objective function, we must observe what is happening on the final market. Vertical relations are also a solution to another assumption of Morrison's model. The demand elasticity of airlines is assumed to be exogenous, since airlines are supposed to pass cost increases on ticket prices. But by modelling vertical relations, the demand elasticity of airlines can be deduced by the demand elasticity of passengers.

Studying competition between airlines leads us to observe how airlines make their choices of prices and number of flights relative to passenger demand. We choose to model this price and number of flights competition in the context of a duopoly competition. This imperfect competition amounts to the present tendency in Europe and in the US: an oligopolistic air transport industry.

The conclusions of Morrison's model come essentially from the assumptions that small aircraft and short flights have a high price elasticity, while large aircraft and long flights have a low price elasticity. It is a common simplification that ATC authorities also make. But since liberalisation, airline strategies have changed. The division between large aircraft and long-distance flights associated with national airlines on the one hand, and small aircraft and short-distance flights associated with minority airlines on the other hand does not hold anymore. Now, airlines use discriminatory pricing corresponding to "Yield Management": flight revenues are maximised by adjusting prices and the capacities of different passenger classes. The revenue an airline can extract from its passengers depends mainly on the respective proportion of business travellers and tourists. There is no reason to assume that that proportion differs according to the distance or to the size of the aircraft.

3.2. Vertical relations and the duopoly model

We consider the following sequential game between the ATC authority and two airlines:

(1) The ATC authority determines a pricing rule;
(2) Knowing this pricing rule, the two airlines choose the number of flights in operation:[7] f_1 and f_2;
(3) Ultimately, the two airlines choose the prices to be paid by passengers: p_1 and p_2.

Let us suppose that there exists a representative passenger whose utility depends on the number of seats supplied by the two airlines (q_1 and q_2) and on the flight frequencies of the airlines. For simplicity we choose a quadratic utility function. We assume also that the representative passenger evaluates the quality of the air transport services by the square root of the frequencies.[8] The demand functions addressed to the two airlines are determined by maximising the representative passenger utility under its budget constraint (the revenue of the representative passenger R is assumed to be exogenous):

$$\begin{cases} \underset{q_1, q_2}{\text{Max}}\ U(q_1, q_2, F_1, F_2) = \gamma q_1 + \gamma q_2 - \alpha \dfrac{q_1^2}{2} - \alpha \dfrac{q_2^2}{2} \\ \qquad\qquad - \beta q_1 q_2 + \sigma q_1 F_1 + \sigma q_2 F_2 \\ \text{s.t.} \quad p_1 q_1 + p_2 q_2 \leq R. \end{cases} \tag{6}$$

By solving this expression one obtains the air transport demand functions:[9,10]

$$d_i(p_i, p_j, F_i, F_j) = A - ap_i + bp_j + cF_i - dF_j. \tag{7}$$

[7]Number of flights will be called "frequencies".
[8]$\sqrt{f} = F$.
[9]With: $A = \frac{\gamma}{\alpha+\beta}$, $a = \frac{\alpha}{\alpha^2+\beta^2}$, $b = \frac{\beta}{\alpha^2+\beta^2}$, $c = \frac{\sigma\alpha}{\alpha^2+\beta^2}$, $d = \frac{\sigma\beta}{\alpha^2+\beta^2}$. Note that $ad = bc$.
[10]We have either $i = 1$ and $j = 2$ or $i = 2$ and $j = 1$ for the whole of the model.

Note that the utility function describe in (6) includes no specific preference of the representative passenger for one airline. Assuming that this utility function is concave leads to two conditions:

$$a^2 > b^2 \quad \text{and} \quad a > 0.$$

It means that direct effect of the price p_i on the demand d_i is greater than the indirect one and that goods are normal.

The airlines are defined by aircraft capacity (k seats) and by their costs. In order to simplify the model, we suppose that variable costs corresponding to the number of passengers are zero. The total cost $W(k)$ for one flight has two components. The first one is the ATC fee (ω). The second element is a capacity cost ($z(k)$). Its derivative with respect to k is positive. It means that large aircraft have operating costs greater than small ones because the leasing cost (or opportunity cost of buying an aircraft), the crew, and the fuel for a large aircraft are heavier than for a small one.

Two cases exist: either airlines have an over-capacity or the capacity constraint is binding. Given that those cases are for the fleet taken as a whole, we can remove one of them. On average in 1999 the passenger load factor of the scheduled traffic of the AEA[11] members was 70.8 per cent. So we will study only the case with a demand inferior to the total number of available seats.

