ACCHANGE: Building Economic Models for Understanding ATC Performance

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***Abstract* — The aim of this paper is to develop a simple economic model that allows us to understand current deficiencies in Air Traffic Control performance. Our model fits within the traditional theory of regulation (surveyed in Laffont & Tirole (1993)), often applied to public utilities in a monopoly position. The model helps to study the implications of the incentive mechanisms that have been implemented in the SES II regulation.**

We find that a change from cost-plus regulation towards price-cap regulation can lead to efficiency improvement. This is the case if the price-cap is effective and the ANSPs act as private profit-maximizing firms, rather than as government controlled entities which maximize a weighted sum of national interests. When ANSPs are able to invest in capacity and are exposed to traffic risk, they will increase their capacity with stronger demand elasticity and if there is more congestion/delay. We further find that capacity is increasing with the degree of traffic risk, with the airline demand and with the ANSP profit margin. Our model also predicts that a regulator with a national perspective has a preference towards a cost-plus regulatory regime, whereas a regulator with a European scope has a stronger drive to push for a price-cap regulation.

We complement our theoretical derivations with a numerical illustration.

Keywords-Economic modelling, pricing, regulation

I. INTRODUCTION AND LITERATURE REVIEW

The cost of providing air navigation services is perceived as relatively high and there are large differences in labour productivity between different national Air Navigation Service Providers (ANSPs) [11]. Furthermore, there is a relatively low degree of equipment standardization, slow adoption of new technologies and little cooperation between various national ANSPs [15].

The aim of this paper is to develop simple economic models that allow us to understand current deficiencies in Air Traffic Control performance. The models are used to explore effects of alternative regulations and institutional frameworks on the provision of air navigation services in Europe.

We start from the standard economic public utility model which explains the interaction between a regulator and a private firm subject to economic regulation. This economic public utility model is summarized in [9]. The efficiency model puts attention to the information disadvantage that the regulator faces in comparison to the regulated entity, and to the regulatory frameworks that a regulator can use to impose performance incentives on the firm. In general, the approach is to set a price-cap more or less equal to the average of the estimated cost level of the firms in the industry. Firms are then accountable for cost overruns beyond the price cap and could keep benefits from performing more efficient than the price cap. This regulatory approach is also called yardstick competition [13]. However, when there is large heterogeneity in the operational practice or in the kind of products and services that the firms provide, benchmarking and the application of yardstick competition become more difficult.

The public utility model of [9] has been extended by [3]. They provide a theoretical framework to explain how inefficiency can arise from a bargaining game between labour union and firm. A regulator can afterwards give performance incentives to the firm's managers such that they invest effort to become more efficient. [4] has developed the public utility economic framework in another direction. They model how campaign contributions by special interest groups can shift regulatory or government objective functions towards the goals of the interest groups.

We use this theoretical economic framework and apply it to the situation of air navigation service provision in Europe. This environment shares a lot of the characteristics of the public utility model. There is a service provider (the ANSP) whose goal it is to provide services of public interest, subject to a certain regulation on his price (the ANSP charges). The application of yardstick competition is difficult in the ANSP context given the strong heterogeneity in airspace networks and operational practice. In addition, there is some evidence that labour interest groups can achieve above market conditions leading to a certain degree of operational inefficiencies. Moreover, lobby groups (for example national manufacturers of ANSP equipment) defend their interests with the government. At the same time, the ANSP activities are in many countries strongly controlled by governments.

We also address the issue of delays which are caused by en-route air traffic flow management. ANSPs can improve the level of service they offer by reducing the amount of delays. We develop this idea using a simple bottleneck model [1]. Our approach is similar to the one developed by [12] who proposes a price increase in ANSP charges in congested areas.

This paper starts with a presentation of the economic agents involved and their objectives. In chapter 3 we outline the model. We first develop the theoretical framework and discuss the main insights. Next, we provide numerical illustrations to explain some of the mechanisms behind the theory and show the practical relevance.

II. Economic agents and their objectives

The model focusses on the interaction between ANSPs and the regulator. The following paragraphs describe the objective functions for both actors.

A. Air navigation service providers

A typical (regulated) firm is often seen as a profit maximizing entity. However, an ANSP cannot be understood as a traditional profit maximizing firm. Airline policy makers usually consider the role of ANSPs to be (at least partly) providing public utility services. This is represented in the governance structure of air navigation service providing entities. ANSPs are sometimes directly controlled by governments. It also happens that stakeholders such as airport or airline representatives are represented at the ANSP board of directors. For this reason, we specify the ANSP objective function as mixed, consisting partly of profits, but also of ANSP consumer interests. These are the benefits that airports, airlines and ultimately the airline passenger derive from air navigation services. In addition to this, we also include a 'national interest' component in the ANSP objective function. This component follows from the fact that ANSPs are often strongly/partly controlled by governments who can have other 'national objectives' in mind. We think, for instance, about national equipment manufacturers.

