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ACCHANGE: Building economic models to analyse the performance of air navigation service providers

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ABSTRACT

This research develops an economic public utility model to analyse the effects of the Single European Sky performance regulation on Air Traffic Control performance. We investigate incentives for air navigation service providers through the development of a high level economic model. This allows us to assess impacts at a strategic level and derive high-level results. The economic model provides insight into the mechanisms through which regulation can drive air traffic management performance improvements, as well as its limitations.

Our model fits within the traditional theory of regulation often applied to public monopolies, originally developed by Laffont & Tirole. We complement theoretical derivations with a numerical illustration. We quantify the identified effects for a single, representative ANSP in Europe.

1. Introduction and literature review

The aim of this research paper is to analyse performance incentives of air navigation service providers (ANSPs) in Europe and to investigate how regulation can influence these incentives. The cost of providing air navigation services in Europe is often perceived as relatively high. In addition, there are large differences in productivity between various national ANSPs (Performance Review Unit of Eurocontrol, 2013). Furthermore, there is a relatively low degree of equipment standardization, slow adoption of new technologies and cooperation between various national ANSPs is less than expected (Adler et al., 2015).

We develop a standard public utility model, originally developed by Laffont & Tirole (Laffont and Tirole, 1993), to analyse how regulatory frameworks can be used to address these concerns. Our model addresses the effects of economic regulation on a private firm's performance incentives. The model is used to explore the effects of alternative regulations and institutional frameworks on the efficiency of air navigation service provision in Europe. We have not aimed at developing a detailed model of ATM provision. We rather develop a high-level model which enables us to derive key strategic insights.

The public utility model has been extended by Dalen, Von der Fehr & Moen (Dalen et al., 2003). In their model, the regulator still provides performance incentives to the firm (management) but they add a bargaining stage between managers and unions. We will follow their approach and add a bargaining stage in one of the extensions of our model.

We apply the public utility model to the context of air traffic management (ATM) service provision in Europe. This model is particularly suited to answering questions in the ATM context because of:

- The semi-public characteristic of ANSPs
- The heterogeneity among various ANSPs which makes direct performance benchmarking difficult
- (Historic) national monopoly character of ANSPs and the natural monopoly character of en-route ATM
- The likely emergence of special interest groups in this context

We start with a presentation of the economic agents involved and their objectives. In section III, we outline the model and the main insights. In section IV, we provide numerical illustrations to demonstrate the mechanism and explain the current equilibria outcome in the European ATM market. Section V discusses the

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conclusions drawn from the modelling approach and potential future directions for analysis.

2. 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.

2.1. 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. Aviation policy makers usually consider the role of ANSPs as providing public utility services. The management of airspace safety is indeed delegated to nation states by the ICAO and ANSPs are the entity in charge of that. This mandate is often represented in the governance structure of air navigation service providers. ANSPs are sometimes directly controlled by governments. In several cases, stakeholders such as airport or airline representatives are represented on 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 benefits accruing to airports, airlines and ultimately the airline passengers. In addition to this, we also include a 'national interest' component in the ANSP objective function. As many ANSPs are monopolies which are (to a greater or lesser extent) owned by the state, the ATM environment is particularly prone to the emergence of specific interests groups.

Thus, we express ANSP objectives as a mixed, additive goal function in line with the special interest model as originally developed by Dixit, Grossman & Helpman (Dixit et al., 1997). This model is particularly suited to investigate the influence of special interest groups on policy-making. They model this as interest groups 'buying' negotiation power through campaign contributions. National interests in the ATM context could take the form of national labour unions who lobby for excess employment or higher wages.[1]

So we specify the ANSP objective function as a mix of:

- maximization of consumer surplus (CS), with weight parameter γ_1^{ANSP}
- maximization of profits π^{ANSP}, with weight parameter γ_2^{ANSP}
- national interests (NI), further specified in our model, with weight γ_3^{ANSP}

This gives the following ANSP objective function:

$$Goal^{ANSP} = \gamma_1^{ANSP} \cdot CS + \gamma_2^{ANSP} \cdot \pi^{ANSP} + \gamma_3^{ANSP} \cdot NI \quad (1)$$

2.2. Regulator

ANSPs have a natural monopoly for en-route services in a given geographical area (charging zone) and a public obligation to provide a certain level of air traffic management services within that area. A regulatory body decides on price regulation and how to monitor the quality of services. Since the Single European Sky (SES) program, aimed at defragmentation of ATM provision in Europe, the European Commission decides on a common regulatory approach and oversees its implementation at national level through the National Supervisory Authorities (NSAs). Under this program, the EC has put in place performance regulation (EC, 2010; EC, 2013) to stimulate ANSP performance. This performance is measured in terms of cost-efficiency and quality of service, with service quality targets on safety, environmental performance capacity.

Regulatory bodies weigh the influence of various actors:

- Consumers who benefit from the services of ANSPs.
- ANSPs that need to collect a reasonable compensation to cover the costs for the services that they provide.
- Air traffic controllers (ATCOs) and other ANSP personnel, represented by their unions.