We are looking for the sub-game perfect equilibrium of the game described above. We use the backwards induction method: assuming the previous actions as given, we are looking for the optimal reaction of the two airlines at one stage. First, we define an equilibrium of the game at the third step, by solving the two airlines' programmes with respect to their own price. Given the passenger demand, an airline's programme is to maximise its profits. Then we replace the computed equilibrium price, as a function of frequencies, in the profit functions. Solving the game at the third stage where the profits are given by:

$$\Pi_i(p_i, p_j, F_i, F_j, k) = p_i(A - ap_i + bp_j + cF_i - dF_j) - W(k)F_i^2, \tag{8}$$

one obtains the equilibrium prices:

$$p_i^*(F_i, F_j, k) = \frac{(2a+b)A + (2ac - bd)F_i - adF_j}{4a^2 - b^2}. \tag{9}$$

Note that $\partial p_i^*/\partial F_i > 0$ and $\partial p_i^*/\partial F_j < 0$, for $i \neq j$. When an airline increases its frequencies, it raises also its price. On the other hand, when one airline

[11]AEA: Association of European Airlines.

increases its frequencies, the other cuts its price, in order to counterbalance a decrease in demand due to the fact that passengers are attracted by more frequencies.

Having obtained the equilibrium prices, we go back to the second stage, which corresponds to the choice of frequencies supplied. The new programme is:

$$\underset{F_i}{\text{Max}}\ \Pi_i(F_i, F_j, k) = a\left(\frac{(2a+b)A + (2ac - bd)F_i - adF_j}{4a^2 - b^2}\right)^2 - W(k)F_i^2, \quad (10)$$

and the equilibrium frequencies[12] follow:

$$F_i^*(k) = F_j^*(k) = \frac{aA(2a+b)(2ac-bd)}{(4a^2-b^2)^2 W(k) - a(2ac-bd)(2ac-bd-ad)}. \quad (11)$$

The equilibrium frequencies depend on the model parameters and on the total cost per flight. They decrease with the latter, but the form of $W(k)$ is still unknown. In order to determine what $W(k)$ would be and more precisely what would be the component $(\omega(k))$ of the total cost $(W(k) = \omega + z(k))$, we compute the frequencies that would occur under the maximisation of the social surplus. The value of ω for which the welfare maximising frequencies are equal to the previous equilibrium frequencies will thus be retained. The social surplus is the sum of the passengers' utility, the firms' profits, including the ATC provider, and the congestion costs, with an obvious negative sign. Let H be the marginal cost of the ATC provider for one flight and δ the external cost by flight. The social surplus is given by:

$$\begin{aligned} S(F_1, F_2) = {} & \frac{A}{a-b}(q_1 + q_2) - \frac{a}{a^2-b^2}\left(\frac{q_1^2}{2} + \frac{q_2^2}{2}\right) - \frac{b}{a^2-b^2}(q_1 q_2) \\ & + \frac{c}{a}(q_1F_1 + q_2F_2) - (z(k) + H + \delta)(F_1^2 + F_2^2). \end{aligned} \quad (12)$$

We replace q_1 and q_2 by their equilibrium values and we equalise the derivatives of S with respect to F_1 and F_2 to zero. Then, the optimal frequencies are:

$$\begin{aligned} \hat{F}_i(k) &= \hat{F}_j(k) \\ &= \frac{aA(2a+b)(6ac-2bd-ad)}{2(4a^2-b^2)^2(z(k)+H+\delta) - a(6ac-2bd-ad)(2ac-bd-ad)}. \end{aligned} \quad (13)$$

[12]The flights supplied by firms 1 and 2 are substitutable, so frequencies are strategic substitutes whereas prices are strategic complements.