Thus, we express ANSP objectives as a mixed goal function with a weight parameter γ_1^{ANSP} on the maximization of consumer surplus and a weight parameter γ_2^{ANSP} on the maximization of profits (π). Thirdly, we include a national interest component, which we specify further in our model, with weight γ_3^{ANSP}. National interests could take the form of national manufacturers who lobby the ANSP (partly controlled by the government) for selling equipment to them. It could also take the form of national labour unions who lobby for excess employment or higher wages[1].

We specify the ANSP objective function as an additive form, following the approach of [4]:

$$Goal_{ANSP} = \gamma_1^{ANSP} \cdot Cons\ Surplus + \gamma_2^{ANSP} \cdot \pi_{ANSP} + \gamma_3^{ANSP} \cdot Nat\ Interests \tag{1.1}$$

B. Regulator

ANSPs have a natural monopoly for a given territory and an obligation to provide a certain level of air traffic management services within that territory. A regulatory body decides on price regulation and how to monitor quality of service. In the SES II performance regulation approach [16], quality of service is measured in terms of safety, environmental performance and capacity provision (to prevent delays).

ANSP regulators have an interest in the following elements:

- Consumers who benefit from the services of ANSPs. The end consumers are the airline passengers; the direct consumers are the airlines themselves. Local airports will also benefit from efficient air traffic management.
- Profits of the ANSPs.
- Air traffic controllers and other ATC personnel, represented by their unions: they want higher than competitive wages, job security and sufficient personnel.
- Suppliers of ATC equipment: they want to sell at good price and have demonstration projects to be able to sell abroad.

The regulator is hence influenced by similar actors as the ANSP. Therefore, we express the objective function of a regulator as a similar, mixed goal function of consumer surplus, ANSP profits and national interests. However, the relative weights in this function γ_1^{REG}, γ_2^{REG} & γ_3^{REG} could be different from the ANSP weights:

$$gf_{REG} = \gamma_1^{REG} \cdot Cons\ Surplus + \gamma_2^{REG} \cdot \pi_{ANSP} + \gamma_3^{REG} \cdot Nat\ Interests \tag{1.2}$$

p

The objectives of an economic regulator are often more pro-consumer[2] and less profit oriented than the objective of the ANSP. Therefore we expect that:

$$\gamma_1^{REG} > \gamma_1^{ANSP}$$

$$\gamma_2^{REG} < \gamma_2^{ANSP}$$

[1] This idea can be pursued in a union bargaining model.

[2] See for example [14]

III. Theoretical Framework

The traditional regulation theory or 'inefficiency model' embodies the idea that there is a relation between the efficiency of air navigation service provision and the type of regulation on ANSP charges. The main focus of the model is on the informational disadvantage of the regulator. He has imperfect information on the cost of service provision, but he adjust price regulation to provide performance incentives for the regulated entity.

A. *Cost and information in traditional regulation theory*

The classic assumption of the traditional regulation model is that production costs can be broken down in three components: an observable cost, a stochastic and unobservable cost (which can be higher than expected or lower than expected) and an unobservable cost reduction, ensuing from managers' efficiency effort. We follow this approach and assume a simple expression for the ANSP cost per flight, consisting of three components:

- There is a fixed observable ANSP cost per flight a.
- The stochastic parameter θ is an efficiency parameter that is imperfectly observable and affects the ANSP cost per flight. The stochasticity reflects the fact that it is difficult to apply ANSP benchmarking and use yardstick competition[3]. This is related to differences in national airspace characteristics, differences in equipment used at ATC centres, etc.
- The ANSP can invest in technologies or implement measures to improve the efficiency of air navigation service provision. The efficiency improvement is represented by e and is also imperfectly observable. We assume that one unit of 'efficiency effort' corresponds to one unit of increased efficiency, equivalent to a decrease in average operating cost for air navigation services by one euro per flight.

Thus, we obtain the following expression for ANSP cost per flight kilometre:

$$c = a + \theta - e \tag{1.3}$$

For the management and personnel of the ANSP, the effort is costly in terms of stress, longer hours etc. We represent this cost as a quadratic function *Cost*(e). This means that exerting more efforts becomes increasingly costly. We further assume that the costs are higher for larger ANSPs, so we include the demand parameter D to represent the scale of operations:

$$Cost(e) = D \cdot \frac{\emptyset \cdot e^2}{2}$$

[3] This is the regulatory technique that consists in comparing performance between ANSPs and setting performance/price targets based on this comparison.