Therefore, the objective function of a regulator is also a 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:

$$Goal^{REG} = \gamma_1^{REG} \cdot CS + \gamma_2^{REG} \cdot \pi^{ANSP} + \gamma_3^{REG} \cdot NI \quad (2)$$

3. Theoretical analysis

The public utility model embodies the idea that there is a relationship between the efficiency of air navigation service provision and the regulation of ANSP charges. In the Single European Sky performance approach, regulators define 'determined costs' for a certain time period which ANSPs are allowed to recover. This mechanism is similar to the introduction of an incentive price-cap in the economic theory of regulation. The aim is to provide ANSPs with an incentive to reduce costs. One way to realize required cost reductions would be the adoption of cost-saving technologies. Another way would be to set up collaboration mechanisms between two or more ANSPs, thus realizing economies of scale. Consequently, appropriate regulatory mechanisms could be a way to stimulate technology adoption and collaboration among various ANSPs.

In this section, we first use the public utility model to explain the link between the type of regulation and cost efficiency. We then analyse when this regulatory approach can lead to unintended consequences and how to address these.

3.1. Cost and information in traditional regulation theory

The common assumption of the traditional regulation model (Dalen et al., 2003; Laffont and Tirole, 1993) is that production costs for providing air navigation services per ANSP can be broken down into three components:

- A fixed observable ANSP cost per flight kilometre controlled, a.
- A cost component θ that varies per ANSP due to complexity of the airspace managed, differences in operational practices, equipment used at Air Traffic Control (ATC) centres, type of support activities, etc. The parameter is imperfectly observable which makes it difficult to benchmark performance between ANSPs.
- an imperfectly observable cost reduction potential e, expressed in average ATM cost per flight kilometre.

We find an expression for ANSP cost per flight kilometre controlled (c) by adding these various terms:

[1] Other specific interests may exist, which lead to barriers for change, such as national sovereignty concerns or national manufacturers that want to sell their own equipment.

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$$c = a + \theta - e \tag{3}$$

For the management and personnel of the ANSP, the effort invested in efficiency improvement e is costly in terms of adaptation to new operational processes, longer/more flexible working hours etc. We represent this cost function $Cost(e)$ as a power function reflecting the underlying assumption that low-cost, 'easy' efficiency improvement measures will be implemented first. Once the 'low-hanging fruit' options have been seized, further efficiency increasing measures become increasingly costly. We take the special case of a quadratic function for further modelling simplicity and because the difference with other forms of the power function is not large over the domain of our function, i.e. positive real numbers. We scale costs with a demand parameter D (expressed in flight kilometres controlled) to represent the scale of operations for this ANSP. We also introduce a cost-scaling parameter $\varnothing$:

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

3.2. Optimal regulation in case of perfect and imperfect information

We investigate optimal regulation from a regulator perspective. As effort is not observable, the regulator cannot simply set the optimal efficiency level for each ANSP. However, the ANSP can be rewarded for good performance. Two common forms of regulation with different implications in terms of accountability are a cost-plus and a price-cap (or fixed price) regulation.

Under cost-plus regulation, the ANSP charges are equal to the total costs divided by traffic served plus a cost mark-up which allows ANSPs to make a small profit margin.[2] So charges are determined ex-post:

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

In this case, there is no reward for good performance and managers will choose e = 0. Costs will fluctuate with the stochastic element and will on average be high.

Under a pure price-cap, the regulator estimates ANSP costs $E(TotCost)$ ex-ante and determines the price-cap based on this. In the context of the Single European Sky performance regulation, the price-cap is equal to determined costs. Determined costs are those costs that ANSPs are allowed to recover. The cost level is set for a reference period covering a number of years. We have now moved from Reference Period 1 (RP1: 2012–2014) towards Reference Period 2 (RP2: 2015–2019) (Huet, 2011).

ANSPs cannot recover costs that exceed the determined cost 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 ANSP is liable for part of the additional profit or loss that results from traffic levels that lie above or below the traffic forecast: $E(D) \neq D$. This is the so-called 'traffic risk'.

The ANSP charge under a price-cap regulation is set as:

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

Implementing a price-cap appears reasonable but determining the precise price level is a difficult task for a public utility regulator.

The current SES II regulation for ANSP charges resembles a price-cap. However, the present level of ANSP charges is influenced by of both price-cap and cost-plus regulatory approaches:

- ANSP charges in Europe were until recently driven by a cost-plus approach.
- Weak enforcement can make a price-cap look much like cost-plus regulation.
- Price-caps are revised from time to time. As price-caps are revised more often, ANSPs may lose the incentives to reduce costs as they recognize that this will only lead to lower caps in the future.[3]

We introduce the parameter B to represent the trade-off between a cost-plus approach ($B = 1$) and a price-cap regulatory approach ($B = 0$):

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

We can now write the dependence of actual ATM charges p_{charge} on performance efficiency e:

$$p_{charge}(e) = A + B \cdot c(e) \tag{4}$$

3.3. The effectiveness of regulation

We now apply the public utility model to study the effects of alternative price setting regimes. We first address how a price-cap can drive cost-efficiency incentives. This is the underlying reason for the determined cost approach and related cost risk as implemented in the SES II performance regulation. We then move on and study unforeseen consequences of the regulatory approach. We analyse the effects on the quality of air navigation services provided, on technology adoption and on cost-effectiveness in a bargaining framework.