By equating $F_i^*(k)$ and $\hat{F}_i(k)$, given by the equations (11) and (13), and using ($W(k) = \omega + z(k)$), we obtain the optimal ATC fee:

$$\hat{\omega}(k, H, \delta) = \frac{-a(2c - d)z(k) + 2(2ac - bd)(H + \delta)}{6ac - 2bd - ad}. \tag{14}$$

We thus obtain the main result: the optimal ATC charges are a decreasing function of the capacity k. Moreover,

$$W(k) = \hat{\omega}(k, H, \delta) + z(k) = \frac{2(2ac - bd)(z(k) + H + \delta)}{6ac - 2bd - ad}. \tag{15}$$

The function $W(k)$ is increasing in k and the frequencies given by equation (11) are decreasing in k. So the equilibrium frequencies that decrease with the total cost decrease also with the capacity. There thus exists a trade-off between the number of available seats and the number of flights. It means that either airlines supply frequent flights with small aircraft or they operate less frequent flights with larger aircraft. Consider two pairs made of a capacity k and a number of flights supplied F, such that the number of available seats for the whole fleet is the same for the two. The airline with the smallest k (and so with the largest F) receives more revenues than another with the opposite because of the increasing passenger demand with frequencies, and its capacity cost is smaller than the other since it increases with k. So operating few frequencies on large aircraft is costly, due to lower revenues and higher capacity cost. As if to reward airlines with large aircraft and less frequent flights, the ATC authority offsets part of those higher costs. So airlines pay less to the ATC provider because they have less frequencies, and the cost for a large aircraft is smaller than for small aircraft.

Frequencies can be seen as the demand function from the airlines to the ATC provider. The fact that equilibrium frequencies decrease with the ATC fees means that the ATC is a normal good for airlines: when price increases, ATC demand decreases.

We can also note that the higher the ATC costs and the congestion cost are, the higher must be the optimal ATC charges. The pricing rule depending on δ leads to an "internalisation" of the external cost by the airlines.

3.3. Analyses and critiques

This model gives new features for the components of an optimal ATC pricing rule. It deals essentially with two of them. An authority pricing aim is to create incentives that induce optimal decisions from agents.

First, the weight of the aircraft must not reinforce its negative effect on total cost. Passengers like a high level of frequencies, as demand increases with the number of flights, but the greater the frequencies, the more flights are delayed, and delays are costly. So the ATC authority has to introduce a pricing rule inversely proportional to the aircraft size.

Second, faced with the congestion externalities, the ATC authority introduces incentives that lead airlines to consider the high level of traffic. By including congestion cost in the pricing rule, airlines will "internalise" the negative effect of too many frequencies on the total social surplus when they determine which level of frequencies to implement.

Nevertheless, other components of usual pricing are not considered here. In the electricity or telecommunication industries, when a firm tackles a periodic congestion problem, namely that numerous users consume the good at the same time every day, discriminatory pricing is introduced: peak load pricing. Models of congestion pricing have already been widely studied for transport. The seminal papers are Vickrey (1969) and Arnott, De Palma and Lindsey (1993). Including time periods in the ATC pricing model could be the subjects of future research. Some airports have already introduced peak and off-peak prices.

Distance is also part of the model. We saw that the distance variable in the present pricing rule can be justified in two ways. One is the same as the weight argument. We said that the assumption that airlines' demand elasticity for ATC is inversely correlated to the flight distance and the aircraft weight does not hold any more. In the new model thatdeparted from this assumption, we do not find distance. But it might be possible that distance remains in the pricing rule due to the second reason: the distance variable is a proxy of the ATC output. Although this indicator is not the best one, it is the easiest on which to collect data and the one that is less biased.

Another indicator of output could be the controlled time required by each flight. The more the speed increases, the less an aircraft is controlled in time. Fast aircraft can reduce congestion and allow more flights to be controlled over a given period. But in the presence of several aircraft with different speeds, those disparities in speeds do not reduce the necessary level of control. So fast aircraft, although they require shorter control times, make the work of controllers more difficult.

4. Concluding Remarks

This article gives first the motivations that were at the origin of the present European ATC pricing rule. Since it was established, things have changed and the European ATC providers are faced with numerous delayed flights. With a new context for air transport, the aim of ATC pricing has to be reconsidered and to take into account the congestion problem.

Reversing the way aircraft weight influences ATC pricing and introducing congestion costs in the ATC pricing rule appear an efficient means to improve the social surplus and tackle the congestion problem. The risk is that such a rule may be unpopular since large aircraft and long-distance flights are commonly associated with national airlines and small aircraft and short-distance flights with minority airlines.

Future research could be on the definition of a more precise indicator of the ATC output. Research on other pricing models could also be useful to complete the proposal of a new pricing rule made in this article: models with peak-load pricing or with asymmetry of information, for instance.

Auction models can also be considered to validate previous models. Due to network externalities in the air transport industry, as in the telecommunication industry, the American FCC spectrum auctions could be a good example to allocate a scarce resource: the civil upper space.

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