The rationale behind the convex shape of the cost function is that disutility is increasing in the amount of effort to be realized. The idea is that minor changes to current operational practice can be acceptable whereas more radical changes incur more resistance.

B. *Optimal regulation in case of perfect and imperfect information*

We investigate the decision of a regulator who has the objective to maximize consumer interests and ANSP profits. This boils down to the minimization of total expected societal costs, equal to:

$$E\big(D \cdot c + Cost(e)\big) = E\left((a + \theta - e) \cdot D + D \cdot \frac{\emptyset \cdot e^2}{2}\right)$$

In the case of perfect information, the regulator can simply choose to set the optimal amount effort e which balances the cost reduction and the cost of effort effects:

$$e^* = 1/\emptyset$$

But as effort is not observable, imposing a given effort level is not feasible. Feasible is to reward the ANSP for good performance with respect to cost containment. This depends on the price regulation for ANSP charges. The two extreme forms of regulation are a cost-plus regime and a regime with a price-cap (or a fixed price).

Under a cost-plus regulation, the ANSP charges are equal to the actual costs divided by actual traffic; plus a cost mark-up which allows air navigation service providers to make a small profit margin[4]. So charges are determined ex-post as a function of economic outcomes. In this case, there is no reward for extra efforts and management will choose $e = 0$. Costs will fluctuate with the stochastic element and will on average be high as there is no incentive to supply a lot of efforts:

$$p_{cost+} = \frac{Tot\ Cost}{D}$$

Another extreme form of price regulation is a pure price-cap. In this case, the regulator estimates ANSP costs $E(TotCost)$ ex-ante and determines the price-cap based on this. In the context of the SES II regulation, the price-cap is equal to the determined costs[5]. ANSPs cannot recover any costs that exceed the determined costs level. If costs are below the target, ANSPs can keep the difference. This is the so-called 'cost risk' to which ANSPs are exposed following the introduction of SES II regulation.

The regulator also estimates the amount of airline traffic in the ANSP airspace $E(D)$. The ANSPs can try to attract extra traffic to increase revenues. This is the so-called 'traffic risk' in SES II regulatory package.

[4] We will further normalize the profit margin to zero.

[5] The 'determined costs' are those costs that ANSPs are allowed to recover. The cost level is set for a five year period (Reference Period 1) and will be adjusted after five years (Reference Period 2) [7].

We can write the ANSP charge under a price-cap regulation as:

$$p_{cap} = \frac{E(Tot\ Cost)}{E(D)}$$

Implementing a price-cap looks obvious but faces some specific difficulties in practice:

a) Determining the price-cap: a public utility regulator cares about the price level for the consumer and so he faces the difficult task to find a low enough p_{cap} such that the ANSP manager still chooses to participate in the game.

b) Guaranteeing sufficient quality: if the ANSP can save costs (increase profits) by reducing quality it will do so.

c) Ensuring costs and prices keep decreasing over time without losing the incentive. ANSPs may fear a ratchet effect [6] by the regulator that keeps tightening the price-cap.

We believe that current ANSP charges are driven by a price regulation which contains elements of both price-cap and cost-plus regulation, even though the regulation for ANSP charges is in principle based on a price-cap system since the implementation of SES II regulation:

- Weak enforcement can make a price-cap system look much like a cost-plus regulation. It is possible that governments actually start subsidizing ANSPs in the presence of a stringent price-cap for the costs that they cannot recover. In such an event the regulatory framework boils down to a nominal price-cap but a cost-plus system in practice.
- Price-caps are revised from time to time. As price-caps are revised more often, ANSPs will recognize this and the incentives that the regulatory system provide will again become much like cost+ regulation.
- Price regulation on ANSP charges in Europe used to be more cost-plus oriented and are now in principle more price-cap oriented. However, the actual costs will only gradually change between the two systems. So current charges may still largely reflect the cost-plus setting.

To allow for a mixed price system, we introduce the parameter B which presents the extent to which a proposed regulatory framework is more like a cost+ approach (B=1) or rather like a price-cap approach (B=0):

$$\begin{aligned} p_{charge} &= (1-B)\cdot p_{cap} + B\cdot p_{cost+} \\ &= (1-B)\cdot\frac{E(Tot\ Cost)}{E(D)} + B\cdot\frac{Tot\ Cost}{D} \end{aligned}$$

We will further use expression (1.3) on the actual ANSP cost per flight to simplify this expression:

$$p_{charge} = (1-B)\cdot\frac{E(Tot\ Cost)}{E(D)} + B\cdot(a+\theta-e) \qquad (1.4)$$

When we represent p_{charge} as a function of efficiency e, we find:

$$p_{charge}(e) = A + B\cdot c(e) \qquad (1.5)$$

In this expression, A is equal to $(1-B)\cdot\frac{E(Tot\ Cost)}{E(D)}$ and hence does not depend on efficiency e.