3.3.1. The effect of performance regulation on cost-efficiency incentives

We first derive the optimal cost-effectiveness, from the ANSP perspective, depending on the type of price regulation and fixed demand $\overline{D}$. As explained above, the parameter B represents the effective power of the price-cap in our model. In reality, this depends on a number of factors such as effective enforcement and timing of revisions. Based on expression (1), the ANSP managers/directors choose how much effort to invest in operational efficiency. They use this decision variable to optimize their goal function:

$$\underset{wrt.\ e}{Goal^{ANSP}} = \gamma_1^{ANSP} \cdot \overline{D} \cdot \left(p_{max} - p_{charge}(e)\right) + \gamma_2^{ANSP} \cdot \overline{D} \cdot \left(p_{charge}(e) - c(e)\right) - \left(\gamma_2^{ANSP} + \gamma_3^{ANSP}\right) \cdot \overline{D} \cdot \frac{\varnothing \cdot e^2}{2} \tag{5}$$

In this expression, we have set the importance of national interests proportional to the cost of efficiency effort:

[2] We further normalize the profit margin to zero.

[3] This is known as the ratchet effect (Freixas et al., 1985).

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

The underlying assumption is that national interest groups prefer the status quo. As an indirect effect, this makes the cost of implementing any new procedures, processes and technologies go up. The parameter γ_3^{ANSP} measures the extent of this effect.

The expression for the optimal ANSP efficiency effort is:

$$e^* = \frac{\gamma_2^{ANSP} + B \cdot \left(\gamma_1^{ANSP} - \gamma_2^{ANSP}\right)}{\left(\gamma_2^{ANSP} + \gamma_3^{ANSP}\right) \cdot \varnothing} \tag{6}$$

We find that the efficiency incentives are increasing with the effective power of the price-cap B in the situation where the ANSP cares more about its own benefits than the benefits of its customers ($\gamma_2^{ANSP} > \gamma_1^{ANSP}$). So ANSP efficiency effort is higher under a price-cap regime ($B = 0$) than under cost-plus regulation ($B = 1$).

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

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

The ANSP efficiency incentives are further increasing in profit-orientation γ_2^{ANSP}, decreasing in the importance of national interests γ_3^{ANSP} and in the cost of efficiency effort $\varnothing$.

According to the public utility model, cost-efficiency incentives increase with the power of the price cap. In the long-run we can therefore expect cost-efficiency to increase and ANSP charges to decrease in the case of an effective price-cap. This is also one of the goals of the SES II performance regulation. With increasing responsibility of ANSPs for the costs, policy makers expect that cost efficiency will increase in the long-run. ANSPs could attain this through the use of cost-saving technologies, by engaging in mutually beneficial collaboration agreements (potentially leading to economies of scale), by implementing more cost-efficient operational procedures, etc.

3.3.2. The effect of performance regulation on the quality of air navigation services

We also investigate the effects of price-cap regulation on other key performance areas in the SES performance scheme. We study the impact on: *capacity*, the provision of sufficient ATC capacity to avoid delays; and *flight efficiency*, leading to lower fuel burn and a reduction in environmental impacts.

We study potential effects of ‘hybrid price-caps’. This is a regulatory approach in which not only the price/cost-level is enforced, but also achievement with respect to other quality targets is rewarded. In the SES performance regulations (RP1 and RP2) none of the performance targets carry direct financial consequences for the ANSP, besides cost-effectiveness. Performance in other key performance areas is also monitored, but without carrying financial consequences. So we compare incentive effects of the current ‘pure price-cap’ performance regulation with a hybrid price-cap regulatory approach.

In the public utility model, regulated entities have an incentive to cut costs by reducing the quality of services, if the regulation is a pure price-cap without monitoring or rewarding of performance in other areas. We expect that the strength of this incentive depends on the various weights of the ANSP objective function, as well as on the extent to which ANSP revenues vary with airline demand. We model quality of services in our model as the provision of adequate ATC capacity to avoid air traffic flow management delays.[4]

We aim to develop a model that gives insight into dependencies between various performance areas and key indicators at a high, strategic level. We do not want to develop a model that provides an accurate representation of these relationships in full detail. Therefore, we make the following simplifying assumptions that are in line with assumptions made by EUROCONTROL's Performance Review Unit (Performance Review Body, 2013):

- There is an inversely proportional relationship between the ATC capacity choice (*cap*) and cost of delays (*del*): $del = \frac{\delta}{cap}$
- The variable cost of ATM provision is increasing in the level of capacity chosen. We have assumed a linear relation in line with the cost elasticity of capacity as defined in Table 1.
- Expected delays are influenced by the ATC capacity and these delays are an element of passenger user costs p_{user}. Passenger user cost is the total cost for making a trip of the passenger. It consists mainly of the ticket price, plus the cost of the time needed for making the trip.

Under these assumptions, the capacity choice for the ANSP becomes a trade-off between the cost of capacity provision and the reduction in passenger user cost (due to reductions in expected delays). The ANSP (management) optimizes its goal function as a function of ATC capacity now, rather than cost-efficiency:

$$\begin{aligned} \underset{wrt.\ cap}{Goal^{ANSP}} = {} & \gamma_1^{ANSP} \cdot D(cap) \cdot (p_{max} - p_{user}(cap)) \\ & + \gamma_2^{ANSP} \cdot D(cap) \cdot \left(p_{charge}(cap) - c(cap)\right) - \left(\gamma_2^{ANSP} \right. \\ & \left. + \gamma_3^{ANSP}\right) \cdot Cost(e) \end{aligned}$$

We first assume that ANSP revenues remain fixed for different capacity levels chosen, either because demand is unresponsive to quality or because ANSP revenues do not vary as a function of variations in air traffic demand. Then, the condition that determines the optimal ATC capacity level under a cost-plus approach is:

$$-\frac{\partial del}{\partial cap^*} = \frac{\partial c}{\partial cap^*}$$

In a price-cap regime, this equation becomes:

$$-\frac{\partial del}{\partial cap^*} \cdot \gamma_1^{ANSP} = \frac{\partial c}{\partial cap^*}$$

So from the simple benchmark case with no demand response, we learn that a pure price-cap regime gives ANSPs an incentive to restrict ATC capacity. This follows from the observation that $\gamma_1^{ANSP} < 1$. ATC capacity reduction represents a lower service quality in our model, because it will lead more ATFM delays. Our model result that a pure price-cap may cause a reduction in quality of air traffic services is in line with an observation by Baumgartner & Finger (Baumgartner and Finger, 2014). They found that the introduction of cost targets in RP1 has mainly led to a reduction in planned capital expenditure at ANSPs, which in the long run could lead to deterioration in quality of services.

We now leave the simplifying assumption of fixed ANSP revenues by introducing demand variation. The extent to which ANSP revenues vary with demand variation is determined by traffic risk (*TR*). The condition that determines optimal capacity for varying air traffic demand and varying ANSP revenues is:

[4] This is an example. A similar analysis could probably be performed for environmental targets, related to efficiency of flight routes.

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$$-\frac{\partial del}{\partial cap^*}\cdot\gamma_1^{ANSP}+\frac{\partial D}{\partial cap^*}\cdot\left(\gamma_1^{ANSP}\cdot\frac{CS}{D}+TR\cdot\gamma_2^{ANSP}\cdot\frac{\pi^{ANSP}}{D}\right)=\frac{\partial c}{\partial cap^*}$$

This equation is not very intuitive, but the main effect of ANSP revenue variations (as a function of demand) is that it gives an ANSP a stronger incentive to invest in service quality; at least in comparison to a situation where demand is fixed. However, we expect this effect to be low because demand elasticity for air navigation services by airlines is likely to be relatively low.[5] We will quantify the extent of this effect in our numerical simulations (see section IV).

A hybrid price-cap could take the form of a bonus-malus component in setting ANSP charges, allowing charges to be higher if performance with respect to targets is positive and reducing charges if performance is bad. With hybrid price-caps, the optimal capacity condition in our model becomes:

$$-\frac{\partial del}{\partial cap^*}\cdot\left(\gamma_1^{ANSP}\cdot(1-BM)+BM\right)=\frac{\partial c}{\partial cap^*}$$

When we set $BM=1$, we are able to restore the quality incentives of the cost-plus regime within the price-cap regulation approach, because the optimal capacity decision is given by:

$$-\frac{\partial del}{\partial cap^*}=\frac{\partial c}{\partial cap^*}$$

So we conclude here that hybrid price-caps can be a powerful tool for simultaneously stimulating cost-efficiency and quality of service. Therefore, we would recommend including financial incentives for reaching quality performance targets in the SES II performance regulations. Of course, our model has taken a somewhat high-level, abstract approach. We have not addressed how to set and monitor the quality targets. This is an important issue because setting the targets in an inefficient way could have unintended side effects.

3.3.3. *Regulation and incentives for technology adoption*

Price-cap regulation and resulting cost-efficiency incentives could help in stimulating technology adoption by ANSPs. This is the case to the extent that these technologies offer more cost-effective options for providing air navigation services. On the other hand, implementation of technologies also requires up-front investments. These are more difficult to undertake in a climate with downward pressures on ANSP charges, as applied by the price-caps. Therefore, it is not clear ex-ante which effect dominates and how price-cap regulation would influence technology adoption.

Moreover, technologies may not only lead to performance improvements in the area of cost-efficiency, but also in other performance domains. We have seen that a pure price-regulation can be detrimental to investments in quality of service if performance in other areas is not fully monitored or enforced. In addition to this, national interests or labour unions could be opposed to the introduction of new technologies that challenges the status-quo and may affect their bargaining positions. In this context, it is at least doubtful whether ANSPs really have an incentive to invest in technologies that lead to reductions in delays or to an increase in flight efficiency.

We now apply the public utility model to investigate the conditions under which technology adoption would be stimulated or blocked. We take the case of a technology that mainly contributes to the flight throughput capacity of ANSPs. This is in line with the European ATM Master Plan, where projections on expected performance improvements show the most significant benefits in the area of capacity (an increase of 27% in airspace throughput and 14% in airport throughput) (SESAR, 2012).

Compared to the previous analysis, we distinguish between fixed costs FC and variable costs VC because technology investments typically require significant up-front investments. These costs are sunk and then need to be written off as a fixed cost over the lifetime of the investment. The general expression for ANSP charges becomes:

$$p_{charge}=A_{FC}+A_{VC}+B\cdot\left(VC+\frac{FC}{D}\right)+BM\cdot(del(T)-del_0)$$

In this expression, the variable B still represents the power of the price regulation. We further include a bonus-malus component BM for reaching a certain delay target del_0. Adopting technology T can help in reaching or outperforming the delay target.