C. *Analysis*

This model allows a comparison of alternative price setting regimes. The first two sections discuss the behaviour of the ANSP. Next, we consider the regulator's choice between different types of regulations given the reaction functions of the ANSPs.

1) The effect of regulation (Cost-plus vs. price-cap) on ANSP costs

We derive the optimal price regulation on ANSP charges under fixed demand $\bar{D}$. ANSP charges are effectively set by the regulator under the SES II regulation, equal to determined costs. Actual ANSP revenues can, however, still depend on the efficiency as long as the price-cap is imperfectly enforced $(B \neq 0)$. For instance, governments could end up partly compensating under-performing ANSPs through subsidies.

We derive an expression for the ANSP efficiency effort as a function of the regulation on ANSP charges (with parameter B representing the effective power of the price-cap). We start from the ANSP objective function, which is based on expression (1.1). The ANSP board can choose how much effort to invest in increasing operational efficiency. They use this decision variable to optimize their goal function:

$$\underset{e}{Goal_{ANSP}} = \gamma_1^{ANSP}\cdot\bar{D}\cdot\left(p_{max} - p_{charge}(e)\right) + \gamma_2^{ANSP}\cdot\bar{D}\cdot\left(p_{charge}(e) - c(e)\right) - \left(\gamma_2^{ANSP} + \gamma_3^{ANSP}\right)\cdot\bar{D}\cdot\frac{\emptyset\cdot e^2}{2}$$

Notice that we have set the importance of national interests proportional to the cost of efficiency effort:

$$\gamma_3^{ANSP}\cdot Nat\ Interests = -\gamma_3^{ANSP}\cdot Cost(e) = -\gamma_3^{ANSP}\cdot D\cdot\frac{\emptyset\cdot e^2}{2}$$

The underlying assumption is that national interest groups put an additional difficulty on realizing efficiency improvements. National interest increases the disutility component of the effort cost. One can think of labour groups who oppose measures to make productivity increase or national manufacturing interests which lead to non-standardized and sub-optimal use of equipment. The parameter γ_3^{ANSP} measures the extent of this effect.

The ANSP decides on efficiency effort depending on the effective power of the price-cap:

$$e^* = \frac{\gamma_2^{ANSP} + B\cdot\left(\gamma_1^{ANSP} - \gamma_2^{ANSP}\right)}{\left(\gamma_2^{ANSP} + \gamma_3^{ANSP}\right)\cdot\emptyset} \qquad (1.6)$$

In case of a pure price-cap (B=0), the expression reduces to:

$$e^* = \frac{\gamma_2^{ANSP}}{(\gamma_2^{ANSP} + \gamma_3^{ANSP}) \cdot \emptyset}$$

The ANSP efficiency effort is increasing in profit-orientation γ_2^{ANSP}, decreasing in the importance of national interests γ_3^{ANSP} and in the cost of efficiency effort $\emptyset$. This expression further shows that ANSP efficiency effort is higher under a price-cap regime (B=0) than under a cost-plus regulation (B=1), under the condition that ANSPs attach more importance to ANSP profit than to consumer surplus $(\gamma_1^{ANSP} < \gamma_2^{ANSP})$.

What happens to ANSP charges? Let us evaluate what happens to expression (1.4) when the power of the price-cap increases (B↓). In case of a pure price-cap, (B=0) and charges are equal to determined costs divided by traffic volumes. When (B≠0), we learn from equation (1.6) that efficiency improves with the power of the price cap. Adding this to the decreasing tendency in determined costs, we obtain that charges for air navigation services p_{charge} decrease with the power of the price-cap (B↓).

2) The effect of 'traffic risk' on ANSP quality of service

We also evaluate the importance of the traffic risk element as introduced in the SES II regulations. For this, we have to leave the assumption of fixed demand $\bar{D}$. ANSPs can improve the quality of the air navigation services that they provide in order to attract more traffic to their charging zone. We operationalize this concept in our model by making demand dependent on (expected) delays and congestion in the charging zone. In their route plans, airlines tend to avoid airspace sections with a lot of en-route ATFM delays if they can. Thus, by investing in ATFM capacity and thereby reducing delays, ANSPs can effectively attract more traffic. ANSPs thus have an additional decision variable at their disposal, ATFM capacity *cap*, which they can use to optimize their objective function[6]:

$$\underset{cap}{Goal_{ANSP}} = \gamma_1^{ANSP} \cdot D(cap) \cdot (p_{max} - p_{charge}) + \gamma_2^{ANSP} \cdot D(cap) \cdot (p_{charge} - c) - (\gamma_2^{ANSP} + \gamma_3^{ANSP}) \cdot C(cap)$$