The ANSP goal function remains the same, with the ANSP deciding whether to implement the technology $T=1$ or not $T=0$. This gives the following goal function:

$$\begin{aligned}\underset{wrt.\,T}{Goal^{ANSP}} &= \gamma_1^{ANSP}\cdot D(T)\cdot(p_{max}-p_{user}(T))\\ &\quad+\gamma_2^{ANSP}\cdot D(T)\cdot\left(p_{charge}(T)-VC(T)\right)-\gamma_2^{ANSP}\cdot FC(T)\end{aligned}$$

In general, we can expect that the ANSP adopts the technology if:

$$Goal^{ANSP}(T=1)>Goal^{ANSP}(T=0)$$

Given the low demand response for ATC services, it is reasonable to assume that demand will not shift drastically as a consequence of technology adoption:

$$D(T=1)=D(T=0)$$

We can now derive the condition that determines whether ANSPs will have an incentive to adopt a technology T. We first analyse the situation where no bonus-malus for reaching delay targets is awarded: $BM=0$. With a pure price-cap approach $B=0$, technology adoption is unlikely. The adoption condition can be written formally as:

$$\gamma_2^{ANSP}\cdot[FC(T=1)-FC(T=0)]<\gamma_1^{ANSP}\cdot D\cdot[p_{user}(T=0)-p_{user}(T=1)]$$

The user benefits have to be very large for the ANSP to adopt this technology, as benefits are discounted by $\gamma_1^{ANSP}<\gamma_2^{ANSP}$. This observation shows that a price-cap could have a detrimental effect on technology adoption by ANSPs. A straightforward way to address this problem is to refund technology adoption costs. This reduces to a 'mini cost-plus' for technology implementation ($B=1$). In this case, the ANSP will adopt the technology as long as user benefits exist:

$$0<\gamma_1^{ANSP}\cdot D\cdot[p_{user}(T=0)-p_{user}(T=1)]$$

Any useful technology which may be reimbursed would be

[5] Measurement of airline demand elasticity towards ATM services has received relatively limited research attention. But it should logically be low because ATM costs represent a relatively small part of airline costs. So we expect airline route choice to be mainly driven by the shortest/most economic path rather than by considerations related to ATM. This makes airlines relatively unresponsive to the ATM service level, which entails that demand variation is a relatively ineffective device for ATM performance incentives. See, for instance: https://www.eurocontrol.int/sites/default/files/content/documents/official-documents/skyway/articles/2014-summer-skyway-viewpoint-klaus-dieter-scheurle.pdf.

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implemented by the ANSP.[6] In this case, careful selection of the technology and some monitoring of implementation costs is a necessary requirement.

An alternative approach is to award a bonus-malus $BM > 0$ towards ANSPs for reaching well-designed performance targets. We again take the example of a delay target. Adoption incentives no longer depend on the value attached to customer benefits rather on a purely privately interested ANSP ($\gamma_1^{ANSP} = \gamma_3^{ANSP} = 0$) that may find it worthwhile to invest if the reduced delay provides a larger private benefit as compared to the investment cost:

$$[FC(T=1) - FC(T=0)] < BM \cdot [del(T=1) - del(T=0)]$$

This type of regulation would lead to a more bottom-up approach towards technology adoption, with the main decision located at the individual ANSP.

3.3.4. The effect of regulation on cost-efficiency – with bargaining

In section III.C.1, we established the link between performance regulation, the power of a price-cap and cost-efficiency incentives. In this section, we extend the public utility model to include a bargaining stage between ATM stakeholders. We evaluate how this element impacts the effectiveness of performance regulation with a price-cap.

Given the importance of labour unions in the ATC sector and the fact that around 60% of ANSP costs are labour costs, we develop the case of labour unions who try to use their bargaining power to extract a 'surplus' labour/employment cost.[7] The economic literature on the union bargaining model is well-established and reviewed by Oswald (Oswald, 1985). The model highlights the influence of bargaining positions and fall-back options, of ANSP management and labour unions, on ANSP employment costs.

The ANSP goal function is the same as above (see expression (5)). The labour union's goal function can be described as the surplus that accrues to labour as a production factor, above the market wage W^0 and the efficient employment level L^0. The total labour surplus can thus be described as $W \cdot L - W^0 \cdot L^0$. This gives the following Nash bargaining product, where the bargaining power of both parties is expressed by the parameter $\vartheta \in [0, 1]$:

$$NB = (Goal\ ANSP)^{\vartheta} \cdot \left(W \cdot L - W^0 \cdot L^0\right)^{1-\vartheta}$$

The mechanism underlying this bargaining model is that ANSP managers and ANSP employees (represented by unions) can 'choose' to cooperate and share the surplus that emerges from this cooperation. In contrast, they can also choose not to cooperate and then each would have to be content with his fall-back position. When ATCOs go on strike, it becomes very difficult for airlines to fly. The ANSPs will therefore not be able to realize any revenues, making so the fall-back position ANSP (management) equal to 0. Were ANSP managers to fire the ATCOs, they can find a job at another employer,[8] so their fall-back position is determined by the employment conditions of the 'outside option' employer, $W^0 \cdot L^0$. Both actors therefore have an interest to collaborate and share the mutual benefits of this collaboration.

We obtain the employment outcomes by maximizing the Nash bargaining product with respect to 'employment conditions' $W \cdot L$. This estimates the $W \cdot L$ which is the best 'mutual outcome' for ANSP managers and labour union representatives[9]:

$$W \cdot L - W^0 \cdot L^0 = \frac{1-\vartheta}{\vartheta} \cdot \left(\frac{\gamma_1^{ANSP} \cdot CS + \gamma_2^{ANSP} \cdot \pi^{ANSP}}{D \cdot \left(\gamma_1^{ANSP} \cdot B + \gamma_2^{ANSP} \cdot (1-B)\right)} \right) \quad (7)$$

We find that the employment cost surplus (i.e. the inverse of cost-efficiency) now depends on a new parameter, ϑ, which measures the bargaining power of ANSP management relative to the union bargaining power. This parameter depends on the ATM sector industrial structure and on the laws and institutions of each country.

The effectiveness of the price regulation is still driven by the values for parameters γ_1^{ANSP} and γ_2^{ANSP} in this model. In the 'normal' situation with $\gamma_2^{ANSP} > \gamma_1^{ANSP}$, the cost surplus depends negatively on the power of the price-cap. As the power of the price-cap increases ($B \rightarrow 0$), the employment cost surplus decreases and thus efficiency increases. This is in line with the results that we obtained without the bargaining stage. However, the relative strengths of the parameters may differ. We will analyse the relative strengths of different parameters on efficiency outcomes in the numerical illustration.

4. Results of a numerical illustrations and discussion

This section illustrates numerically how the various parameters of the public utility model translate into performance outcomes. This numerical analysis highlights the strengths of the relationships identified. We first describe the data used. Then, using Mathematica, we simulate effects on cost-efficiency. Finally, we study the effects on the quality of service.

4.1. Description of data used

In this illustration, we use data from the ATC cost-effectiveness benchmarking report 2011 (PRU, 2013) as shown in Table 1. We use European averages for all air navigation service providers. Based on data from (Performance Review Commission, 2012) we calculate ANSP charges per flight kilometre of around 1 €/flight km controlled.

4.2. Power of price-cap and cost-effectiveness in public utility model

The public utility model permits an analysis of the relationship between model parameters and cost-efficiency. We will use centralized services as an example of a potential cost-saving model which could be blocked due to national interests. Eurocontrol has estimated the potential efficiency improvement of centralized service provision at around 200 million € per year[10]. We use this potential efficiency improvement as the benchmark case in our analysis.

Table 2 presents potential efficiency improvements under various parameter values, as predicted by the model. We set the ANSP objective parameters at $\gamma_1^{ANSP} = 0.5$ and $\gamma_2^{ANSP} = 1$ to reflect the idea of ANSPs as partly private, partly public entities. They care more for own revenues than for the revenues of their customers, as normal firms would, so $\gamma_2^{ANSP} > \gamma_1^{ANSP}$, but the weight they put on consumer benefits is not equal to zero, so $\gamma_1^{ANSP} > 0$. We further let

[6] Any technology with user benefits $p_{user}(T=0) < p_{user}(T=1)$.

[7] In Adler (Adler et al., 2015) we investigate the relation between union bargaining power and ANSP performance in more detail.

[8] They could work at another ANSP under the European ATCO licensing regulation 2015/340 or do another job in aviation industry or beyond.

[9] For the sake of interpretation, we immediately write this in the form of 'employment cost surplus': $W \cdot L - W^0 \cdot L^0$.

[10] EUROCONTROL (2013). Determining the benefit and cost of centralized services. Available at: https://www.eurocontrol.int/sites/default/files/content/documents/official-documents/skyway/articles/2013-Winter-Skyway-13-Focus-CBA-centralised-services.pdf.

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Table 1
Data description.

Data description	Number	Unit	Source
Cost/minute of delay	83	€/min	Based on University of Westminster (2011)
En-route ATM delays	11 807 738	Delay minutes	Performance Review Unit of Eurocontrol (2013) (avg '04–'11)
Total delay cost	980 042 213	€	Calculated
Flight hours	14 000 000	Hours	Performance Review Unit of Eurocontrol (2013)
Average capacity	1.15	Flight hours/minute	Calculated
Cost elasticity of capacity	0.7	% cost/% capacity	Performance Review Body (2013)
Avg flight kilometers/flight hours	646	Km/h	Performance Review Body (2013)
Capacity cost	0.156	€/flight kilometre	Performance Review Body (2013)
Passenger demand elasticity[a,b] (upper bound)	−2.8	% decrease in passenger demand for flights/% increase in flight user cost	IATA (2008)
Profit margin of ANSP services (upper bound)	0.1	€/flightkm	Performance Review Unit of Eurocontrol (2013)
Average passenger user cost	85	€/flight	Eurocontrol (2013)
Average number of passengers	102	Passengers/flight	Eurocontrol (2013)

[a] Note that airline demand elasticity with respect to ATC charges (and service provision) has not been measured up to now. Therefore, we derive an indicative estimate for airline elasticity to ATM charges from the elasticity of passenger demand. Passenger demand elasticity is well-documented (IATA, 2008).
[b] The figure is an upper bound on passenger demand elasticity. We obtain this by combining all the maximum elasticity figures in the IATA study (Huet, 2011). The aim is to investigate the potential impact of demand responsiveness at its maximum level.

the other two parameters, price-cap effectiveness B and national interests γ_3^{ANSP}, vary between 0 and 1. In the table, we show the resulting efficiency improvement in million € per year. These numbers can be put in perspective by comparing them with the benchmark case of 200 million € savings per year, which is the expected maximum. This potential will be realized in our model when there is a pure price-cap ($B = 0$), ANSPs have profit-maximization objectives $\gamma_2^{ANSP} = 1$, some weight on customer benefits $\gamma_1^{ANSP} = 0.5$ and no importance with respect to national interests $\gamma_3^{ANSP} = 0$.