As specified in the SES II regulation, ANSPs are allowed to keep a share from the profit that they can make by attracting more traffic than expected. We represent this share by $TR \in [0,1]$. We assume for simplicity that ANSPs act as profit-maximizing agencies[7] $(\gamma_1^{ANSP} = 0, \gamma_2^{ANSP} = 1, \gamma_3^{ANSP} = 0)$ and obtain the following ANSP goal function:

$$\underset{cap}{Goal_{ANSP}} = TR \cdot D(cap) \cdot (p_{charge} - c) - C(cap) \quad (1.7)$$

We express congestion by the following equation, with δ as a congestion parameter:

$$CG(cap) = \frac{\delta}{cap}$$

Capacity cost is equal to:

$$C(cap) = Z \cdot cap$$

The optimal capacity decision is then given by:

$$cap^* = \frac{(av\ flightkm/flight) \cdot \delta}{(av\ pass/flight)^2 \cdot coef}\left(-1 + \sqrt{\frac{TR \cdot (p_{charge} - c)\left((av\ pass/flight) \cdot p_{max} - OC - p_{charge}\right)}{(av\ flightkm/flight) \cdot \delta \cdot Z}}\right) \quad (1.8)$$

In the expression:

- *coef* is a demand parameter with a lower *coef* representing stronger demand elasticity.
- *OC* is the operating cost per flight

For a full derivation of this expression, we refer to the working paper.

We learn that optimal capacity is higher for stronger demand elasticity and for a stronger congestion effect. We further see that capacity is increasing with the square root of the traffic risk parameter *TR*, the square root of a mark-up for ANSPs per flight kilometre served $(p_{charge} - c)$ and the square root of a term which represents the strength of airline demand $\left((av\ pass/flight) \cdot p_{max} - OC - p_{charge}\right)$. Capacity is lower for a higher capacity cost *Z*.

3) Regulator's choice between different types of regulation

We also calculate which type of price regulation a regulator prefers depending on his objectives. For this, we optimize the regulatory objective function. For simplicity, we again assume a fixed demand $\bar{D}$:

$$\underset{B}{Goal_{ANSP}} = \gamma_1^{REG} \cdot \bar{D} \cdot \left(p_{max} - p_{charge}(e(B))\right) + \gamma_2^{REG} \cdot \bar{D} \cdot \left(p_{charge}(e(B)) - c(e(B))\right) - \gamma_3^{REG} \cdot \bar{D} \cdot \frac{\emptyset \cdot e(B)^2}{2}$$

Taking into account the ANSP reaction function, which we derived earlier:

6 We express the dependency of demand on ATFM capacity by *D*(*cap*) while *C*(*cap*) represents capacity cost.

7 Essentially, our results hold under the assumption that the ANSP puts less weight on consumer benefits than on its own revenues.

$$e^* = \frac{\gamma_2^{ANSP} + B \cdot (\gamma_1^{ANSP} - \gamma_2^{ANSP})}{\gamma_3^{ANSP} \cdot \emptyset}$$

The expression for the optimal B depending on the regulatory objectives is given by the following expression:

$$B^* = \frac{\gamma_2^{Reg} \cdot (1+\gamma_3^{ANSP}) - \gamma_2^{ANSP} \cdot (\gamma_2^{Reg} + \gamma_3^{Reg})}{(\gamma_2^{Reg} - \gamma_1^{Reg}) \cdot (1+\gamma_3^{ANSP}) - (\gamma_2^{Reg} + \gamma_3^{Reg}) \cdot (\gamma_2^{ANSP} - \gamma_1^{ANSP})} \quad (1.9)$$

We learn that the regulatory choice on the type of price regulation depends on his preferences with respect to consumer surplus (γ_1^{Reg}) ,ANSP profit (γ_2^{Reg}) and labour/ national interests (γ_3^{Reg}) . On the other hand, the regulatory choice also depends on his perception of the objectives of the regulated ANSP: with respect to consumer surplus (γ_1^{ANSP}), profit-making γ_2^{ANSP} and labour/national interests (γ_3^{ANSP}) .