Table 2 shows how national interests are an obstructing factor preventing the implementation of efficiency improvements in our model. As γ_3^{ANSP} increases along the vertical axis, expected efficiency savings go down. A regulator/policy maker can counterbalance this effect by increasing the power of the price-cap (as B goes down along the horizontal axis).

This positive effect of price-cap regulation is also relatively strong in the public utility model. For example, starting from the case ($B = 0.6$ & $\gamma_3^{ANSP} = 0$), when the ANSP places equal importance on national interests as on benefits of his consumers ($\gamma_1^{ANSP} = \gamma_3^{ANSP} = 0.5$) the expected efficiency improvement drops to 93.6 M€ per year. However, a regulator could in principle almost completely restore cost-efficiency incentives by increasing the power of the price-cap ($B = 0$) thus achieving 133.6 M€ in savings.

So we conclude that in the public utility model the price-regulation has relatively powerful cost-efficiency incentives. We need of course to be careful with the interpretation of this result, as we have not approached the question of setting the optimal price-cap.

4.3. Power of price-cap and cost-effectiveness – with bargaining

In the theoretical analysis, we have shown how the introduction of a bargaining stage leads to a new parameter driving cost-efficiency, namely the relative bargaining power parameter ϑ (next to the power of the price-cap B). We use result (7) to investigate the relative impact of both parameters on cost-efficiency numerically, as shown in Table 3 [11]:

We find the new bargaining power parameter ϑ to have a stronger effect on cost-efficiency than the price-cap regulation parameter B. Whereas a change in B over the full range of the parameter (from 1 to 0) has a maximum yearly effect of 123 M€, a relatively small change in ϑ (over a range of 0.2) has a maximum impact of 142 M€ on costs per year. In addition, the effectiveness of the price-cap regulation also depends on the value of the bargaining power parameter ϑ, with higher potential gains to be made when union bargaining power is strong.

Table 2
Efficiency improvement depending on parameter values; with price-cap effectiveness increasing on horizontal axis ($B\downarrow$) and weight of national interests increasing on vertical axis ($\gamma_3\uparrow$).

γ_3^{ANSP}	B					
	1	0.8	0.6	0.4	0.2	0
0	100 M	120 M	140 M	160 M	180 M	200 M
0.1	91.2 M	108.8 M	127.2 M	145.6 M	163.2 M	181.6 M
0.2	83.2 M	100 M	116.8 M	133.6 M	149.6 M	166.4 M
0.3	76.8 M	92 M	108 M	123.2 M	138.4 M	153.6 M
0.4	71.2 M	85.6 M	100 M	114.4 M	128 M	142.4 M
0.5	66.4 M	80 M	93.6 M	106.4 M	120 M	133.6 M

Numbers are in million € per year.

[11] Note that a reduction in the employment cost surplus $W \cdot L - W^0 \cdot L^0$ is the equivalent of an increase in cost-efficiency e.

Table 3
Efficiency improvement depending on parameter values; with price-cap effectiveness increasing on horizontal axis ($B\downarrow$) and union bargaining power decreasing on vertical axis ($\vartheta\downarrow$).

ϑ	B				
	1	0.75	0.5	0.25	0
0.85	148 M	169 M	182 M	192 M	200 M
0.8	113 M	141 M	159 M	172 M	182 M
0.75	78 M	113 M	136 M	152 M	164.5 M
0.7	42 M	84 M	112 M	132 M	147 M
0.65	6 M	55 M	88 M	111 M	129 M

Numbers are in million € per year.

4.4. Regulatory instruments to control quality of services

We now turn our attention to the effects of performance regulation on quality of service. We study how the ANSP capacity decision (*cap*), and the cost of delay (*del*) that results from it, are different under various regulatory approaches.

We calculate the optimal ATC capacity level under each type of regulation from the expressions given in section 3.3.2. In Table 4, we provide an overview of the results. We present the capacity for an average ANSP in Europe in flight hours per minute. A flight hour is the output quantity measure here, i.e. the maximum amount of ATC work that can be produced by the ANSP each minute. (Flight kilometres would be an alternative output measure.) Cost of delay is expressed as an average cost for Europe in €/flight hour, with flight hour again as the output quantity indicator.[12]

We observe, in line with our theoretical derivations, that cost-plus regulation provides balanced incentives for capacity provision. In a pure price-cap, on the other hand, the ANSPs are tempted to reduce capacity provision, thereby causing more delays. By saving on quality of service, they can increase profitability, which they are allowed to keep under this regime. Making the ANSP revenues responsive to demand variation provides only very limited incentives to counterbalance the quality reduction incentives.[13] The underlying reason is that the impact of ANSP behaviour on airline route choice optimization is small. Because of this limited demand response, exposing ANSPs to demand variability is a relatively ineffective tool for stimulating quality of service.

The bonus-malus system and the explicit compensation for reaching certain quality of service targets is a much more effective regulatory instrument for providing quality of service incentives. This is demonstrated by the last two columns of Table 3. The final column shows how one can obtain the equivalent quality of service result under a price-cap in comparison to a cost-plus approach, by introducing a 100% bonus-malus compensation.

Table 4
Optimal capacity choice under various regulations.

	Cost-plus	Price-cap	Cap with demand variation	BM = 0.5	BM = 1
Capacity (flight hrs/min)	1.17	0.59	0.676	0.88	1.17
Cost of delay (€/flight hr)	71	141	123	94	71

[12] Notice that multiplying cost of delay with annual flight hours for Europe (approx. 14 M) leads to a total cost of delay estimate in the range of those reported in recent performance review reports (Performance Review Commission, 2012; Performance Review Unit of Eurocontrol, 2013).

[13] We have assumed a 100% traffic risk in our calculations, whereas in reality traffic risk is much smaller under RP1. We have thus estimated the maximum potential traffic risk here.

5. Conclusions and further work

Exploring the public utility model approach, we learn that:

1) Cost-plus regulation leads to excessive costs and capital investments as has occurred historically in the European ATC sector. There is very little incentive to collaborate. This helps to explain the low standardization in the ATM industry leading to difficulties in comparing ATM performance. Cost-plus regulation is better suited for an ANSP that has customer interests well-represented in its decision making bodies.
2) Price cap regulation incentivizes cost efficiency and is a more appropriate regulatory for profit-maximizing ANSPs that are more similar to private firms. However, setting the price cap right requires extensive information. Also, ANSPs have an incentive to cut back on quality of service delivered. In our model, we have shown how ANSP could decide to reduce ATC capacity which could lead to higher delays. Therefore, we suggest to introduce hybrid price-caps in the SES performance regulation, rewarding ANSPs for outperforming service quality targets through a bonus-malus scheme.
3) Performance regulation affects technology implementation incentives. A pure price-cap provides weak incentives for investing in new technologies as ANSPs have to bear all the costs of the investments and see only limited benefits. A cost-plus approach, compensating ANSPs for the fixed investment cost, makes ANSPs more inclined to invest. However, the approach is still cost recovery based and depends on the ANSPs willingness to consider consumer benefits. A bonus-malus mechanism also leads to direct revenues for ANSPs thereby increasing their technology adoption incentives and potentially sharing airspace benefits more equitably among various actors (airlines, airports and ANSPs).
4) Our numerical results show how price-cap regulation is an efficient instrument for incentivizing cost-efficiency based on the public utility model. We show how the inclusion of a bargaining setting with national interests changes the perspective on the most important determinant driving cost-efficiency performance.
5) Relying on demand variability to discipline ANSPs and stimulating quality of service is not a very effective tool in the ATM context, because demand response is likely to be low. Therefore, effective regulatory tools are necessary to stimulate performance improvements in the current sector context.

Our conclusions are based on a stylised, high-level strategic model. The aim of the model is not to simulate operational processes up to a high level of detail. We have rather used a number of simplifying assumptions to be able to focus on key strategic messages. Data permitting, it would be interesting to add more realism to the model. However, this would most likely not alter the main insights while it would complicate the tractability of the mechanisms and results.

In our future work we plan to include a small network to be able to analyse strategic effects between various actors in the network. In addition, it could be useful to do thorough sensitivity analysis on the parameters used. After all, our parameters are European averages whereas performance between ANSPs varies much in practice. Another option would be to assess the predictive statements of our model in a Delphi study involving ANSP participants. The study of shifts in ATM demand, as a consequence of technology adoption or improved service quality, is another important research need.

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Appendix: Notation

CS: consumer surplus of ATM services accruing to airports, airlines and airline passengers
π_{ANSP}: profit of the ANSP
NI: national interest component
γ_1^{ANSP}: weight in the goal function of the ANSP; consumer surplus
γ_2^{ANSP}: weight in the goal function of the ANSP: profit
γ_3^{ANSP}: weight in the goal function of the ANSP: labour and national interests
γ_1^{REG}: weight in the goal function of the European regulator: consumer surplus
γ_2^{REG}: weight in the goal function of the European regulator: ANSP profit
γ_3^{REG}: weight in the goal function of the European regulator: labour and national interests
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: cost per flightkm after accounting for efficiency gains
$\varnothing$: effort cost for realizing efficiency improvements
D: annual European airline demand for ATM services (expressed in flightkm or flighthours)
p_{charge}: ANSP charge to the airlines for services (in €/flightkm)
p_{user}: average user cost of an airline flight per passenger (ticket cost plus cost of time)
p_{max}: maximum willingness to pay for ATM services by airlines (expressed in €/flightkm)
B: fixed share of costs per flight that an ANSP can pass through to airlines in the form of ANSP charges
cap: ATC capacity (expressed in maximum en-route flight hour control ability per minute)
δ: delay cost parameter in € per minute of delay
del: cost of delay for an average flight in Europe (expressed in €/flight hour)
BM: bonus-malus component of ANSP charges
T: dummy variable indicating whether (ATM quality enhancing) technology is adopted
TR: variable ranging from 0 to 1 indicating the share of air traffic demand variation to which the ANSP is accountable
W: average wage level at ANSP
L: employment at ANSP
W^0: market-conform wage
L^0: efficient employment level
ϑ: bargaining power parameter (ranges from 0 to 1)

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