We study a number of special cases to gain insight into the mechanisms that govern regulatory choice. We simplify the expression and assume that the regulator perceives the ANSP as a profit-making entity $(\gamma_1^{ANSP} = \gamma_3^{ANSP} = 0)$ & $(\gamma_2^{ANSP} = 1)$. We then obtain the following expression for $B*$ which shows that the regulator prefers a stronger price-cap as he puts more weight on consumer interests (γ_1^{Reg}) and less weight to national interests/interest groups (γ_3^{Reg}) :

$$B^* = \frac{\gamma_3^{Reg}}{\gamma_3^{Reg} + \gamma_1^{Reg}}$$

We compare the preference on the regulatory regime between a national regulator and a regulator with a European scope. Lobbying theories, such as papers related to [4] and political decision making theories (surveyed in [2]) tell us that national and European regulators will pursue different objectives. A national regulator only cares for part of the consumer surplus, namely the consumer surplus for domestic airspace users: domestic passengers, home carriers and airports. A national regulator will be much less motivated to defend the interests of transit passengers and transit carriers. On the other hand, a regulator with a European scope has a broader perspective and also takes the interests of transit passengers and airlines into account. This entails that:

$$\gamma_1^{Reg\ NATIONAL} < \gamma_1^{Reg\ EU}$$

We also expect that a European regulator will be somewhat more independent from national labour interests than a national regulator. Therefore, we can write that:

$$\gamma_3^{Reg\ NATIONAL} > \gamma_3^{Reg\ EU}$$

Our formulation predicts that a national regulator will have a preference that is more oriented towards a cost+ regime and a European regulator has a preference that is more price-cap oriented:

$$B_{EU}^* < B_{NAT}^*$$

This observation can possibly explain the shift from a more cost-plus oriented regulation on ANSP charges in a European ATM context which was dominated by nation states, towards a price-cap regulatory approach in a more integrated European governance for air traffic management.

IV. NUMERICAL ILLUSTRATIONS

Our aim in this section is to illustrate the traditional regulation theory using data from the European air traffic management sector. We focus on modelling and understanding the effects of the incentive mechanisms which have been introduced in the SES II regulatory package: cost risk and traffic risk. Cost risk is introduced by setting expected costs ex-ante ('determined costs') and allowing ANSPs to achieve profitability when they succeed in outperforming the expected cost level. Traffic risk is introduced because ANSPs are allowed to keep part of the profit they make by attracting surplus flights to their charging zone.

1) Price-cap vs. cost-plus regulation and 'cost risk'

We use expression (1.6) to demonstrate the expected effect of cost risk on ANSP decision-making:

$$e^* = \frac{\gamma_2^{ANSP} + B \cdot (\gamma_1^{ANSP} - \gamma_2^{ANSP})}{\emptyset \cdot (\gamma_2^{ANSP} + \gamma_3^{ANSP})} \quad (1.10)$$

Notice that this expression reduces to the simple expression that we obtained before in case of a price-cap (B=0), profit-maximization objectives $(\gamma_2^{ANSP} = 1)$ and no importance for national interests ()$(\gamma_3^{ANSP} = 0)$:

$$e^* = \frac{1}{\emptyset}$$

We now illustrate with an example how varying objectives, national interests and power of price regulation can shape ANSP operational efficiency. We take the example of centralized services, because we consider this as a good example of a potential efficiency improvement at European scale which could incur resistance from national interests. Eurocontrol has estimated the potential efficiency improvement of centralized service provision at around 200 million € per year. In comparison to around 8 billion € in ANSP costs per year, this represents a cost reduction of 2.5%.

We use data from [10] to calculate For simplicity we round up the average ANSP charge at 1€/flightkm. The reduction of 2.5% in ANSP charges from centralized services thus amounts to e*=0.025. Using this, we can derive a value for $\emptyset = 40$.

We now explore the actual efficiency improvement from the introduction of centralized services. We assume as a benchmark case the situation of a pure price-cap (B=0), profit-maximization objectives $(\gamma_2^{ANSP} = 1)$ and no weight on national interests $(\gamma_3^{ANSP} = 0)$. We can further explore the efficiency improvement under different parameter values.

When we set $\gamma_1^{ANSP} = 0.5$, $\gamma_2^{ANSP} = 0.5$ and $\gamma_3^{ANSP} = 0.1$, we obtain an efficiency improvement of around 2% instead of the 2.5% which is possible in the 'ideal situation without national interests, profit-oriented ANSPs and an effective price-cap.

Table 1provides an illustration of efficiency improvement from centralized services under various values for price-cap effectiveness B and national interests (γ_3^{ANSP}). The efficiency numbers are expressed in percentages of total yearly ANSP cost. For simplicity we analyse the situation in which the ANSP puts no weight on consumer surplus ($\gamma_1^{ANSP} = 0$), but rather maximizes his profits $(\gamma_2^{ANSP} = 1)$. The numbers in the middle of the table represent the percentage efficiency improvement in comparison to the current ANSP charge per flightkm.

TABLE I. EXPLORATION OF POTENTIAL EFFICIENCY IMPROVEMENT UNDER VARIOUS SCENARIOS; WITH PRICE-CAP EFFECTIVENESS INCREASING ON HORIZONTAL AXIS (B↓) AND WEIGHT OF NATIONAL INTERESTS INCREASING ON VERTICAL AXIS ($\gamma_3 \uparrow$)

γ_3	*B*					
	1	***0.8***	***0.6***	***0.4***	***0.2***	***0***
0	0	0.5%	1%	1.5%	2%	2.5%
0.1	0	0.45%	0.9%	1.4%	1.8%	2.27%
0.2	0	0.42%	0.83%	1.25%	1.67%	2.08%
0.3	0	0.38%	0.77%	1.15%	1.53%	1.92%
0.4	0	0.36%	0.71%	1.07%	1.43%	1.78%
0.5	0	0.33%	0.67%	1%	1.33%	1.67%

Numbers are in expected cost reduction for ANSPs (in %) from centralized service provision

Our model suggests that the cost per flight km for delivering air navigation services could decrease following the introduction of centralized services. However, the theoretical potential of 2.5% yearly cost reduction (or 200 million € yearly) will only be achieved in a situation of a pure price-cap (B=0) and the absence of national interests in ANSP decision making$(\gamma_3^{ANSP} = 0)$. Without performance incentives (corresponding to a cost-plus regulation B=1), the expected benefit will be equal to zero because ANSPs have no benefit in implementing the proposed changes. The expected benefit from introducing centralized services also decreases with higher importance attached to national interests γ_3^{ANSP}.

We need to be careful in the interpretation of these results. First, we neglected the information asymmetry between regulator and ANSP, implementing a full price-cap regime requires implementing the optimal price-cap level. Second we neglected the indirect effect price caps may have on standardisation of equipment and on development of equipment and its cost reduction effects.

2) Demand effect by improving level of service and 'traffic risk'

We also evaluate the importance of the traffic risk element as introduced in the SES II regulations. For this, we use expression (1.8) in which we have already filled in the average distance travelled by an airplane in the Spanish charging zone (484 km/flight) and the average number of passengers per flight (102 pass/flight). The expression of optimal capacity for AENA[8] under various traffic risk regulations *TR* is then equal to:

$$cap^* = \frac{484 \cdot \delta}{102^2 \cdot coef} \left(-1 + \sqrt{\frac{TR \cdot (p_{charge} - c)(102 \cdot p_{max} - OC - p_{charge})}{484 \cdot \delta \cdot Z}} \right) \quad (1.11)$$

We evaluate the optimal capacity decision using the following data:

TABLE II. DATA DESCRIPTION

Data description			
	Number	***Unit***	***Source***
capacity	2000	Flight km/minute	Based on [10]
delay	2.771.000	Delay minutes	[10]
delay	230.000.000	€(delay cost)	Based on [10]
delay	0.26	€/flight km (delay cost)	Based on [10]
Demand elasticity	-1	% decrease in passenger demand for flights/% increase in flight user costs	[8]
Demand elasticity	(-0.2,-0.3)	% decrease in airline demand in charging zone/ % increase in ANSP cost of service	Based on [8]
Maximum willingness to pay from airline passengers	205	€ (for a flight of average distance in European airspace – 765 km)	[5]
ANSP capacity cost	25.000	€/(flightkm/minute)	Based on [10] – variable cost of AENA services
Profit margin of ANSP services	0.08	#/flightkm	Based on "cost risk" derivation
Average OC	7.497	€/flight	[5]
Average number of passengers	102	Passengers/flight	[5]
Average distance travelled in AENA airspace	484	kilometre	Based on [10]

Our model suggests that AENA will invest in additional airspace capacity under a price regulation regime with traffic risk. Table III gives an overview of capacity extension, including its dependence on demand elasticity and type of

[8] We choose AENA because it is one of the ANSPs with a relatively high amount of ATFM related en-route delays in the year 2011.

traffic risk. We use the numbers from the current SES II regulation on traffic risk sharing [7]. This regulation stipulates that in a band of 0 to 2% of traffic variance with respect to forecasted traffic, the ANSPs should bear all costs or benefits from this variation. This corresponds to a situation of full traffic risk, or TR = 1. In a band of 2% to 10% of variation in comparison to traffic forecast, the ANSPs bear 30% of costs or benefits. This corresponds to a situation of moderate traffic risk, or TR = 0.3. In case of traffic variation beyond 10%, the ANSPs face no traffic risk (TR = 0).

TABLE III. CAPACITY INCREASE BY AENA DEPENDING ON LEVEL OF TRAFFIC RISK AND DEMAND ELASTICITY (ILLUSTRATIVE RESULTS) – IN % INCREASE

% increase in capacity compared to current levels	***Full traffic risk (TR=1)***	***Moderate traffic risk (TR= 0.3)***	***No traffic risk (TR=0)***
High demand elasticity $\varepsilon_{ANSP} = -0.3$	1.6%	0.84%	0%
Lower demand elasticity $\varepsilon_{ANSP} = -0.2$	0.8%	0.145%	0%

We observe that ANSPs are more motivated to invest in capacity in a high demand elasticity situation because a higher elasticity ensures that airspace users are more willing to shift to alternative charging zones which in turn lead to stronger incentives to invest in capacity expansion. The incentives to invest in capacity are also stronger in a situation where the ANSP can keep all the profits from the additional traffic (full traffic risk) than in a situation where they can only keep a portion, for example 10% (moderate traffic risk). We find that under high demand elasticity and full traffic risk, AENA will effectively increase capacity by 1.6% for our parameter values. This would lead to a reduction in yearly en-route ATFM delay costs in the Spanish charging zone by 3.7 M€. It would drive down aggregate yearly delay cost from a total of 230 M€ to 226.3 M€.

V. CONCLUSION AND FURTHER WORK

According to the public efficiency regulatory modelling approach, we learn that:

1) Cost-plus regulation leads to excessive costs and over-investment in capital as has occurred historically in the European ATC sector. The fact that national air navigation equipment is often very specific per country and difficult to integrate compare, may reflect the fact that national equipment manufacturers succeed in lobbying their government. The government, in turn, often has important decision powers at the national ANSP.

2) Price cap regulation incentivizes cost efficiency but requires extensive information collection and public decisions with respect to required quality levels, for example in terms of acceptable delay levels, in order to ensure that under investment does not impact users excessively. This is frequently known as hybrid price caps. Unfortunately, the asymmetric information available makes quality level decisions rather complicated, hence tends to lead to substantial negotiation across stakeholders with differing objectives, as occurs today in the airport sector.

3) The EU is an important stakeholder in the ATC system. We identify a lack of incentives to encourage efficiency at the Member State level, which is overcome when intra-European traffic is analysed at the EU level. The move from a cost-plus to a price-cap regulatory approach may be the result of a more European approach towards air navigation service provision in Europe. We provide a model that provides insights into the incentive structure for adoption of centralized services, depending on regulatory and ANSP objectives. Our numerical results illustrate how efficiency improves under different parameters.

4) We also provided an illustration of how the introduction of traffic risk (imposed in the SES II regulation) could have an impact on ANSP incentives to improve the quality of their services. In particular, we focused on the incentive to improve reduce en-route delay costs. We find that the effect of the traffic risk is relatively modest. Moreover, the extent to which incentives increase with the traffic risk exposure is decreasing. Capacity roughly doubles following an increase in traffic risk from 30% to 100%. The effect of demand elasticity on capacity, on the other hand, is stronger with incentives to expand capacity increasing linearly with demand elasticity.

In our future work we plan the following extensions:

- Inclusion of a small network. This will allow for an analysis of cooperation between ATC centers (horizontal cooperation).
- Integration of airports and airlines. This would allow for an analysis of cooperation between airlines, airports and an ATC center (vertical cooperation – or regional forerunner).
- Distinguishing between national users and transit users as their influence on the regulator might be different.

In a separate paper we discuss the influence of labour unions on the performance of ANSPs.

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APPENDIX I: NOTATION

π_{ANSP}	Profit of the ANSP
γ_1^{ANSP}	Weight in the goal function of the ANSP for consumer surplus
γ_2^{ANSP}	Weight in the goal function of the ANSP for its profit
γ_3^{ANSP}	Weight in the goal function of the ANSP for labour and national interests
γ_1^{REG}	Weight in the goal function of the European regulator for the consumer surplus
γ_2^{REG}	Weight in the goal function of the European regulator for the ANSP's profit
γ_3^{REG}	Weight in the goal function of the European regulator for labour and national interests
$\emptyset$	Effort cost for realizing efficiency improvements
CS_{air}	Consumer surplus for air travel
a	Average operating cost per flightkm for ANSP
θ	Stochastic variation on operating cost per flightkm for ANSP
e	Level of efficiency improvement in ATM cost per flightkm
c	(Actual) cost per flightkm after accounting for efficiency gains
p_{charge}	Fee charged by the ANSPs to the airlines for its services (in €/flightkm)
p_{user}	Average user cost of an airline flight, per passenger
p_{max}	Maximum willingness to pay for an airline flight, per passenger
B	Fixed share of costs per flight that the ANSPs can pass through
D	Annual European airline demand (expressed in flight kilometre)
OC	Operating costs for the airlines per flight
ε_{ANSP}	Demand elasticity for air navigation services in Europe
$coef$	Demand coefficient corresponding to demand elasticity for ANSP services ε_{ANSP}
δ	Congestion coefficient parameter in € per flightkm per year
cap	Air navigation capacity in number of flightkm per year
Z	Capacity cost in € per flightkm per year